EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

FERMILAB-PUB-14-440-CMS

CERN-PH-EP/2014-248
2014/10/22

CMS-BPH-12-011

Measurement of the ratio $\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm\pi^\pm\pi^\mp)/\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)$ and the production cross sections times branching fractions of $B_c^\pm \to J/\psi\pi^\pm$ and $B^\pm \to J/\psi K^\pm$ in pp collisions at $\sqrt{s} = 7\,\text{TeV}$

The CMS Collaboration*

Abstract

The $B_c^\pm \to J/\psi\pi^\pm$ and $B_c^\pm \to J/\psi\pi^\pm\pi^\pm\pi^\mp$ decay modes are studied in proton-proton collisions at a center-of-mass energy of 7 TeV with the CMS detector at the LHC. The kinematic region investigated requires $B_c^\pm$ mesons with transverse momentum $p_T > 15\,\text{GeV}$ and rapidity $|y| < 1.6$. The data sample corresponds to an integrated luminosity of $5.1\,\text{fb}^{-1}$. The ratio of the branching fractions $\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm\pi^\pm\pi^\mp)/\mathcal{B}(B_c^\pm \to J/\psi\pi^\pm)$ is measured to be $2.55 \pm 0.80\,(\text{stat}) \pm 0.33\,(\text{syst})^{+0.04}_{-0.01}\,(\tau_{B_c^\pm})$. The ratio of the production cross sections times branching fractions $\left(\sigma(B_c^+)\mathcal{B}(B_c^+ \to J/\psi\pi^+)\right)/\left(\sigma(B^+)\mathcal{B}(B^+ \to J/\psi K^+)\right)$ is determined to be $[0.48 \pm 0.05\,(\text{stat}) \pm 0.03\,(\text{syst}) \pm 0.05\,(\tau_{B_c})]\%$.

Submitted to the Journal of High Energy Physics

*See Appendix A for the list of collaboration members

1 Introduction

The pseudoscalar B_c^+ (B_c^-) meson, the ground state of the $\overline{b}c$ ($b\overline{c}$) system, is the lightest particle containing two heavy quarks of different flavors and thus represents a unique laboratory in which to study heavy-quark dynamics. The investigation of the B_c^+ meson properties (charge conjugation is implied throughout this paper) is of special interest compared to the flavor symmetric heavy-quarkonium ($b\overline{b}$, $c\overline{c}$) states, and provides a new testing ground for predictions in the context of effective models inspired by quantum chromodynamics [1]. The decay processes of the B_c^+ meson can be generically divided into three classes: those involving the decay of the b quark, the decay of the c quark, and the annihilation of the b and c quarks [1–3]. The $b \to c$ transition, accounting for about 20% of the decay rate [1], offers an easily accessible experimental signature, having a high probability of producing a J/ψ meson. Consequently, the first B_c^+ observation was made in the semileptonic channel $B_c^+ \to J/\psi \ell^+ \nu$ ($\ell = e, \mu$) by the CDF Collaboration [4].

The advent of the CERN LHC has opened a new era for B_c^+ investigations; a rich program of measurements involving new decay modes is being carried out by the LHCb Collaboration [5–11]. The ATLAS experiment has recently observed a new state whose mass is consistent with the predicted mass for the second S-wave state of the B_c^+ meson [12]. The CMS experiment, owing to its excellent muon identification system and tracking detectors, is particularly well suited to the study of final states containing J/ψ mesons, where $J/\psi \to \mu^+\mu^-$.

In this Letter, analyses of the multi-body $B_c^+ \to J/\psi \pi^+\pi^+\pi^-$ decay and the two-body $B_c^+ \to J/\psi \pi^+$ channel are presented, along with a measurement of the ratio of their branching fractions $R_{B_c} \equiv \mathcal{B}(B_c^+ \to J/\psi \pi^+\pi^+\pi^-)/\mathcal{B}(B_c^+ \to J/\psi \pi^+)$. The $B_c^+ \to J/\psi \pi^+\pi^+\pi^-$ decay was detected for the first time by the LHCb Collaboration [10]. The measurement of the relative branching fractions of the two hadronic decays is independent of the poorly known B_c^+ production cross section. The $B_c^+ \to J/\psi \pi^+$ mode is compared to the $B^+ \to J/\psi K^+$ decay, which has a similar vertex topology. The ratio of their production cross sections times branching fractions $R_{c/u} \equiv \left(\sigma(B_c^+)\mathcal{B}(B_c^+ \to J/\psi \pi^+)\right)/\left(\sigma(B^+)\mathcal{B}(B^+ \to J/\psi K^+)\right)$ is measured for B_c^+ transverse momentum $p_T > 15\,\text{GeV}$ and in the central rapidity region, $|y| < 1.6$, complementary to that accessible in the LHCb experiment. This measurement contributes to a more complete understanding of B_c^+ production in pp collisions.

2 CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter and 3.8 T field. Within the superconducting solenoid volume are silicon pixel and strip trackers, a crystal electromagnetic calorimeter, and a brass/scintillator hadron calorimeter. Muons are measured in gas-ionization detectors embedded in the steel return yoke. The subdetectors relevant for this analysis are the silicon tracker and the muon systems. The inner tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. It consists of layers totaling 66 million $100 \times 150\ \mu\text{m}^2$ silicon pixels and 9.6 million silicon strips with pitches ranging from 80 to 183 μm. Muons are measured in the pseudorapidity range $|\eta| < 2.4$ with detection planes constructed using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. The first level of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events in a fixed time interval of less than 4 μs. The high level trigger processor farm further decreases the event rate from around 100 kHz to approximately 400 Hz before data storage. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [13].

3 Event selection

This analysis is based on pp data collected with the CMS detector at a center-of-mass energy of 7 TeV in 2011. Events selected with displaced-vertex dimuon triggers are considered, corresponding to an integrated luminosity of 5.1 fb^{-1}. The analysis is driven by the J/ψ meson reconstruction. The dimuon triggers apply topological and kinematic selections on dimuon candidates: $\cos\alpha > 0.9$, where α is the pointing angle, in the transverse plane, between the dimuon momentum and the direction from the mean pp collision position (beam spot) to the dimuon vertex; $L_{xy}/\sigma_{xy} > 3$, where L_{xy} is the transverse distance between the beