

Measurement of $B_c(2S)^+$ and $B_c^*(2S)^+$ cross section ratios in proton-proton collisions at $\sqrt{s} = 13$ TeV

A. M. Sirunyan *et al.*^{*}
(CMS Collaboration)

 (Received 19 August 2020; accepted 29 September 2020; published 16 November 2020)

The ratios of the $B_c(2S)^+$ to B_c^+ , $B_c^*(2S)^+$ to B_c^+ , and $B_c^*(2S)^+$ to $B_c(2S)^+$ production cross sections are measured in proton-proton collisions at $\sqrt{s} = 13$ TeV, using a data sample collected by the CMS experiment at the LHC, corresponding to an integrated luminosity of 143 fb^{-1} . The three measurements are made in the B_c^+ meson phase space region defined by the transverse momentum $p_T > 15 \text{ GeV}$ and absolute rapidity $|y| < 2.4$, with the excited $B_c^{(*)}(2S)^+$ states reconstructed through the $B_c^{(*)+} \pi^+ \pi^-$, followed by the $B_c^+ \rightarrow J/\psi \pi^+$ and $J/\psi \rightarrow \mu^+ \mu^-$ decays. The $B_c(2S)^+$ to B_c^+ , $B_c^*(2S)^+$ to B_c^+ , and $B_c^*(2S)^+$ to $B_c(2S)^+$ cross section ratios, including the unknown $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ branching fractions, are $(3.47 \pm 0.63(\text{stat}) \pm 0.33(\text{syst}))\%$, $(4.69 \pm 0.71(\text{stat}) \pm 0.56(\text{syst}))\%$, and $1.35 \pm 0.32(\text{stat}) \pm 0.09(\text{syst})$, respectively. None of these ratios shows a significant dependence on the p_T or $|y|$ of the B_c^+ meson. The normalized dipion invariant mass distributions from the decays $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ are also reported.

DOI: [10.1103/PhysRevD.102.092007](https://doi.org/10.1103/PhysRevD.102.092007)

I. INTRODUCTION

The production cross sections of the B_c^+ family of mesons, quark-antiquark bound states of two different flavors, charm and beauty, are significantly smaller than those of the charmonium and bottomonium states. The unprecedented collision energies and integrated luminosities of the proton-proton (pp) data samples collected at the CERN LHC allow, for the first time, detailed studies regarding the production and properties of B_c^+ quarkonia. The observation of the $B_c(2S)^+$ and $B_c^*(2S)^+$ states was recently reported by the CMS experiment [1], using a pp data sample collected at $\sqrt{s} = 13$ TeV between 2015 and 2018, on the basis of well-resolved peaks in the $B_c^+ \pi^+ \pi^-$ invariant mass distribution, with the B_c^+ meson reconstructed in the $B_c^+ \rightarrow J/\psi \pi^+$ decay channel, and $J/\psi \rightarrow \mu^+ \mu^-$. The LHCb Collaboration also reported the observation of the $B_c^*(2S)^+$ state, using a pp data sample collected at 7, 8, and 13 TeV [2]. Masses of the $B_c(2S)^+$ and $B_c^*(2S)^+$ states are found to be consistent with theoretical predictions [3–5]. These results stimulated new theoretical studies aimed at reaching a better

understanding of the B_c^+ quarkonium family, such as those reported in Refs. [6,7].

The present paper reports an analysis that complements the previous observation of the $B_c(2S)^+$ and $B_c^*(2S)^+$ states [1] with the measurement of the $B_c(2S)^+$ to B_c^+ , $B_c^*(2S)^+$ to B_c^+ , and $B_c^*(2S)^+$ to $B_c(2S)^+$ cross section ratios, an important step in making further progress on understanding these two excited B_c^+ states. The invariant mass distributions of the pair of pions emitted in the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ decays are also presented, to probe the existence of possible intermediate structure analogous to the ones observed in decays between the 2S and 1S states of charmonium and bottomonium [6,7]. Throughout this paper, $B_c^{(*)+}$ denotes B_c^+ or B_c^{*+} , and $B_c^{(*)}(2S)^+$ denotes $B_c(2S)^+$ or $B_c^*(2S)^+$. Charge-conjugate states are also implied, unless stated otherwise. The data sample of 13 TeV pp collisions used in this analysis corresponds to an integrated luminosity of 143 fb^{-1} and was collected by CMS between 2015 and 2018. The measurements are performed in a phase space region defined by the B_c^+ meson transverse momentum $p_T > 15 \text{ GeV}$ and rapidity $|y| < 2.4$.

II. EXPERIMENTAL APPARATUS, DATA SAMPLE, AND EVENT SELECTION

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

^{*}Full author list given at the end of the article.

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP³.

electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two end cap sections. Muons are measured in the pseudorapidity range $|\eta| < 2.4$, with detection planes made using three technologies: drift tubes, cathode strip chambers, and resistive plate chambers. Matching muons to tracks measured in the silicon tracker results in a relative transverse momentum resolution, for muons with p_T up to 100 GeV, of 1% in the barrel and 3% in the end caps [8]. The single-muon trigger efficiency exceeds 90% over the full η range, and the efficiency to reconstruct and identify muons is greater than 96%. A more detailed description of the CMS detector, together with a definition of the coordinate system used and relevant kinematic variables, can be found in Ref. [9].

The event sample was collected with a two-level trigger system [10]. At level 1, custom hardware processors select events with two muons. The high-level trigger requires an opposite-sign muon pair of invariant mass in the range 2.9–3.3 GeV, a dimuon vertex fit χ^2 probability larger than 10%, a distance of closest approach between the two muons smaller than 0.5 cm, and a distance between the dimuon vertex and the beam axis, L_{xy} , larger than 3 times its uncertainty. Both muons must have $p_T > 4$ GeV and $|\eta| < 2.5$. In addition $\vec{p}_T$ must be aligned with the dimuon transverse decay displacement vector $\vec{L}_{xy}$ by requiring $\cos \theta > 0.9$, where $\cos \theta = \vec{L}_{xy} \cdot \vec{p}_T / (L_{xy} p_T)$. The trigger also requires a third track in the event, compatible with being produced at the dimuon vertex (normalized $\chi^2 < 10$), and having $p_T > 1.2$ GeV, $|\eta| < 2.5$, and a significance on the track impact parameter of at least 2. The off-line reconstruction requires two opposite-sign muons matching those that triggered the detector readout, with some requirements being stricter than at the trigger level, such as $|\eta| < 2.4$ and $\cos \theta > 0.98$. The muon candidates must pass high-purity track quality requirements [11], and fulfill the soft-muon identification requirements [8], which imply, in particular, that there are more than five hits in the silicon tracker, with at least one in the pixel layers. The two muons must also be close to each other in angular space: $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.2$, where $\Delta\eta$ and $\Delta\phi$ are the differences in pseudorapidity and azimuthal angle, respectively, between their momenta.

III. MEASUREMENT OF THE CROSS SECTION RATIOS

A. Introduction

The ratios of the $B_c^{(*)}(2S)^+$ to B_c^+ and $B_c^*(2S)^+$ to $B_c(2S)^+$ cross sections, R^{*+} , R^+ , and R^{*+}/R^+ , respectively, reported in this paper are derived from the ratios of the measured yields, corrected by the detection efficiencies, ϵ :

$$\begin{aligned} R^+ &\equiv \frac{\sigma(B_c(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c(2S)^+ \rightarrow B_c^+ \pi^+ \pi^-) \\ &= \frac{N(B_c(2S)^+)}{N(B_c^+)} \frac{\epsilon(B_c^+)}{\epsilon(B_c(2S)^+)}, \\ R^{*+} &\equiv \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c^+)} \mathcal{B}(B_c^*(2S)^+ \rightarrow B_c^+ \pi^+ \pi^-) \\ &= \frac{N(B_c^*(2S)^+)}{N(B_c^+)} \frac{\epsilon(B_c^+)}{\epsilon(B_c^*(2S)^+)}, \\ R^{*+}/R^+ &= \frac{\sigma(B_c^*(2S)^+)}{\sigma(B_c(2S)^+)} \frac{\mathcal{B}(B_c^*(2S)^+ \rightarrow B_c^+ \pi^+ \pi^-)}{\mathcal{B}(B_c(2S)^+ \rightarrow B_c^+ \pi^+ \pi^-)} \\ &= \frac{N(B_c^*(2S)^+)}{N(B_c(2S)^+)} \frac{\epsilon(B_c(2S)^+)}{\epsilon(B_c^*(2S)^+)}. \end{aligned} \quad (1)$$

The $\mathcal{B}$ parameters are the unknown branching fractions of the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ decays. The B_c^{*+} meson is assumed to decay to the B_c^+ ground state and a low-energy photon with a branching fraction of 100%, where the photon is not reconstructed.

B. Measurement of the B_c^+ yield

The $B_c^+ \rightarrow J/\psi \pi^+$ candidates are reconstructed through a kinematic vertex fit, combining the dimuon with another track. The dimuon invariant mass is constrained to the world-average J/ψ mass [12] and the other track assumed to be a pion must fulfill $|\eta| < 2.4$ and $p_T > 3.5$ GeV. The primary vertex (PV) associated with the B_c^+ candidate is selected among all the reconstructed vertices [13] as the one with the smallest angle between the reconstructed B_c^+ momentum and the vector joining the PV with the B_c^+ decay vertex. To avoid biases, this PV is then refitted without the tracks associated with the muons and the pion. The B_c^+ candidates are required to have $p_T > 15$ GeV, $|y| < 2.4$, a kinematic vertex fit χ^2 probability larger than 10%, and a decay length (distance between the $J/\psi \pi^+$ vertex and the PV) larger than 100 μm . If several B_c^+ candidates are found in the same event, which happens in 1.6% of the events, only the one with the highest p_T is kept. Simulation studies show that this choice identifies the correct candidate with 99% probability. These selection criteria were defined through studies of simulated signal samples and measured sideband events [1].

Figure 1 shows the invariant mass distribution of the reconstructed and selected $B_c^+ \rightarrow J/\psi \pi^+$ candidates, where the B_c^+ signal is clearly seen as a prominent peak [1]. The result of an unbinned maximum-likelihood fit is also shown, together with the signal and background contributions. The underlying background is modeled as the sum of three terms: (a) uncorrelated J/ψ -track combinations (combinatorial background) parametrized by a first-order polynomial, (b) partially reconstructed $B_c^+ \rightarrow J/\psi \pi^+ X$ decays, only relevant for invariant mass values below 6.2 GeV and parametrized by a generalized ARGUS

function [14] convolved with a Gaussian resolution, and (c) a small contribution from $B_c^+ \rightarrow J/\psi K^+$ decays, with a shape fixed from simulation studies (described later) and a normalization fixed by the $B_c^+ \rightarrow J/\psi \pi^+$ yield, scaled by the ratio of the corresponding branching fractions [15] and reconstruction efficiencies. The B_c^+ signal peak is modeled by a double-Gaussian function,

$$wG(\mu, \sigma_1) + (1 - w)G(\mu, \sigma_2), \quad (2)$$

where $G(\mu, \sigma)$ represents a Gaussian function with mean μ and standard deviation σ , and w is the relative fraction of the narrower Gaussian in the fit. The single mean μ corresponds to the average reconstructed B_c^+ mass. The fit gives $w = 47\%$, $\sigma_1 = 21$ MeV, and $\sigma_2 = 42$ MeV, the very different Gaussian widths reflecting the fact that the B_c^+ mass resolution depends on rapidity degrading from the barrel to the end cap regions. The B_c^+ mass resolution [1] agrees with expectations from simulation studies, of approximately 34 MeV.

The fitted B_c^+ mass is $M(B_c^+) = 6271.1 \pm 0.5$ MeV and the B_c^+ signal yield is 7629 ± 225 events, where the uncertainties are statistical only. The measured invariant mass distribution is well reproduced by the sum of the fitted contributions reflected in the χ^2 between the binned distribution and the fit function of 35 for 30 degrees of freedom.

C. Measurement of the $B_c(2S)^+$ and $B_c^*(2S)^+$ yields

The $B_c(2S)^+$ and $B_c^*(2S)^+$ candidates are also reconstructed through vertex kinematic fits, combining a B_c^+ candidate with two opposite-sign, high-purity tracks assumed to be pions. The selected B_c^+ candidates must

have invariant mass in the 6.2–6.355 GeV range, where the low-mass edge is selected so as to avoid the background caused by partially reconstructed decays (represented by the gray area below 6.2 GeV in Fig. 1). The lifetimes of the $B_c(2S)^+$ and $B_c^*(2S)^+$ are assumed to be negligible with respect to the measurement resolution, so that the production and decay vertices essentially coincide. Therefore, the daughter pions are among the tracks used in the refitted PV. Furthermore, one of the pions must have $p_T > 0.8$ GeV and the other $p_T > 0.6$ GeV. The $B_c^+ \pi^+ \pi^-$ candidates must have $|y| < 2.4$ and a vertex kinematic fit χ^2 probability larger than 10%. As before, if several $B_c^+ \pi^+ \pi^-$ candidates are found in the same event, only the one with the highest p_T is kept.

Figure 2 shows the $M(B_c^+ \pi^+ \pi^-) - M(B_c^+) + m_{B_c^+}$ distribution, where $M(B_c^+ \pi^+ \pi^-)$ and $M(B_c^+)$ are the reconstructed invariant masses of the $B_c^+ \pi^+ \pi^-$ and B_c^+ candidates, respectively, and $m_{B_c^+}$ is the world-average B_c^+ mass [12]. This variable is used in the analysis because it is measured with a better resolution than $M(B_c^+ \pi^+ \pi^-)$, given that some of the measurement uncertainties cancel in the difference. The measured distribution is fitted to a superposition of two signal peaks using the same parametrization as in Eq. (2), plus a third-order Chebyshev polynomial modeling the nonpeaking, combinatorial background. Two background contributions arising from $B_c^+ \rightarrow J/\psi K^+$ decays are also considered, with shapes identical to those of the signal peaks, ignoring a negligible shift (less than 1 MeV) to lower mass values, and normalizations fixed by the ratio of the $B_c^+ \rightarrow J/\psi K^+$ to $B_c^+ \rightarrow J/\psi \pi^+$ signal yields.

Given the small number of events in the two signal peaks, the w and σ_2 double-Gaussian parameters are fixed to values determined in simulation studies: $w = 92\%$ and

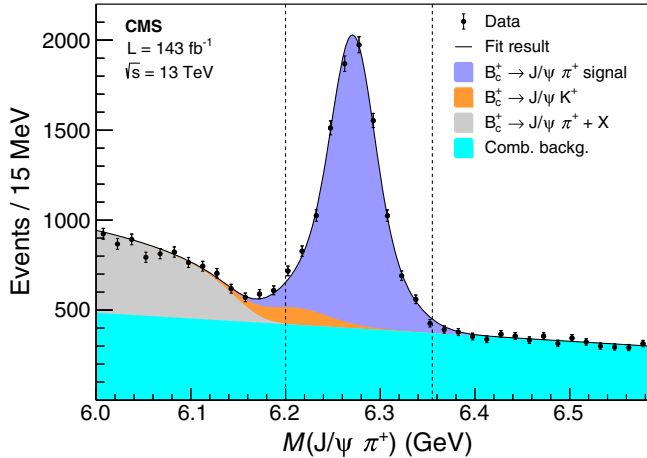


FIG. 1. Invariant mass distribution of the $B_c^+ \rightarrow J/\psi \pi^+$ candidates, after applying all event selection criteria [1]. The fitted contributions are shown by the stacked distributions, the solid line representing their sum. The vertical dashed lines indicate the mass window used to select the B_c^+ candidates for the $B_c^*(2S)^+$ reconstruction.

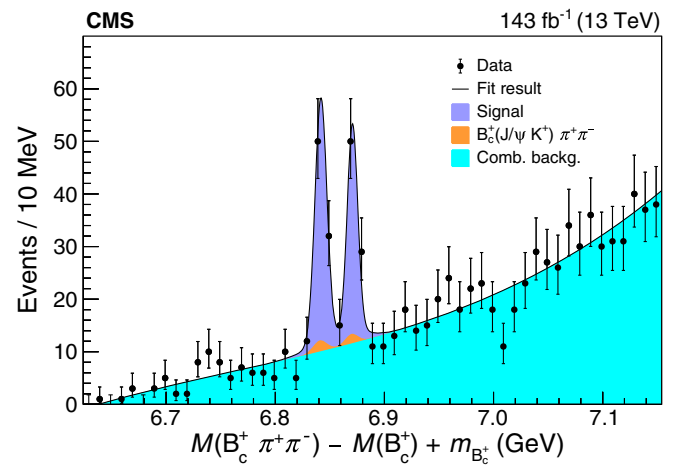


FIG. 2. Invariant mass distribution of the $B_c^*(2S)^+ \rightarrow B_c^+(2S)^+ \pi^+ \pi^-$ candidates [1]. The $B_c^*(2S)^+$ corresponds to the lower-mass peak, the $B_c(2S)^+$ to the higher. The fitted contributions are shown by the stacked distributions, the solid line representing their sum.

$\sigma_2 = 3.1\sigma_1$ for the lower-mass peak, and $w = 86\%$ and $\sigma_2 = 2.8\sigma_1$ for the higher-mass peak. The two resonances are well resolved, with a mass difference of 28.9 ± 1.5 MeV, where the uncertainty is statistical only. The widths of the peaks are consistent with the measurement resolution evaluated through simulation studies, which is approximately $\sigma = 6$ MeV [1]. The unbinned extended maximum-likelihood fit gives 67 ± 10 and 52 ± 9 events for the lower- and higher-mass peaks, respectively. The quality of the fit can be quantified through the χ^2 per degrees of freedom ratio, 41/35.

As explained in Ref. [1], the $B_c^*(2S)^+$ peak is seen in the $B_c^+ \pi^+ \pi^-$ invariant mass distribution at a mass value lower than that of the $B_c(2S)^+$ peak. The reason is that, contrary to what happens to the $B_c(2S)^+$, which decays directly to $B_c^+ \pi^+ \pi^-$, the $B_c^*(2S)^+$ meson decays to $B_c^{*+} \pi^+ \pi^-$ where the photon emitted in the subsequent $B_c^{*+} \rightarrow B_c^+ \gamma$ decay has too low energy to be reconstructed. Therefore, the $B_c^*(2S)^+$ peak is seen in the $B_c^+ \pi^+ \pi^-$ mass spectrum at the mass $M(B_c(2S)^+) - \Delta M$, where $\Delta M \equiv [M(B_c^{*+}) - M(B_c^+)] - [M(B_c^*(2S)^+) - M(B_c(2S)^+)]$. Since $M(B_c^{*+}) - M(B_c^+)$ is expected to be larger than $M(B_c^*(2S)^+) - M(B_c(2S)^+)$, the $B_c^*(2S)^+$ state corresponds to the lower-mass peak [3–5].

D. Reconstruction efficiencies

With respect to the observation analysis reported in Ref. [1], the main challenge in the determination of the $B_c^{(*)}(2S)^+$ to B_c^+ cross section ratios is the evaluation of the corresponding (relative) detection efficiencies. Since the trigger requires $J/\psi \rightarrow \mu^+ \mu^-$ from the $B_c^+ \rightarrow J/\psi \pi^+$ decay, the trigger efficiencies for the B_c^+ and $B_c^+ \pi^+ \pi^-$ candidates are essentially the same and cancel in the cross section ratios. So only the reconstruction efficiencies need to be evaluated, which is done using simulated event samples. All three mesons [B_c^+ , $B_c(2S)^+$, and $B_c^*(2S)^+$] are generated using the BCVEGPY 2.2 [16] Monte Carlo event generator. The events are then passed to PYTHIA 8.230 [17] to simulate the hadronization process. The decays are performed by the EVTGen 1.6.0 package [18] and the quantum electrodynamic final-state radiation is modeled with PHOTOS 3.61 [19]. The simulated events are then processed through a detailed simulation of the CMS detector, based on the GEANT4 package [20], using the same trigger and reconstruction algorithms used to collect and process the data. The simulated events include multiple pp interactions in the same or nearby beam crossings (pileup), with a distribution matching the one observed in the data. Monte Carlo samples were extensively validated using control regions in the data.

The $B_c(2S)^+$ and $B_c^*(2S)^+$ efficiencies are computed as $N_{\text{rec}}(B_c^{(*)}(2S)^+)/N_{\text{gen}}(B_c^{(*)}(2S)^+)$, where $N_{\text{gen}}(B_c^{(*)}(2S)^+)$ are the numbers of $B_c^{(*)}(2S)^+$ events generated in the $B_c^{(*)+} \pi^+ \pi^-$ channel, in the phase space region of the analysis, $p_T(B_c^+) > 15$ GeV and $|y(B_c^+)| < 2.4$, and

TABLE I. Ratios of the reconstruction efficiencies relevant for the determination of the R^+ , R^{*+} , and R^{*+}/R^+ cross section ratios. The central values are followed by the several uncertainties presented in the text.

	Central	Stat.	Spread	Pions
$\epsilon(B_c(2S)^+)/\epsilon(B_c^+)$	0.196	1.1%	1.8%	4.2%
$\epsilon(B_c^*(2S)^+)/\epsilon(B_c^+)$	0.187	1.0%	1.6%	4.2%
$\epsilon(B_c^*(2S)^+)/\epsilon(B_c(2S)^+)$	0.955	1.4%	0.9%	...

$N_{\text{rec}}(B_c^{(*)}(2S)^+)$ are the numbers of events that survive all the reconstruction steps and event selection criteria. The B_c^+ efficiency is computed in a completely analogous way, except that it uses B_c^+ events generated in the $B_c^+ \rightarrow J/\psi \pi^+$ decay channel. These evaluations are independently made for the 2016, 2017, and 2018 running periods. The events collected in 2015, corresponding to 2% of the total sample, are treated the same as the 2016 sample for the purpose of efficiency determination. It was checked that the 2016 Monte Carlo simulation describes the 2015 data well enough so that no residual systematic uncertainty is required. The final efficiencies are obtained as weighted averages, using the integrated luminosities as weights: 2.8 + 36.1, 42.1, and 61.6 fb⁻¹, respectively, for the 2015 + 2016, 2017, and 2018 periods [21–24]. The results are $\epsilon(B_c^+) = 1.31\%$, $\epsilon(B_c(2S)^+) = 0.26\%$, and $\epsilon(B_c^*(2S)^+) = 0.24\%$. The $B_c(2S)^+$ and $B_c^*(2S)^+$ reconstruction efficiencies are very similar, the slightly smaller $B_c^*(2S)^+$ value reflecting the (missed) low-energy photon, which implies a small reduction of the $B_c^+ \pi^+ \pi^-$ phase space.

Table I lists the efficiency ratios relevant for the determination of the cross section ratios. The first uncertainty (“Stat.”) shown reflects the finite size of the three simulated samples. The second (“Spread”) reflects the standard deviation of the computed values around their average and is used to conservatively cover potential residual mismatches between the running conditions and the settings used in simulation. For example, it could be that the simulated samples do not accurately reproduce the time evolution of the instantaneous luminosity within each data-taking period, which would create differences in the measured and simulated pileup distributions. The last column (“Pions”) reflects the uncertainty in the reconstruction efficiency [25] of the two pions emitted in the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ decays. This uncertainty is relevant for the R^{*+} and R^+ ratios, but cancels in the R^{*+}/R^+ ratio.

E. Determination of the cross section ratios

Correcting the yield ratios by the corresponding efficiency ratios leads to the following $B_c(2S)^+$ to B_c^+ , $B_c^*(2S)^+$ to B_c^+ , and $B_c^*(2S)^+$ to $B_c(2S)^+$ cross section ratios, always including the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ branching fractions, and always for $p_T(B_c^+) > 15$ GeV and $|y(B_c^+)| < 2.4$:

$$\begin{aligned}
R^+ &= (3.47 \pm 0.63)\%, \\
R^{*+} &= (4.69 \pm 0.71)\%, \quad \text{and} \\
R^{*+}/R^+ &= 1.35 \pm 0.32.
\end{aligned} \tag{3}$$

The quoted uncertainties are statistical only. The fact that the $B_c^{(*)}(2S)^+$ events are a subset of the B_c^+ events has a negligible effect (less than 1%) on the uncertainties. The correlation between $B_c^*(2S)^+$ and $B_c(2S)^+$ yields, used in the double cross section ratio, is taken into account using an alternative fit to the $M(B_c^+\pi^+\pi^-) - M(B_c^+) + m_{B_c^+}$ distribution, which directly provides the ratio of these yields. It is worth noting again that these ratios include branching fractions [shown in Eq. (1)] that have not yet been measured.

F. Dependence on the B_c^+ kinematics

In order to probe if these cross section ratios show a dependence on the kinematics of the B_c^+ meson, the analysis is redone after splitting the events into three B_c^+ meson p_T bins and (independently) into three $|y|$ bins. The bin edges are chosen so as to have similar uncertainties in the three bins: 15, 22.5, 30, and 60 GeV for p_T , and 0, 0.4, 0.8, and 2.4 for $|y|$. The amount of events with $p_T > 60$ GeV corresponds to 3.4% of the total sample and they are excluded from these kinematical distributions.

As shown in Fig. 3, none of the measured ratios shows significant variations with the p_T or $|y|$ of the B_c^+ meson, within the probed kinematical regions. The markers are shown at the average B_c^+ p_T or $|y|$ values of the events contributing to each bin. The horizontal displacements between the markers seen in the top panels reflect the differences between the $B_c(2S)^+$ and $B_c^*(2S)^+$ kinematic distributions.

Reporting the cross section ratios as a function of the B_c^+ kinematics and in a phase space domain defined by the B_c^+ is the choice that best reflects the data analysis procedure and that cancels to the largest extent the systematic uncertainties related to the B_c^+ detection. Given the relatively small mass difference between the mother $B_c^{(*)}(2S)^+$ and the daughter B_c^+ states, the ratio of laboratory momentum to mass remains practically unchanged in the decays, on average, so that the following kinematical relations hold to a very good approximation: $y^M = y^d$ and $p_T^M = (M/m)p_T^d$, where y^M , p_T^M , and M (respectively y^d , p_T^d , and m) are the rapidity, p_T , and mass of the mother (respectively daughter) [26].

G. Systematic uncertainties

Several sources of systematic effects that could potentially affect the measurement of the cross section ratios have been considered. For each of those effects, the analysis has been redone using an alternative option and the resulting cross section ratios are compared to those obtained in the baseline analysis. The observed difference

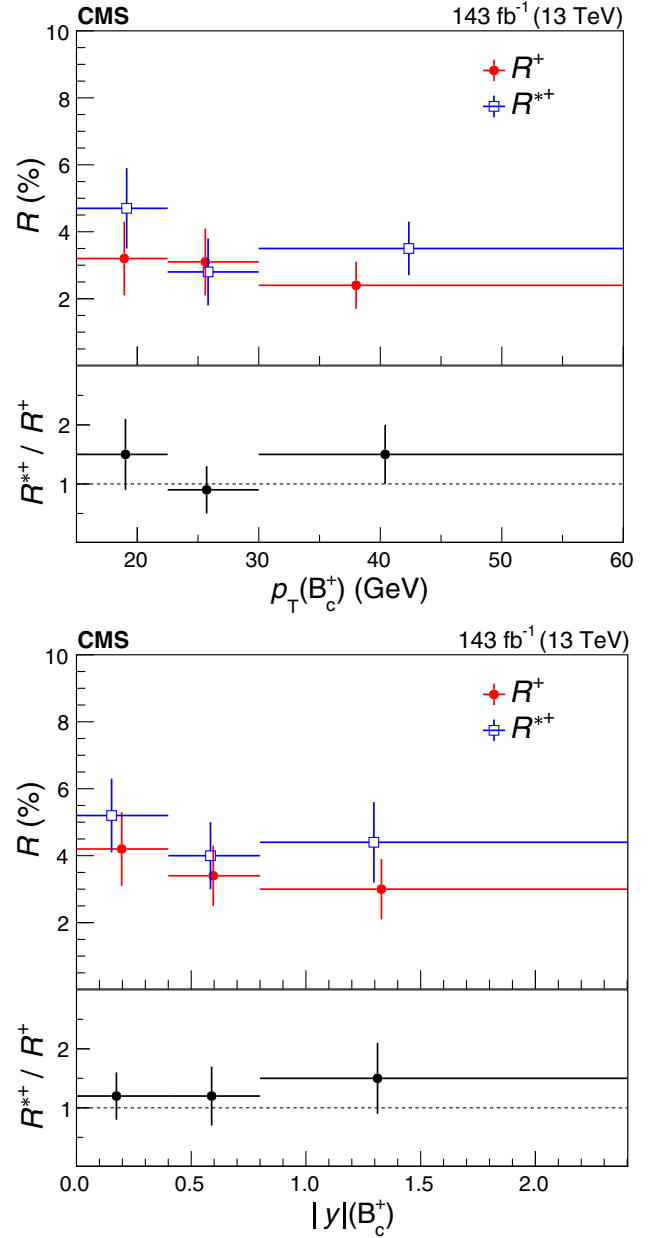


FIG. 3. The R^+ and R^{*+} (upper), and R^{*+}/R^+ (lower) cross section ratios, including the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+}\pi^+\pi^-$ branching fractions, as functions of the B_c^+ p_T (left) and $|y|$ (right). The horizontal bars show the bin widths. The markers are shown at the average B_c^+ p_T or $|y|$ values of the events contributing to each bin, in the background-subtracted distributions, and the vertical bars represent the statistical uncertainties only. The systematic uncertainties are essentially independent of the B_c^+ kinematics.

between the two results is taken as the systematic uncertainty associated with that specific effect.

Naturally, no uncertainties are considered in factors that affect identically the numerator and denominator values that provide the cross section ratios, such as the efficiency of the J/ψ trigger used to collect the event sample or the efficiency of the event selections that determine the total

number of $B_c^+ \rightarrow J/\psi\pi^+$ candidates contributing to Fig. 1. But even if the integral of the measured $J/\psi\pi^+$ invariant mass distribution does not change, it is possible to vary the extracted B_c^+ yield by changing the functions used in the fit to describe the shapes of the signal and background contributions, given that such variations might change the assignment of some events from the B_c^+ yield to the background yield, or vice versa. The importance of this effect is evaluated by independently varying the signal and background models used in the fit.

The background model is varied by using an exponential function, instead of a first-order polynomial, to describe the uncorrelated $J/\psi\pi^+$ pairs. The varied scenario for the B_c^+ signal line shape consisted in replacing the double-Gaussian function by a Student's t function [27]. Since these two variations only change the fitted B_c^+ yield, having no effect on the number of $B_c^+ \rightarrow J/\psi\pi^+$ candidates used in the search for the $B_c^{(*)}(2S)^+$ excited states, the corresponding (relative) systematic uncertainties, 4.3% for the signal model and 3.5% for the background model, are identical for the R^+ and R^{*+} ratios, and cancel in the R^{*+}/R^+ double ratio.

The measurement of the $B_c(2S)^+$ and $B_c^{*}(2S)^+$ yields is also affected by the choices made to model the shapes of the signal peaks and the underlying combinatorial background seen in Fig. 2. The effect of the signal modeling is evaluated with two independent approaches. First, the default double-Gaussian function having a common mean and fixing the relative widths and amplitudes from fits to the simulated distributions is replaced by a single-Gaussian function. The number of free parameters for each signal peak remains at three, but this simpler model is unable to describe the non-Gaussian tails of the peaks. Second, the signal yields are evaluated with a simple procedure that avoids fitting the mass region of the two signal peaks, thereby being insensitive to specific signal shape models. It starts by fitting the signal-free mass sidebands with the background function and then integrating that function within the two signal regions to evaluate the background yields under the peaks, which are then subtracted from the total number of events in those two regions. To evaluate the impact of the background model, these alternative fits have been made with the third-order Chebyshev polynomial used in the baseline analysis and also with the function $\delta^\lambda \exp(\nu\delta)$, where $\delta \equiv M(B_c^+\pi^+\pi^-) - q_0$, and λ , ν , and q_0 are free parameters. Comparing the cross section ratios obtained using the alternative fits with those of the baseline fit leads to fit modeling systematic uncertainties of 5.9%, 2.9%, and 2.9%, respectively for the R^+ , R^{*+} , and R^{*+}/R^+ ratios.

The fit of the $B_c^+\pi^+\pi^-$ invariant mass distribution also includes two small contributions representing the cases where the B_c^+ meson decays through the $B_c^+ \rightarrow J/\psi K^+$ channel rather than through the $B_c^+ \rightarrow J/\psi\pi^+$ channel assumed in the reconstruction. In the baseline analysis, these terms are modeled using the same shapes as the

$B_c^{(*)}(2S)^+$ signal shapes and yields fixed to the yields of those resonances, scaled by the ratio of the two branching fractions, 0.079 ± 0.008 [15], and by the ratio of the two reconstruction efficiencies, 1.06 ± 0.01 , in the signal region defined above. To evaluate the influence of these terms on the measured cross section ratios, the analysis is redone varying those two scale factors by their uncertainties. The results are insensitive to those variations, so no systematic uncertainty is assigned to this source.

When searching for $B_c^{(*)}(2S)^+$ candidates, the baseline analysis starts from an event sample composed of $B_c^+ \rightarrow J/\psi\pi^+$ events with invariant mass in the 6.2–6.355 GeV range. In order to probe if a potential residual contribution of the partially reconstructed B_c^+ decays could have a significant effect on the determination of the cross section ratios, the analysis is repeated with the lowest allowed invariant mass value changed from 6.2 to 6.1 GeV. The results remain essentially identical, the variations being smaller than their statistical uncertainties evaluated taking into account that one event sample is a subset of the other, so that the results are fully correlated. Therefore, no systematic uncertainty is assigned to this potential effect.

The uncertainties affecting the ratios of reconstruction efficiencies already presented in Table I translate directly into corresponding systematic uncertainties in the cross section ratios. In the evaluation of the $B_c^{(*)}(2S)^+$ reconstruction efficiencies, it is assumed that the two pions emitted in the $B_c^+\pi^+\pi^-$ decay have no kinematical correlations between them, besides the constraint of being decay products of the same mother particle. To evaluate the sensitivity of the measured cross section ratios to this assumption, the reconstruction efficiencies are recomputed under two other scenarios. These assume that the $\pi^+\pi^-$ kinematic distributions (a) reflect the existence of an intermediate resonance, or (b) are dependent on the (different) spins of the $B_c(2S)^+$ and $B_c^{*}(2S)^+$ states. The first scenario is simulated by independently reweighting the generated $B_c^{(*)}(2S)^+$ event samples, which previously reflected a simple phase space model, so that their $\pi^+\pi^-$ invariant mass distributions (“decay kinematics”) match that in the data (presented in Sec. IV). The second scenario follows an analogous procedure using the helicity angle distribution (“helicity angle”), where the helicity angle is the angle between the directions of the π^+ and B_c^+ in the dipion rest frame. The differences between the resulting ratios of reconstruction efficiencies and those obtained in the baseline scenario are considered as systematic uncertainties: 1.5%, 6.9%, and 4.2% for the decay kinematics, and 1.0%, 6.0%, and 3.5% for the helicity angle, respectively, for the R^+ , R^{*+} , and R^{*+}/R^+ ratios.

Several studies have been performed to verify the stability of the results with respect to the selection criteria, including the threshold values used to select the daughter particles. The variations in the reported ratios were smaller

TABLE II. Relative systematic uncertainties (in %) in the cross section ratios, including the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+}\pi^+\pi^-$ branching fractions, corresponding to the sources described in the text. The total uncertainty is the sum in quadrature of the individual terms.

	R^+	R^{*+}	R^{*+}/R^+
$J/\psi\pi^+$ fit model	5.5	5.5	...
$B_c^+\pi^+\pi^-$ fit model	5.9	2.9	2.9
Efficiencies: statistical uncertainty	1.1	1.0	1.4
Efficiencies: spread among years	1.8	1.6	0.9
Efficiencies: pion tracking	4.2	4.2	...
Decay kinematics	1.5	6.9	4.2
Helicity angle	1.0	6.0	3.5
Total	9.5	12.0	6.4

than the respective uncertainties computed accounting for the correlation induced by the overlap of the baseline and varied event samples, so that no corresponding systematic uncertainty has been considered.

All the values mentioned above are listed in Table II, which also shows the total systematic uncertainties computed as the sum in quadrature of the individual terms.

IV. INVARIANT MASS DISTRIBUTION OF THE DIPION SYSTEM

As a complement to the measurement of the cross section ratios, it is also interesting to measure the invariant mass distributions of the dipions emitted in the $B_c^+\pi^+\pi^-$ decays of the two $B_c^{(*)}(2S)^+$ states. In particular, comparing these distributions to those seen in the analogous $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ and $\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ decays should provide relevant information to characterize the excited B_c^+ states and their production processes [6,7].

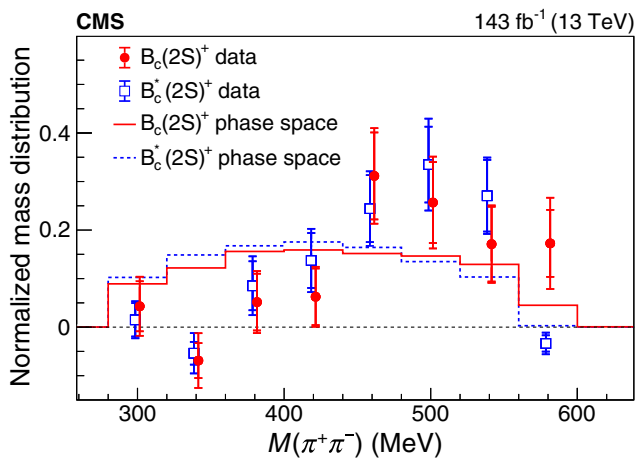


FIG. 4. The dipion invariant mass distributions from $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+}\pi^+\pi^-$ decays in data, normalized to unity. The inner and outer tick marks designate the statistical and total uncertainties, respectively. The lines show the corresponding predictions from phase space simulations.

Figure 4 compares the invariant mass distributions normalized to unity, of the dipions emitted in the $B_c(2S)^+$ (closed red circles) and $B_c^*(2S)^+$ (open blue squares) decays between themselves and with the two corresponding simulated phase space distributions (lines). The $B_c^{(*)}(2S)^+$ data distributions are derived from the $B_c^+\pi^+\pi^-$ invariant mass distribution shown in Fig. 2. The contribution of the background events under the peaks is subtracted using the shape of the measured same-sign dipion invariant mass spectrum and normalizing the sum of the $B_c^+\pi^+\pi^+$ and $B_c^+\pi^-\pi^-$ events to the $B_c^+\pi^+\pi^-$ spectrum in the invariant mass sideband regions. The dipion invariant mass distributions have also been obtained using the sPlot technique [28] to subtract the background, which resulted in distributions consistent with those reported in Fig. 4.

Simulation studies show no dependence of the reconstruction efficiencies on the $\pi^+\pi^-$ invariant mass, so no correction is applied to these normalized distributions, where only the shapes are informative. For the same reason, systematic uncertainties that affect the distributions globally are not relevant, as they have no impact on the shapes and are canceled by the normalizations.

The dipion mass-dependent systematic uncertainties have been evaluated by comparing, bin by bin, the baseline distributions with those obtained in alternative analyses, where variations are made, as mentioned above, on the models used to fit the signal and background components of the $B_c^+\pi^+\pi^-$ mass distribution and on the small contributions from the $B_c^+ \rightarrow J/\psi K^+$ and partially reconstructed B_c^+ decays.

As seen in Fig. 4, the $B_c^{(*)}(2S)^+$ dipion invariant mass distributions are compatible with each other within the uncertainties, and have shapes different from the rather flat distributions predicted from the phase space simulations.

V. SUMMARY

The ratios of the $B_c(2S)^+$ to B_c^+ , $B_c^*(2S)^+$ to B_c^+ , and $B_c^*(2S)^+$ to $B_c(2S)^+$ production cross sections, R^+ , R^{*+} , and R^{*+}/R^+ , respectively, have been measured in proton-proton collisions at $\sqrt{s} = 13$ TeV. The dataset used in the analysis corresponds to an integrated luminosity of 143 fb^{-1} collected by the CMS experiment at the LHC between 2015 and 2018.

The $B_c^{(*)}(2S)^+$ mesons have been reconstructed through the decays $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+}\pi^+\pi^-$, followed by the $B_c^+ \rightarrow J/\psi\pi^+$ and $J/\psi \rightarrow \mu^+\mu^-$. The measured cross section ratios, including the (unknown) $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+}\pi^+\pi^-$ branching fractions, are

$$\begin{aligned}
 R^+ &= (3.47 \pm 0.63(\text{stat}) \pm 0.33(\text{syst}))\%, \\
 R^{*+} &= (4.69 \pm 0.71(\text{stat}) \pm 0.56(\text{syst}))\%, \quad \text{and} \\
 R^{*+}/R^+ &= 1.35 \pm 0.32(\text{stat}) \pm 0.09(\text{syst}).
 \end{aligned} \tag{4}$$

No significant dependences on the transverse momentum p_T or rapidity $|y|$ of the B_c^+ mesons have been observed for any of these three ratios. The normalized dipion invariant mass distributions for the $B_c^{(*)}(2S)^+ \rightarrow B_c^{(*)+} \pi^+ \pi^-$ decays have also been reported. These results obtained in the phase space region defined by B_c^+ meson $p_T > 15$ GeV and $|y| < 2.4$ may provide new important input to improve the theoretical understanding of the nature of the $\bar{b}c$ heavy-quarkonium states and their production processes.

ACKNOWLEDGMENTS

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centers and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: 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 IUT, 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); 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. 752730, and No. 765710 (European Union); the Leventis

Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the 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”—No. 390833306; 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 Bilateral Scientific and Technological Cooperation Program between Italy and Mexico 2018–2020 (Project No. MX18MO11 and additional MAECI Project No. PGR 00783/2019); 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 No. 2014/14/M/ST2/00428, Opus No. 2014/13/B/ST2/02543, No. 2014/15/B/ST2/03998, and No. 2015/19/B/ST2/02861, Sonata-bis No. 2012/07/E/ST2/01406; the National Priorities Research Program by Qatar National Research Fund; the Ministry of Science and Higher Education, Project No. 02.a03.21.0005 (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 Talis 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; the Weston Havens Foundation (USA).

- [1] CMS Collaboration, Observation of Two Excited B_c^+ States and Measurement of the $B_c(2S)^+$ Mass in pp Collisions at $\sqrt{s} = 13$ TeV, *Phys. Rev. Lett.* **122**, 132001 (2019).
- [2] LHCb Collaboration, Observation of an Excited B_c^+ State, *Phys. Rev. Lett.* **122**, 232001 (2019).
- [3] E. B. Gregory, C. T. H. Davies, E. Follana, E. Gamiz, I. D. Kendall, G. P. Lepage, H. Na, J. Shigemitsu, and K. Y. Wong, A Prediction of the B_c^+ Mass in Full Lattice QCD, *Phys. Rev. Lett.* **104**, 022001 (2010).
- [4] R. J. Dowdall, C. T. H. Davies, T. C. Hammant, and R. R. Horgan, Precise heavy-light meson masses and hyperfine splittings from lattice QCD including charm quarks in the sea, *Phys. Rev. D* **86**, 094510 (2012).
- [5] N. Mathur, M. Padmanath, and S. Mondal, Precise Predictions of Charmed-Bottom Hadrons from Lattice QCD, *Phys. Rev. Lett.* **121**, 202002 (2018).
- [6] E. J. Eichten and C. Quigg, Mesons with beauty and charm: New horizons in spectroscopy, *Phys. Rev. D* **99**, 054025 (2019).
- [7] A. V. Berezhnoy, I. N. Belov, A. K. Likhoded, and A. V. Luchinsky, B_c^+ excitations at LHC experiments, *Mod. Phys. Lett. A* **34**, 1950331 (2019).
- [8] 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).
- [9] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [10] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [11] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [12] M. Tanabashi *et al.* (Particle Data Group), Review of particle physics, *Phys. Rev. D* **98**, 030001 (2018).
- [13] R. Frühwirth, W. Waltenberger, and P. Vanlaer, Adaptive vertex fitting, *J. Phys. G* **34**, N343 (2007).
- [14] H. Albrecht *et al.* (ARGUS Collaboration), Search for hadronic $b \rightarrow u$ decays, *Phys. Lett. B* **241**, 278 (1990).
- [15] LHCb Collaboration, Measurement of the ratio of branching fractions $\mathcal{B}(B_c^+ \rightarrow J/\psi K^+)/\mathcal{B}(B_c^+ \rightarrow J/\psi \pi^+)$, *J. High Energy Phys.* **09** (2016) 153.
- [16] C.-H. Chang, X.-Y. Wang, and X.-G. Wu, BCVEGPY2.2: A newly upgraded version for hadronic production of the meson B_c and its excited states, *Comput. Phys. Commun.* **197**, 335 (2015).
- [17] 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).
- [18] D. Lange, The EvtGen particle decay simulation package, *Nucl. Instrum. Methods Phys. Res., Sect. A* **462**, 152 (2001).
- [19] N. Davidson, T. Przedzinski, and Z. Was, PHOTOS interface in C++: Technical and physics documentation, *Comput. Phys. Commun.* **199**, 86 (2016).
- [20] S. Agostinelli *et al.* (GEANT4 Collaboration), GEANT4—A simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [21] CMS Collaboration, Report No. CMS-PAS-LUM-15-001, 2017, <https://cds.cern.ch/record/2138682>.
- [22] CMS Collaboration, Report No. CMS-PAS-LUM-17-001, 2017, <https://cds.cern.ch/record/2257069>.
- [23] CMS Collaboration, Report No. CMS-PAS-LUM-17-004, 2018, <https://cds.cern.ch/record/2621960>.
- [24] CMS Collaboration, Report No. CMS-PAS-LUM-18-002, 2019, <https://cds.cern.ch/record/2676164>.
- [25] CMS Collaboration, Report No. CMS-DP-2018-050, 2018, <https://cds.cern.ch/record/2634940>.
- [26] P. Faccioli, C. Lourenço, M. Araújo, V. Knünz, I. Krätschmer, and J. Seixas, Quarkonium production at the LHC: A data-driven analysis of remarkably simple experimental patterns, *Phys. Lett. B* **773**, 476 (2017).
- [27] S. Jackman, *Bayesian Analysis for the Social Sciences* (John Wiley & Sons, New York, 2009).
- [28] M. Pivk and F. R. Le Diberder, SPlot: A statistical tool to unfold data distributions, *Nucl. Instrum. Methods Phys. Res., Sect. A* **555**, 356 (2005).

A. M. Sirunyan,^{1,a} A. Tumasyan,¹ W. Adam,² F. Ambrogio,² T. Bergauer,² M. Dragicevic,² J. Erö,² A. Escalante Del Valle,² R. Frühwirth,^{2,b} M. Jeitler,^{2,b} N. Krammer,² L. Lechner,² D. Liko,² T. Madlener,² I. Mikulec,² F. M. Pitters,² N. Rad,² J. Schieck,^{2,b} R. Schöfbeck,² M. Spanring,² S. Templ,² W. Waltenberger,² C.-E. Wulz,^{2,b} M. Zarucki,² V. Chekhovsky,³ A. Litomin,³ V. Makarenko,³ J. Suarez Gonzalez,³ M. R. Darwish,^{4,c} E. A. De Wolf,⁴ D. Di Croce,⁴ X. Janssen,⁴ T. Kello,^{4,d} A. Lelek,⁴ M. Pieters,⁴ H. Rejeb Sfar,⁴ H. Van Haeve, P. Van Mechelen,⁴ S. Van Putte,⁴ N. Van Remortel,⁴ F. Blekman,⁵ E. S. Bols,⁵ S. S. Chhibra,⁵ J. D'Hondt,⁵ J. De Clercq,⁵ D. Lontkovskiy,⁵ S. Lowette,⁵ I. Marchesini,⁵ S. Moortgat,⁵ A. Morton,⁵ Q. Python,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 B. Dorney,⁶ L. Favart,⁶ A. Grebenyuk,⁶ A. K. Kalsi,⁶ I. Makarenko,⁶ L. Moureaux,⁶ L. Pétré,⁶ A. Popov,⁶ N. Postiau,⁶ E. Starling,⁶ L. Thomas,⁶ C. Vander Velde,⁶ P. Vanlaer,⁶ D. Vannerom,⁶ L. Wezenbeek,⁶ T. Cornelis,⁷ D. Dobur,⁷ M. Gruchala,⁷ I. Khvastunov,^{7,e} M. Niedziela,⁷ C. Roskas,⁷ K. Skovpen,⁷ M. Tytgat,⁷ W. Verbeke,⁷ B. Vermassen,⁷ M. Vit,⁷ G. Bruno,⁸ F. Bury,⁸ C. Caputo,⁸ P. David,⁸ C. Delaere,⁸ M. Delcourt,⁸ I. S. Donertas,⁸ A. Giammanco,⁸ V. Lemaitre,⁸ K. Mondal,⁸ J. Prisciandaro,⁸ A. Taliencio,⁸ M. Teklishyn,⁸ P. Vischia,⁸ S. Wuyckens,⁸ J. Zobec,⁸ G. A. Alves,⁹ G. Correia Silva,⁹ C. Hensel,⁹ A. Moraes,⁹ W. L. Aldá Júnior,¹⁰ E. Belchior Batista Das Chagas,¹⁰ H. Brandao Malbouisson,¹⁰ W. Carvalho,¹⁰ J. Chinellato,^{10,f} E. Coelho,¹⁰ E. M. Da Costa,¹⁰ G. G. Da Silveira,^{10,g}

D. De Jesus Damiao,¹⁰ S. Fonseca De Souza,¹⁰ J. Martins,^{10,h} D. Matos Figueiredo,¹⁰ M. Medina Jaime,^{10,i} M. Melo De Almeida,¹⁰ C. Mora Herrera,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 E. J. Tonelli Manganote,^{10,f} 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 M. Bonchev,¹³ A. Dimitrov,¹³ T. Ivanov,¹³ L. Litov,¹³ B. Pavlov,¹³ P. Petkov,¹³ A. Petrov,¹³ W. Fang,^{14,d} Q. Guo,¹⁴ H. Wang,¹⁴ L. Yuan,¹⁴ M. Ahmad,¹⁵ Z. Hu,¹⁵ Y. Wang,¹⁵ E. Chapon,¹⁶ G. M. Chen,^{16,j} H. S. Chen,^{16,j} M. Chen,¹⁶ A. Kapoor,¹⁶ D. Leggat,¹⁶ H. Liao,¹⁶ Z. Liu,¹⁶ R. Sharma,¹⁶ A. Spiezia,¹⁶ J. Tao,¹⁶ J. Thomas-wilsker,¹⁶ J. Wang,¹⁶ H. Zhang,¹⁶ S. Zhang,^{16,j} J. Zhao,¹⁶ A. Agapitos,¹⁷ Y. Ban,¹⁷ C. Chen,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} 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 M. Rodriguez,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 T. Sculac,²³ Z. Antunovic,²⁴ M. Kovac,²⁴ V. Brigljevic,²⁵ D. Ferencek,²⁵ D. Majumder,²⁵ M. Roguljic,²⁵ A. Starodumov,^{25,k} T. Susa,²⁵ M. W. Ather,²⁶ A. Attikis,²⁶ E. Erodotou,²⁶ A. Ioannou,²⁶ G. Kole,²⁶ M. Kolosova,²⁶ S. Konstantinou,²⁶ G. Mavromanolakis,²⁶ J. Mousa,²⁶ C. Nicolaou,²⁶ F. Ptochos,²⁶ P. A. Razis,²⁶ H. Rykaczewski,²⁶ H. Saka,²⁶ D. Tsiakkouri,²⁶ M. Finger,^{27,l} M. Finger Jr.,^{27,l} A. Kveton,²⁷ J. Tomsa,²⁷ E. Ayala,²⁸ E. Carrera Jarrin,²⁹ H. Abdalla,^{30,m} S. Elgammal,^{30,n} A. Mohamed,^{30,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 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. Laurila,³⁴ S. Lehti,³⁴ T. Lindén,³⁴ H. Siikonen,³⁴ E. Tuominen,³⁴ J. Tuominiemi,³⁴ P. Luukka,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,p} M. Titov,³⁶ G. B. Yu,³⁶ S. Ahuja,³⁷ F. Beaudette,³⁷ M. Bonanomi,³⁷ A. Buchot Perraguin,³⁷ P. Busson,³⁷ C. Charlot,³⁷ O. Davignon,³⁷ B. Diab,³⁷ G. Falmagne,³⁷ R. Granier de Cassagnac,³⁷ A. Hakimi,³⁷ I. Kucher,³⁷ A. Lobanov,³⁷ C. Martin Perez,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,q} J. Andrea,³⁸ D. Bloch,³⁸ G. Bourgatte,³⁸ J.-M. Brom,³⁸ E. C. Chabert,³⁸ C. Collard,³⁸ J.-C. Fontaine,^{38,q} D. Gelé,³⁸ 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 L. Torterotot,³⁹ G. Touquet,³⁹ M. Vander Donckt,³⁹ S. Viret,³⁹ D. Lomidze,⁴⁰ Z. Tsamalaidze,^{40,1} L. Feld,⁴¹ K. Klein,⁴¹ M. Lipinski,⁴¹ D. Meuser,⁴¹ A. Pauls,⁴¹ M. Preuten,⁴¹ M. P. Rauch,⁴¹ J. Schulz,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 H. Keller,⁴² L. Mastrolorenzo,⁴² M. Merschmeyer,⁴² A. Meyer,⁴² P. Millet,⁴² G. Mocellin,⁴² S. Mondal,⁴² S. Mukherjee,⁴² D. Noll,⁴² A. Novak,⁴² T. Pook,⁴² A. Pozdnyakov,⁴² T. Quast,⁴² M. Radziej,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,r} O. Hlushchenko,⁴³ T. Kress,⁴³ A. Nowack,⁴³ C. Pistone,⁴³ O. Pooth,⁴³ D. Roy,⁴³ H. Sert,⁴³ A. Stahl,^{43,s} 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,t} V. Botta,⁴⁴ D. Brunner,⁴⁴ A. Campbell,⁴⁴ A. Cardini,⁴⁴ P. Connor,⁴⁴ S. Consuegra Rodríguez,⁴⁴ V. Danilov,⁴⁴ A. De Wit,⁴⁴ M. M. Defranchis,⁴⁴ L. Didukh,⁴⁴ D. Domínguez Damiani,⁴⁴ G. Eckerlin,⁴⁴ D. Eckstein,⁴⁴ T. Eichhorn,⁴⁴ L. I. Estevez Banos,⁴⁴ E. Gallo,^{44,u} A. Geiser,⁴⁴ A. Giralaldi,⁴⁴ A. Grohsjean,⁴⁴ M. Guthoff,⁴⁴ A. Harb,⁴⁴ A. Jafari,^{44,v} N. Z. Jomhari,⁴⁴ H. Jung,⁴⁴ A. Kasem,^{44,t} 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,w} R. Mankel,⁴⁴ I.-A. Melzer-Pellmann,⁴⁴ J. Metwally,⁴⁴ A. B. Meyer,⁴⁴ M. Meyer,⁴⁴ M. Missiroli,⁴⁴ J. Mnich,⁴⁴ A. Mussgiller,⁴⁴ V. Myronenko,⁴⁴ Y. Otari,⁴⁴ D. Pérez Adán,⁴⁴ S. K. Pflitsch,⁴⁴ D. Pitzl,⁴⁴ A. Raspereza,⁴⁴ A. Saggio,⁴⁴ A. Saibel,⁴⁴ M. Savitskyi,⁴⁴ V. Scheurer,⁴⁴ P. Schütze,⁴⁴ C. Schwanenberger,⁴⁴ A. Singh,⁴⁴ R. E. Sosa Ricardo,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 O. Zenaiev,⁴⁴ R. Zlebicki,⁴⁴ R. Aggleton,⁴⁵ S. Bein,⁴⁵ L. Benato,⁴⁵ A. Benecke,⁴⁵ K. De Leo,⁴⁵ T. Dreyer,⁴⁵ A. Ebrahimi,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 C. E. N. Niemeyer,⁴⁵ A. Nigamova,⁴⁵ K. J. Pena Rodriguez,⁴⁵ O. Rieger,⁴⁵ P. Schleper,⁴⁵ S. Schumann,⁴⁵ J. Schwandt,⁴⁵ D. Schwarz,⁴⁵ J. Sonneveld,⁴⁵ H. Stadie,⁴⁵ G. Steinbrück,⁴⁵ B. Vormwald,⁴⁵ I. Zoi,⁴⁵ M. Baselga,⁴⁶ S. Baur,⁴⁶ J. Bechtel,⁴⁶ T. Berger,⁴⁶ E. Butz,⁴⁶ R. Caspart,⁴⁶ T. Chwalek,⁴⁶ W. De Boer,⁴⁶ A. Dierlamm,⁴⁶ A. Droll,⁴⁶ K. El Morabit,⁴⁶ N. Faltermann,⁴⁶ K. Flöh,⁴⁶ M. Giffels,⁴⁶ A. Gottmann,⁴⁶ F. Hartmann,^{46,s} C. Heidecker,⁴⁶ U. Husemann,⁴⁶ M. A. Iqbal,⁴⁶ I. Katkov,^{46,x} P. Keicher,⁴⁶ R. Koppenhöfer,⁴⁶ S. Maier,⁴⁶ M. Metzler,⁴⁶ S. Mitra,⁴⁶ D. Müller,⁴⁶ Th. Müller,⁴⁶ M. Musich,⁴⁶ G. Quast,⁴⁶ K. Rabbertz,⁴⁶ J. Rauser,⁴⁶ D. Savoie,⁴⁶ D. Schäfer,⁴⁶ M. Schnepf,⁴⁶ M. Schröder,⁴⁶ D. Seith,⁴⁶ I. Shvetsov,⁴⁶ H. J. Simonis,⁴⁶ R. Ulrich,⁴⁶ M. Wassmer,⁴⁶ M. Weber,⁴⁶ R. Wolf,⁴⁶ S. Wozniowski,⁴⁶ G. Anagnostou,⁴⁷ P. Asenov,⁴⁷ G. Daskalakis,⁴⁷ T. Geralis,⁴⁷ A. Kyriakis,⁴⁷ D. Loukas,⁴⁷ G. Paspalaki,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 K. Vellidis,⁴⁸ E. Vourliotis,⁴⁸ G. Bakas,⁴⁹ K. Kousouris,⁴⁹ I. Papakrivopoulos,⁴⁹ G. Tsiopolitis,⁴⁹ A. Zacharopoulou,⁴⁹ I. Evangelou,⁵⁰ C. Foudas,⁵⁰ P. Gianneios,⁵⁰ P. Katsoulis,⁵⁰ P. Kokkas,⁵⁰ S. Mallios,⁵⁰ K. Manitaras,⁵⁰ N. Manthos,⁵⁰ I. Papadopoulos,⁵⁰ J. Strologas,⁵⁰ M. Bartók,^{51,y} R. Chudasama,⁵¹ M. Csanad,⁵¹ M. M. A. Gadallah,^{51,z} S. Lökös,^{51,aa} P. Major,⁵¹ K. Mandal,⁵¹ A. Mehta,⁵¹ G. Pasztor,⁵¹ O. Surányi,⁵¹ G. I. Veres,⁵¹ G. Bencze,⁵² C. Hajdu,⁵² D. Horvath,^{52,bb} F. Sikler,⁵² V. Veszpremi,⁵² G. Vesztergombi,^{52,aaa} S. Czellar,⁵³ J. Karancsi,^{53,y} J. Molnar,⁵³ Z. Szillasi,⁵³ D. Teyssier,⁵³ P. Raics,⁵⁴ Z. L. Trocsanyi,⁵⁴ B. Ujvari,⁵⁴ T. Csorgo,⁵⁵ F. Nemes,⁵⁵ T. Novak,⁵⁵ S. Choudhury,⁵⁶ J. R. Komaragiri,⁵⁶ D. Kumar,⁵⁶ L. Panwar,⁵⁶ P. C. Tiwari,⁵⁶ S. Bahinipati,^{57,cc} D. Dash,⁵⁷ C. Kar,⁵⁷ P. Mal,⁵⁷ T. Mishra,⁵⁷ V. K. Muraleedharan Nair Bindhu,⁵⁷ A. Nayak,^{57,dd} D. K. Sahoo,^{57,cc} N. Sur,⁵⁷ S. K. Swain,⁵⁷ S. Bansal,⁵⁸ S. B. Beri,⁵⁸ V. Bhatnagar,⁵⁸ S. Chauhan,⁵⁸ N. Dhingra,^{58,ee} R. Gupta,⁵⁸ A. Kaur,⁵⁸ S. Kaur,⁵⁸ P. Kumari,⁵⁸ M. Lohan,⁵⁸ M. Meena,⁵⁸ K. Sandeep,⁵⁸ S. Sharma,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,ff} R. Bhattacharya,⁶⁰ S. Bhattacharya,⁶⁰ D. Bhowmik,⁶⁰ S. Dutta,⁶⁰ S. Ghosh,⁶⁰ B. Gomber,^{60,gg} M. Maity,^{60,hh} S. Nandan,⁶⁰ P. Palit,⁶⁰ A. Purohit,⁶⁰ P. K. Rout,⁶⁰ G. Saha,⁶⁰ S. Sarkar,⁶⁰ M. Sharan,⁶⁰ B. Singh,^{60,ff} S. Thakur,^{60,ff} 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. Kumar,⁶² K. Naskar,^{62,ii} P. K. Netrakanti,⁶² L. M. Pant,⁶² P. Shukla,⁶² T. Aziz,⁶³ M. A. Bhat,⁶³ S. Dugad,⁶³ R. Kumar Verma,⁶³ G. B. Mohanty,⁶³ U. Sarkar,⁶³ S. Banerjee,⁶⁴ S. Bhattacharya,⁶⁴ S. Chatterjee,⁶⁴ M. Guchait,⁶⁴ S. Karmakar,⁶⁴ S. Kumar,⁶⁴ G. Majumder,⁶⁴ K. Mazumdar,⁶⁴ S. Mukherjee,⁶⁴ D. Roy,⁶⁴ N. Sahoo,⁶⁴ S. Dube,⁶⁵ B. Kansal,⁶⁵ K. Kotheekar,⁶⁵ S. Pandey,⁶⁵ A. Rane,⁶⁵ A. Rastogi,⁶⁵ S. Sharma,⁶⁵ H. Bakhshiansohi,^{66,jj} S. Chenarani,^{67,kk} 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,ll} 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. 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,70b} S. Braibant-Giacomelli,^{70a,70b} 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. Diotallevi,^{70a,70b} F. Fabbri,^{70a} A. Fanfani,^{70a,70b} E. Fontanesi,^{70a,70b} P. Giacomelli,^{70a} L. Giommi,^{70a,70b} C. Grandi,^{70a} L. Guiducci,^{70a,70b} F. Iemmi,^{70a,70b} S. Lo Meo,^{70a,mm} S. Marcellini,^{70a} G. Masetti,^{70a} F. L. Navarra,^{70a,70b} A. Perrotta,^{70a} F. Primavera,^{70a,70b} T. Rovelli,^{70a,70b} G. P. Siroli,^{70a,70b} N. Tosi,^{70a} S. Albergo,^{71a,71b,nn} S. Costa,^{71a,71b} A. Di Mattia,^{71a} R. Potenza,^{71a,71b} A. Tricomi,^{71a,71b,nn} 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} 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} A. Beschi,^{75a,75b} F. Brivio,^{75a,75b} F. Cettorelli,^{75a,75b} V. Ciriolo,^{75a,75b,s} 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} 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,s} D. Zuolo,^{75a,75b} S. Buontempo,^{76a} N. Cavallo,^{76a,76c} A. De Iorio,^{76a,76b} F. Fabozzi,^{76a,76c} F. Fienga,^{76a} A. O. M. Iorio,^{76a,76b} L. Lista,^{76a,76b} S. Meola,^{76a,76d,s} P. Paolucci,^{76a,s} B. Rossi,^{76a} C. Sciacca,^{76a,76b} E. Voevodina,^{76a,76b} P. Azzi,^{77a} N. Bacchetta,^{77a} D. Bisello,^{77a,77b} A. Boletti,^{77a,77b} 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,oo}
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} A. Tiko,^{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} M. Biasini,^{79a,79b} G. M. Bilei,^{79a}
D. Ciangottini,^{79a,79b} L. Fanò,^{79a,79b} P. Lariccia,^{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} K. Androssov,^{80a}
P. Azzurri,^{80a} G. Bagliesi,^{80a} V. Bertacchi,^{80a,80c} L. Bianchini,^{80a} T. Boccali,^{80a} R. Castaldi,^{80a} M. A. Ciocci,^{80a,80b}
R. Dell'Orso,^{80a} M. R. Di Domenico,^{80a,80b} S. Donato,^{80a} L. Giannini,^{80a,80c} 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} 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} A. Venturi,^{80a} P. G. Verdini,^{80a} 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,81b} 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} C. Biino,^{82a}
A. Cappati,^{82a,82b} 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} V. Monaco,^{82a,82b} E. Monteil,^{82a,82b} M. Monteno,^{82a}
M. M. Obertino,^{82a,82b} G. Ortona,^{82a} L. Pacher,^{82a} N. Pastrone,^{82a} M. Pelliccioni,^{82a} G. L. Pinna Angioni,^{82a,82b}
M. Ruspa,^{82a,82c} R. Salvatico,^{82a,82b} F. Siviero,^{82a,82b} V. Sola,^{82a} A. Solano,^{82a,82b} D. Soldi,^{82a,82b} A. Staiano,^{82a}
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}
F. Vazzoler,^{83a,83b} S. Dogra,⁸⁴ C. Huh,⁸⁴ B. Kim,⁸⁴ D. H. Kim,⁸⁴ G. N. 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 B. Francois,⁸⁶ T. J. Kim,⁸⁶ J. Park,⁸⁶
S. Cho,⁸⁷ S. Choi,⁸⁷ Y. Go,⁸⁷ S. Ha,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 K. Lee,⁹⁰ S. Lee,⁹⁰ K. Nam,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 H. D. Yoo,⁹² Y. Choi,⁹³
C. Hwang,⁹³ Y. Jeong,⁹³ H. Lee,⁹³ Y. Lee,⁹³ I. Yu,⁹³ V. Veckalns,^{94,pp} A. Juodagalvis,⁹⁵ A. Rinkevicius,⁹⁵ G. Tamulaitis,⁹⁵
W. A. T. Wan Abdullah,⁹⁶ M. N. Yusli,⁹⁶ Z. Zolkapli,⁹⁶ J. F. Benitez,⁹⁷ A. Castaneda Hernandez,⁹⁷ J. A. Murillo Quijada,⁹⁷
L. Valencia Palomo,⁹⁷ H. Castilla-Valdez,⁹⁸ E. De La Cruz-Burelo,⁹⁸ I. Heredia-De La Cruz,^{98,qq} R. Lopez-Fernandez,⁹⁸
C. A. Mondragon Herrera,⁹⁸ D. A. Perez Navarro,⁹⁸ A. Sanchez-Hernandez,⁹⁸ S. Carrillo Moreno,⁹⁹ C. Oropeza Barrera,⁹⁹
M. Ramirez-Garcia,⁹⁹ F. Vazquez Valencia,⁹⁹ J. Eysermans,¹⁰⁰ I. Pedraza,¹⁰⁰ H. A. Salazar Ibarguen,¹⁰⁰ C. Uribe Estrada,¹⁰⁰
A. Morelos Pineda,¹⁰¹ J. Mijuskovic,^{102,e} N. Raicevic,¹⁰² D. Krofcheck,¹⁰³ S. Bheesette,¹⁰⁴ P. H. Butler,¹⁰⁴ A. Ahmad,¹⁰⁵
M. I. Asghar,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 A. Byszek,^{108,rr} K. Doroba,¹⁰⁸ A. Kalinowski,¹⁰⁸
M. Konecki,¹⁰⁸ J. Krolikowski,¹⁰⁸ M. Olszewski,¹⁰⁸ M. Walczak,¹⁰⁸ M. Araujo,¹⁰⁹ P. Bargassa,¹⁰⁹ D. Bastos,¹⁰⁹
P. Faccioli,¹⁰⁹ M. Gallinaro,¹⁰⁹ J. Hollar,¹⁰⁹ N. Leonardo,¹⁰⁹ T. Niknejad,¹⁰⁹ J. Seixas,¹⁰⁹ K. Shchelina,¹⁰⁹ O. Toldaiev,¹⁰⁹
J. Varela,¹⁰⁹ S. Afanasiev,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,ss,tt} P. Moisezenz,¹¹⁰ 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. Gavrilo,¹¹¹ V. Golovtsov,¹¹¹ Y. Ivanov,¹¹¹ V. Kim,^{111,uu} E. Kuznetsova,^{111,vv} 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. Karneyev,¹¹² M. Kirsanov,¹¹² N. Krasnikov,¹¹² A. Pashenkov,¹¹² G. Pivovarov,¹¹² D. Tlisov,^{112,a}
A. Toropin,¹¹² V. Epshteyn,¹¹³ V. Gavrilo,¹¹³ N. Lychkovskaya,¹¹³ A. Nikitenko,^{113,ww} V. Popov,¹¹³ G. Safronov,¹¹³
A. Spiridonov,¹¹³ A. Steppenov,¹¹³ M. Toms,¹¹³ E. Vlasov,¹¹³ A. Zhokin,¹¹³ T. Aushev,¹¹⁴ R. Chistov,^{115,xx} M. Danilov,^{115,yy}
A. Oskin,¹¹⁵ P. Parygin,¹¹⁵ S. Polikarpov,^{115,yy} V. Andreev,¹¹⁶ M. Azarkin,¹¹⁶ I. Dremin,¹¹⁶ M. Kirakosyan,¹¹⁶
A. Terkulov,¹¹⁶ A. Belyaev,¹¹⁷ E. Boos,¹¹⁷ M. Dubinin,^{117,zz} 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,aaa}
T. Dimova,^{118,aaa} L. Kardapoltsev,^{118,aaa} I. Ovtin,^{118,aaa} Y. Skovpen,^{118,aaa} 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 A. Iuzhakov,¹²⁰ V. Okhotnikov,¹²⁰ L. Sukhikh,¹²⁰ V. Borchsh,¹²¹ V. Ivanchenko,¹²¹
 E. Tcherniaev,¹²¹ P. Adzic,^{122,bbb} P. Cirkovic,¹²² M. Dordevic,¹²² P. Milenovic,¹²² J. 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
 J. A. Brochero Cifuentes,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 A. García Alonso,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
 A. Triossi,¹²³ L. Urda Gómez,¹²³ C. Willmott,¹²³ C. Albajar,¹²⁴ 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 S. Sanchez Cruz,¹²⁵ A. Trapote,¹²⁵
 I. J. Cabrillo,¹²⁶ A. Calderon,¹²⁶ B. Chazin Quero,¹²⁶ J. Duarte Campderros,¹²⁶ M. Fernandez,¹²⁶ P. J. Fernández Manteca,¹²⁶
 G. Gomez,¹²⁶ C. Martinez Rivero,¹²⁶ P. Martinez Ruiz del Arbol,¹²⁶ F. Matorras,¹²⁶ J. Piedra Gomez,¹²⁶ C. Prieels,¹²⁶
 F. Ricci-Tam,¹²⁶ T. Rodrigo,¹²⁶ A. Ruiz-Jimeno,¹²⁶ L. Scodellaro,¹²⁶ I. Vila,¹²⁶ J. M. Vizán García,¹²⁶ MK Jayananda,¹²⁷
 B. Kailasapathy,^{127,ccc} D. U. J. Sonnadara,¹²⁷ DDC Wickramaratna,¹²⁷ W. G. D. Dharmaratna,¹²⁸ K. Liyanage,¹²⁸
 N. Perera,¹²⁸ N. Wickramage,¹²⁸ T. K. Aarrestad,¹²⁹ D. Abbaneo,¹²⁹ B. Akgun,¹²⁹ E. Auffray,¹²⁹ G. Auzinger,¹²⁹
 J. Baechler,¹²⁹ P. Baillon,¹²⁹ A. H. Ball,¹²⁹ D. Barney,¹²⁹ J. Bendavid,¹²⁹ N. Beni,¹²⁹ M. Bianco,¹²⁹ A. Bocci,¹²⁹
 P. Bortignon,¹²⁹ E. Bossini,¹²⁹ E. Brondolin,¹²⁹ T. Camporesi,¹²⁹ G. Cerminara,¹²⁹ L. Cristella,¹²⁹ D. d'Enterria,¹²⁹
 A. Dabrowski,¹²⁹ N. Daci,¹²⁹ V. Daponte,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. Emrskova,¹²⁹ F. Fallavollita,^{129,ddd} D. Fasanella,¹²⁹ S. Fiorendi,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. Guillaud,¹²⁹
 D. Gulhan,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 P. Lecoq,¹²⁹ K. Long,¹²⁹ C. Lourenço,¹²⁹ L. Malgeri,¹²⁹
 M. Mannelli,¹²⁹ A. Massironi,¹²⁹ F. Meijers,¹²⁹ S. Mersi,¹²⁹ E. Meschi,¹²⁹ F. Moortgat,¹²⁹ M. Mulders,¹²⁹ J. Ngadiuba,¹²⁹
 J. Niedziela,¹²⁹ S. Orfanelli,¹²⁹ L. Orsini,¹²⁹ F. Pantaleo,^{129,s} L. Pape,¹²⁹ E. Perez,¹²⁹ M. Peruzzi,¹²⁹ A. Petrilli,¹²⁹
 G. Petrucciani,¹²⁹ A. Pfeiffer,¹²⁹ M. Pierini,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,eee} J. Steggemann,¹²⁹ S. Summers,¹²⁹ V. R. Tavolaro,¹²⁹ D. Treille,¹²⁹ A. Tsiros,¹²⁹ G. P. Van Onsem,¹²⁹
 A. Vartak,¹²⁹ M. Verzetti,¹²⁹ K. A. Wozniak,¹²⁹ W. D. Zeuner,¹²⁹ L. Caminada,^{130,fff} W. Erdmann,¹³⁰ R. Horisberger,¹³⁰
 Q. Ingram,¹³⁰ H. C. Kaestli,¹³⁰ D. Kotlinski,¹³⁰ U. Langenegger,¹³⁰ T. Rohe,¹³⁰ 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 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 M. T. Meinhard,¹³¹
 F. Micheli,¹³¹ F. Nessi-Tedaldi,¹³¹ F. Pauss,¹³¹ V. Perovic,¹³¹ G. Perrin,¹³¹ L. Perrozzi,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 M. L. Vesterbacka Olsson,¹³¹ R. Wallny,¹³¹ D. H. Zhu,¹³¹ C. Amsler,^{132,ggg} C. Botta,¹³² D. Brzhechko,¹³²
 M. F. Canelli,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 K. Schweiger,¹³² Y. Takahashi,¹³² S. Wertz,¹³² C. Adloff,^{133,hhh} C. M. Kuo,¹³³ W. Lin,¹³³ A. Roy,¹³³
 T. Sarkar,^{133,hh} 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 B. Asavapibhop,¹³⁵ C. Asawatangtrakuldee,¹³⁵
 N. Srimanobhas,¹³⁵ F. Boran,¹³⁶ S. Damarseckin,^{136,iii} Z. S. Demiroglu,¹³⁶ F. Dolek,¹³⁶ C. Dozen,^{136,jjj} I. Dumanoglu,^{136,kkk}
 E. Eskut,¹³⁶ G. Gokbulut,¹³⁶ Y. Guler,¹³⁶ E. Gurpinar Guler,^{136,lll} I. Hos,^{136,mmm} C. Isik,¹³⁶ E. E. Kangal,^{136,nnn} O. Kara,¹³⁶
 A. Kayis Topaksu,¹³⁶ U. Kiminsu,¹³⁶ G. Onengut,¹³⁶ K. Ozdemir,^{136,ooo} A. Polatoz,¹³⁶ A. E. Simsek,¹³⁶ B. Tali,^{136,ppp}
 U. G. Tok,¹³⁶ S. Turkcapar,¹³⁶ I. S. Zorbakir,¹³⁶ C. Zorbilmez,¹³⁶ B. Isildak,^{137,qqq} G. Karapinar,^{137,rrr} K. Ocalan,^{137,sss}
 M. Yalvac,^{137,ttt} I. O. Atakisi,¹³⁸ E. Gülmez,¹³⁸ M. Kaya,^{138,uuu} O. Kaya,^{138,vvv} Ö. Özçelik,¹³⁸ S. Tekten,^{138,www}
 E. A. Yetkin,^{138,xxx} A. Cakir,¹³⁹ K. Cankocak,^{139,kkk} Y. Komurcu,¹³⁹ S. Sen,^{139,yyy} F. Aydogmus Sen,¹⁴⁰ S. Cerci,^{140,ppp}
 B. Kaynak,¹⁴⁰ S. Ozkorucuklu,¹⁴⁰ D. Sunar Cerci,^{140,ppp} B. Grynyov,¹⁴¹ L. Levchuk,¹⁴² E. Bhal,¹⁴³ S. Bologna,¹⁴³
 J. J. Brooke,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 J. Taylor,¹⁴³ A. Titterton,¹⁴³

K. W. Bell,¹⁴⁴ A. Belyaev,^{144,zzz} 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 A. Bundock,¹⁴⁵ V. Cepaitis,¹⁴⁵ G. S. Chahal,^{145,aaaa} D. Colling,¹⁴⁵ P. Dauncey,¹⁴⁵ G. Davies,¹⁴⁵ M. Della Negra,¹⁴⁵ G. Fedi,¹⁴⁵ G. Hall,¹⁴⁵ G. Iles,¹⁴⁵ J. Langford,¹⁴⁵ L. Lyons,¹⁴⁵ A.-M. Magnan,¹⁴⁵ S. Malik,¹⁴⁵ A. Martelli,¹⁴⁵ V. Milosevic,¹⁴⁵ J. Nash,^{145,bbbb} 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 M. Stoye,¹⁴⁵ A. Tapper,¹⁴⁵ K. Uchida,¹⁴⁵ T. Virdee,^{145,s} N. Wardle,¹⁴⁵ S. N. Webb,¹⁴⁵ D. Winterbottom,¹⁴⁵ A. G. Zecchinelli,¹⁴⁵ J. E. Cole,¹⁴⁶ P. R. Hobson,¹⁴⁶ A. Khan,¹⁴⁶ P. Kyberd,¹⁴⁶ C. K. Mackay,¹⁴⁶ I. D. Reid,¹⁴⁶ L. Teodorescu,¹⁴⁶ S. Zahid,¹⁴⁶ A. Brinkerhoff,¹⁴⁷ K. Call,¹⁴⁷ B. Caraway,¹⁴⁷ J. Dittmann,¹⁴⁷ K. Hatakeyama,¹⁴⁷ A. R. Kanuganti,¹⁴⁷ C. Madrid,¹⁴⁷ B. McMaster,¹⁴⁷ N. Pastika,¹⁴⁷ S. Sawant,¹⁴⁷ C. Smith,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 S. V. Gleyzer,¹⁴⁹ C. Henderson,¹⁴⁹ P. Rumerio,¹⁴⁹ C. West,¹⁴⁹ A. Akpinar,¹⁵⁰ A. Albert,¹⁵⁰ D. Arcaro,¹⁵⁰ C. Cosby,¹⁵⁰ Z. Demiragli,¹⁵⁰ D. Gastler,¹⁵⁰ C. Richardson,¹⁵⁰ J. Rohlf,¹⁵⁰ K. Salyer,¹⁵⁰ D. Sperka,¹⁵⁰ D. Spitzbart,¹⁵⁰ I. Suarez,¹⁵⁰ S. Yuan,¹⁵⁰ D. Zou,¹⁵⁰ G. Benelli,¹⁵¹ B. Burkle,¹⁵¹ X. Coubez,^{151,t} D. Cutts,¹⁵¹ Y. t. Duh,¹⁵¹ M. Hadley,¹⁵¹ U. Heintz,¹⁵¹ J. M. Hogan,^{151,cccc} K. H. M. Kwok,¹⁵¹ E. Laird,¹⁵¹ G. Landsberg,¹⁵¹ K. T. Lau,¹⁵¹ J. Lee,¹⁵¹ M. Narain,¹⁵¹ S. Sagir,^{151,dddd} R. Syarif,¹⁵¹ E. Usai,¹⁵¹ W. Y. Wong,¹⁵¹ D. Yu,¹⁵¹ W. Zhang,¹⁵¹ R. Band,¹⁵² C. Brainerd,¹⁵² R. Breedon,¹⁵² M. Calderon De La Barca Sanchez,¹⁵² M. Chertok,¹⁵² J. Conway,¹⁵² R. Conway,¹⁵² P. T. Cox,¹⁵² R. Erbacher,¹⁵² C. Flores,¹⁵² G. Funk,¹⁵² F. Jensen,¹⁵² W. Ko,^{152,a} O. Kukral,¹⁵² R. Lander,¹⁵² M. Mulhearn,¹⁵² D. Pellett,¹⁵² J. Pilot,¹⁵² M. Shi,¹⁵² D. Taylor,¹⁵² K. Tos,¹⁵² M. Tripathi,¹⁵² Y. Yao,¹⁵² F. Zhang,¹⁵² M. Bachtis,¹⁵³ R. Cousins,¹⁵³ A. Dasgupta,¹⁵³ A. Florent,¹⁵³ D. Hamilton,¹⁵³ J. Hauser,¹⁵³ M. Ignatenko,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 S. M. A. Ghiasi Shirazi,¹⁵⁴ G. Hanson,¹⁵⁴ G. Karapostoli,¹⁵⁴ O. R. Long,¹⁵⁴ N. Manganelli,¹⁵⁴ M. Olmedo Negrete,¹⁵⁴ M. I. Paneva,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 M. Derdzinski,¹⁵⁵ J. Duarte,¹⁵⁵ R. Gerosa,¹⁵⁵ D. Gilbert,¹⁵⁵ B. Hashemi,¹⁵⁵ V. Krutelyov,¹⁵⁵ J. Letts,¹⁵⁵ M. Masciovecchio,¹⁵⁵ S. May,¹⁵⁵ S. Padhi,¹⁵⁵ M. Pieri,¹⁵⁵ V. Sharma,¹⁵⁵ M. Tadel,¹⁵⁵ F. Würthwein,¹⁵⁵ A. Yagil,¹⁵⁵ N. Amin,¹⁵⁶ C. Campagnari,¹⁵⁶ M. Citron,¹⁵⁶ A. Dorsett,¹⁵⁶ V. Dutta,¹⁵⁶ J. Incandela,¹⁵⁶ B. Marsh,¹⁵⁶ H. Mei,¹⁵⁶ A. Ovcharova,¹⁵⁶ H. Qu,¹⁵⁶ M. Quinlan,¹⁵⁶ J. Richman,¹⁵⁶ U. Sarica,¹⁵⁶ D. Stuart,¹⁵⁶ S. Wang,¹⁵⁶ D. Anderson,¹⁵⁷ A. Bornheim,¹⁵⁷ O. Cerri,¹⁵⁷ I. Dutta,¹⁵⁷ J. M. Lawhorn,¹⁵⁷ N. Lu,¹⁵⁷ J. Mao,¹⁵⁷ H. B. Newman,¹⁵⁷ T. Q. Nguyen,¹⁵⁷ J. Pata,¹⁵⁷ M. Spiropulu,¹⁵⁷ J. R. Vlimant,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 M. Sun,¹⁵⁸ I. Vorobiev,¹⁵⁸ J. P. Cumalat,¹⁵⁹ W. T. Ford,¹⁵⁹ E. MacDonald,¹⁵⁹ T. Mulholland,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 A. Datta,¹⁶⁰ A. Frankenthal,¹⁶⁰ K. McDermott,¹⁶⁰ J. Monroy,¹⁶⁰ J. R. Patterson,¹⁶⁰ D. Quach,¹⁶⁰ A. Ryd,¹⁶⁰ W. Sun,¹⁶⁰ S. M. Tan,¹⁶⁰ Z. Tao,¹⁶⁰ J. Thom,¹⁶⁰ P. Wittich,¹⁶⁰ M. Zientek,¹⁶⁰ S. Abdullin,¹⁶¹ 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 V. D. Elvira,¹⁶¹ J. Freeman,¹⁶¹ Z. Gecse,¹⁶¹ E. Gottschalk,¹⁶¹ L. Gray,¹⁶¹ D. Green,¹⁶¹ S. Grünendahl,¹⁶¹ O. Gutsche,¹⁶¹ R. M. Harris,¹⁶¹ S. Hasegawa,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 S. Lammel,¹⁶¹ D. Lincoln,¹⁶¹ R. Lipton,¹⁶¹ M. Liu,¹⁶¹ T. Liu,¹⁶¹ J. Lykken,¹⁶¹ K. Maeshima,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,zz} 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 W. J. Spalding,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. Bourilov,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 K. Shi,¹⁶² J. Wang,¹⁶² S. Wang,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,eeee} M. Hohmann,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 M. Alhusseini,¹⁶⁶ K. Dilsiz,^{166,ffff} S. Durgut,¹⁶⁶ R. P. Gandrajula,¹⁶⁶ M. Haytmyradov,¹⁶⁶ V. Khristenko,¹⁶⁶ O. K. Köseyan,¹⁶⁶ J.-P. Merlo,¹⁶⁶ A. Mestvirishvili,^{166,gggg} A. Moeller,¹⁶⁶ J. Nachtman,¹⁶⁶ H. Ogul,^{166,hhhh} Y. Onel,¹⁶⁶ F. Ozok,^{166,iiii} A. Penzo,¹⁶⁶ C. Snyder,¹⁶⁶ E. Tiras,¹⁶⁶ J. Wetzel,¹⁶⁶ K. Yi,^{166,jjjj} O. Amram,¹⁶⁷ B. Blumenfeld,¹⁶⁷ L. Corcodilos,¹⁶⁷ M. Eminizer,¹⁶⁷ A. V. Gritsan,¹⁶⁷ S. Kyriacou,¹⁶⁷ P. Maksimovic,¹⁶⁷ C. Mantilla,¹⁶⁷ J. Roskes,¹⁶⁷ M. Swartz,¹⁶⁷ T. Á. Vami,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 A. Mohammadi,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 G. Y. Jeng,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 B. Allen,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 D. Hsu,¹⁷² M. Hu,¹⁷² M. Klute,¹⁷² D. Kovalskyi,¹⁷² J. Krupa,¹⁷² Y.-J. Lee,¹⁷² P. D. Luckey,¹⁷² B. Maier,¹⁷² A. C. Marini,¹⁷² C. McGinn,¹⁷² C. Mironov,¹⁷² S. Narayanan,¹⁷² X. Niu,¹⁷² C. Paus,¹⁷² D. Rankin,¹⁷² C. Roland,¹⁷² G. Roland,¹⁷² Z. Shi,¹⁷² G. S. F. Stephans,¹⁷² K. Sumorok,¹⁷² K. Tatar,¹⁷² D. Velicanu,¹⁷² J. Wang,¹⁷² T. W. Wang,¹⁷² Z. Wang,¹⁷² B. Wyslouch,¹⁷² R. M. Chatterjee,¹⁷³ A. Evans,¹⁷³ S. Guts,^{173,a} 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 S. Chauhan,¹⁷⁵ D. R. Claes,¹⁷⁵ C. Fangmeier,¹⁷⁵ L. Finco,¹⁷⁵ F. Golf,¹⁷⁵ J. R. González Fernández,¹⁷⁵ I. Kravchenko,¹⁷⁵ J. E. Siado,¹⁷⁵ G. R. Snow,^{175,a} B. Stieger,¹⁷⁵ W. Tabb,¹⁷⁵ F. Yan,¹⁷⁵ G. Agarwal,¹⁷⁶ H. Bandyopadhyay,¹⁷⁶ C. Harrington,¹⁷⁶ L. Hay,¹⁷⁶ I. Iashvili,¹⁷⁶ A. Kharchilava,¹⁷⁶ C. McLean,¹⁷⁶ D. Nguyen,¹⁷⁶ J. Pekkanen,¹⁷⁶ S. Rappoccio,¹⁷⁶ B. Roozbahani,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. Bucci,¹⁷⁹ N. Dev,¹⁷⁹ R. Goldouzian,¹⁷⁹ M. Hildreth,¹⁷⁹ K. Hurtado Anampa,¹⁷⁹ C. Jessop,¹⁷⁹ D. J. Karmgard,¹⁷⁹ K. Lannon,¹⁷⁹ W. Li,¹⁷⁹ N. Loukas,¹⁷⁹ N. Marinelli,¹⁷⁹ I. Mcalister,¹⁷⁹ F. Meng,¹⁷⁹ K. Mohrman,¹⁷⁹ Y. Musienko,^{179,ss} R. Ruchti,¹⁷⁹ P. Siddireddy,¹⁷⁹ S. Taroni,¹⁷⁹ M. Wayne,¹⁷⁹ A. Wightman,¹⁷⁹ M. Wolf,¹⁷⁹ L. Zygala,¹⁷⁹ J. Alimena,¹⁸⁰ B. Bylsma,¹⁸⁰ B. Cardwell,¹⁸⁰ L. S. Durkin,¹⁸⁰ B. Francis,¹⁸⁰ C. Hill,¹⁸⁰ A. Lefeld,¹⁸⁰ B. L. Winer,¹⁸⁰ B. R. Yates,¹⁸⁰ P. Das,¹⁸¹ G. Dezoort,¹⁸¹ P. Elmer,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 J. Luo,¹⁸¹ D. Marlow,¹⁸¹ K. Mei,¹⁸¹ I. Ojalvo,¹⁸¹ J. Olsen,¹⁸¹ C. Palmer,¹⁸¹ P. Piroué,¹⁸¹ D. Stickland,¹⁸¹ C. Tully,¹⁸¹ S. Malik,¹⁸² S. Norberg,¹⁸² V. E. Barnes,¹⁸³ R. Chawla,¹⁸³ S. Das,¹⁸³ L. Gutay,¹⁸³ M. Jones,¹⁸³ A. W. Jung,¹⁸³ B. Mahakud,¹⁸³ G. Negro,¹⁸³ N. Neumeister,¹⁸³ C. C. Peng,¹⁸³ S. Piperov,¹⁸³ H. Qiu,¹⁸³ J. F. Schulte,¹⁸³ M. Stojanovic,^{183,p} N. Trevisani,¹⁸³ F. Wang,¹⁸³ R. Xiao,¹⁸³ W. Xie,¹⁸³ T. Cheng,¹⁸⁴ J. Dolen,¹⁸⁴ N. Parashar,¹⁸⁴ A. Baty,¹⁸⁵ S. Dildick,¹⁸⁵ K. M. Ecklund,¹⁸⁵ S. Freed,¹⁸⁵ F. J. M. Geurts,¹⁸⁵ M. Kilpatrick,¹⁸⁵ A. Kumar,¹⁸⁵ W. Li,¹⁸⁵ B. P. Padley,¹⁸⁵ R. Redjimi,¹⁸⁵ J. Roberts,^{185,a} J. Rorie,¹⁸⁵ 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,w} 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,kkkk} M. Dalchenko,¹⁸⁹ A. Delgado,¹⁸⁹ R. Eusebi,¹⁸⁹ J. Gilmore,¹⁸⁹ T. Huang,¹⁸⁹ T. Kamon,^{189,llll} H. Kim,¹⁸⁹ S. Luo,¹⁸⁹ S. Malhotra,¹⁸⁹ R. Mueller,¹⁸⁹ D. Overton,¹⁸⁹ L. Perniè,¹⁸⁹ D. Rathjens,¹⁸⁹ A. Safonov,¹⁸⁹ J. Sturdy,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 R. Janjam,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. Verweij,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 Y. Wang,¹⁹² E. Wolfe,¹⁹² F. Xia,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 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 D. Pinna,¹⁹⁴ T. Ruggles,¹⁹⁴ A. Savin,¹⁹⁴ V. Shang,¹⁹⁴ V. Sharma,¹⁹⁴
 W. H. Smith,¹⁹⁴ D. Teague,¹⁹⁴ S. Trembath-reichert,¹⁹⁴ and W. Vetens¹⁹⁴

(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 Físicas, 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 Politécnica 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,
Paris, 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*
^{69b}*Università di Bari*
^{69c}*Politecnico di Bari*
^{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*
^{76b}*Università di Napoli 'Federico II'*
^{76c}*Università della Basilicata*
^{76d}*Università G. Marconi*
^{77a}*INFN Sezione di Padova, Padova, Italy*
^{77b}*Università di Padova, Padova, Italy*
^{77c}*Università di Trento, Trento, Italy*
^{78a}*INFN Sezione di Pavia*
^{78b}*Università di Pavia*
^{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*
^{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*

- ⁸⁷Korea University, Seoul, Korea
⁸⁸Kyung Hee University, Department of Physics, Seoul, Republic of Korea
⁸⁹Sejong University, Seoul, Korea
⁹⁰Seoul National University, Seoul, Korea
⁹¹University of Seoul, Seoul, Korea
⁹²Yonsei University, Department of Physics, Seoul, Korea
⁹³Sungkyunkwan University, Suwon, Korea
⁹⁴Riga Technical University, Riga, Latvia
⁹⁵Vilnius University, Vilnius, Lithuania
⁹⁶National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
⁹⁷Universidad de Sonora (UNISON), Hermosillo, Mexico
⁹⁸Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
⁹⁹Universidad Iberoamericana, Mexico City, Mexico
¹⁰⁰Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
¹⁰¹Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
¹⁰²University of Montenegro, Podgorica, Montenegro
¹⁰³University of Auckland, Auckland, New Zealand
¹⁰⁴University of Canterbury, Christchurch, New Zealand
¹⁰⁵National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
¹⁰⁶AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
¹⁰⁷National Centre for Nuclear Research, Swierk, Poland
¹⁰⁸Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
¹⁰⁹Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
¹¹⁰Joint Institute for Nuclear Research, Dubna, Russia
¹¹¹Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
¹¹²Institute for Nuclear Research, Moscow, Russia
¹¹³Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia
¹¹⁴Moscow Institute of Physics and Technology, Moscow, Russia
¹¹⁵National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
¹¹⁶P.N. Lebedev Physical Institute, Moscow, Russia
¹¹⁷Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
¹¹⁸Novosibirsk State University (NSU), Novosibirsk, Russia
¹¹⁹Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia
¹²⁰National Research Tomsk Polytechnic University, Tomsk, Russia
¹²¹Tomsk State University, Tomsk, Russia
¹²²University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia
¹²³Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
¹²⁴Universidad Autónoma de Madrid, Madrid, Spain
¹²⁵Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
¹²⁶Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
¹²⁷University of Colombo, Colombo, Sri Lanka
¹²⁸University of Ruhuna, Department of Physics, Matara, Sri Lanka
¹²⁹CERN, European Organization for Nuclear Research, Geneva, Switzerland
¹³⁰Paul Scherrer Institut, Villigen, Switzerland
¹³¹ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
¹³²Universität Zürich, Zurich, Switzerland
¹³³National Central University, Chung-Li, Taiwan
¹³⁴National Taiwan University (NTU), Taipei, Taiwan
¹³⁵Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
¹³⁶Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
¹³⁷Middle East Technical University, Physics Department, Ankara, Turkey
¹³⁸Bogazici University, Istanbul, Turkey
¹³⁹Istanbul Technical University, Istanbul, Turkey
¹⁴⁰Istanbul University, Istanbul, Turkey
¹⁴¹Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine
¹⁴²National 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, WI, Wisconsin, USA*

^aDeceased.^bAlso at Vienna University of Technology, Vienna, Austria.^cAlso at Department of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport.^dAlso at Université Libre de Bruxelles, Bruxelles, Belgium.^eAlso at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.^fAlso at Universidade Estadual de Campinas, Campinas, Brazil.

- ^gAlso at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
- ^hAlso at UFMS.
- ⁱAlso at Universidade Federal de Pelotas, Pelotas, Brazil.
- ^jAlso at University of Chinese Academy of Sciences.
- ^kAlso at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC ‘Kurchatov Institute’, Moscow, Russia.
- ^lAlso at Joint Institute for Nuclear Research, Dubna, Russia.
- ^mAlso at Cairo University, Cairo, Egypt.
- ⁿAlso at British University in Egypt, Cairo, Egypt.
- ^oAlso at Zewail City of Science and Technology, Zewail, Egypt.
- ^pAlso at Purdue University, West Lafayette, Indiana, USA.
- ^qAlso at Université de Haute Alsace, Mulhouse, France.
- ^rAlso at Erzincan Binali Yildirim University, Erzincan, Turkey.
- ^sAlso at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
- ^tAlso at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
- ^uAlso at University of Hamburg, Hamburg, Germany.
- ^vAlso at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
- ^wAlso at Brandenburg University of Technology, Cottbus, Germany.
- ^xAlso at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia.
- ^yAlso at Institute of Physics, University of Debrecen, Debrecen, Hungary.
- ^zAlso at Physics Department, Faculty of Science, Assiut University.
- ^{aa}Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
- ^{bb}Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- ^{cc}Also at IIT Bhubaneswar, Bhubaneswar, India.
- ^{dd}Also at Institute of Physics, Bhubaneswar, India.
- ^{ee}Also at G. H. G. Khalsa College, Punjab, India.
- ^{ff}Also at Shoolini University, Solan, India.
- ^{gg}Also at University of Hyderabad, Hyderabad, India.
- ^{hh}Also at University of Visva-Bharati, Santiniketan, India.
- ⁱⁱAlso at Indian Institute of Technology (IIT), Mumbai, India.
- ^{jj}Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
- ^{kk}Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
- ^{ll}Also at INFN Sezione di Bari, Università di Bari, Politecnico di Bari, Bari, Italy.
- ^{mm}Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development.
- ⁿⁿAlso at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia.
- ^{oo}Also at INFN Sezione di Napoli, Università di Napoli ‘Federico II’, Napoli, Italy, Università della Basilicata, Potenza, Italy, Università G. Marconi, Roma, Italy.
- ^{pp}Also at Riga Technical University, Riga, Latvia.
- ^{qq}Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ^{rr}Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland.
- ^{ss}Also at Institute for Nuclear Research, Moscow, Russia.
- ^{tt}Also at National Research Nuclear University ‘Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia.
- ^{uu}Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia.
- ^{vv}Also at University of Florida, Gainesville, Florida, USA.
- ^{ww}Also at Imperial College, London, United Kingdom.
- ^{xx}Also at Moscow Institute of Physics and Technology, Moscow, Russia.
- ^{yy}Also at P.N. Lebedev Physical Institute, Moscow, Russia.
- ^{zz}Also at California Institute of Technology, Pasadena, California, USA.
- ^{aaa}Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia.
- ^{bbb}Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
- ^{ccc}Also at Trincomalee Campus, Eastern University, Sri Lanka.
- ^{ddd}Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
- ^{eee}Also at National and Kapodistrian University of Athens, Athens, Greece.
- ^{fff}Also at Universität Zürich, Zurich, Switzerland.
- ^{ggg}Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- ^{hhh}Also at Laboratoire d’Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- ⁱⁱⁱAlso at Şırnak University.
- ^{jjj}Also at Department of Physics, Tsinghua University, Beijing, China.
- ^{kkk}Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey.
- ^{lll}Also at Beykent University, Istanbul, Turkey.

- ^{mmm} Also at Istanbul Aydin University, Application and Research Center for Advanced Studies (App. & Res. Cent. for Advanced Studies).
- ⁿⁿⁿ Also at Mersin University, Mersin, Turkey.
- ^{ooo} Also at Piri Reis University, Istanbul, Turkey.
- ^{ppp} Also at Adiyaman University, Adiyaman, Turkey.
- ^{qqq} Also at Ozyegin University, Istanbul, Turkey.
- ^{rrr} Also at Izmir Institute of Technology, Izmir, Turkey.
- ^{sss} Also at Necmettin Erbakan University, Konya, Turkey.
- ^{ttt} Also at Bozok Universititesi Rektörlüğü.
- ^{uuu} Also at Marmara University, Istanbul, Turkey.
- ^{vvv} Also at Milli Savunma University.
- ^{www} Also at Kafkas University, Kars, Turkey.
- ^{xxx} Also at Istanbul Bilgi University, Istanbul, Turkey.
- ^{yyy} Also at Hacettepe University, Ankara, Turkey.
- ^{zzz} Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ^{aaaa} Also at IPPP Durham University.
- ^{bbbb} Also at Monash University, Faculty of Science, Clayton, Australia.
- ^{cccc} Also at Bethel University, St. Paul, Minneapolis, USA.
- ^{dddd} Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- ^{eeee} Also at Ain Shams University, Cairo, Egypt.
- ^{fff} Also at Bingol University, Bingol, Turkey.
- ^{gggg} Also at Georgian Technical University, Tbilisi, Georgia.
- ^{hhhh} Also at Sinop University, Sinop, Turkey.
- ⁱⁱⁱⁱ Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- ^{jjjj} Also at Nanjing Normal University Department of Physics.
- ^{kkkk} Also at Texas A&M University at Qatar, Doha, Qatar.
- ^{llll} Also at Kyungpook National University, Daegu, Korea.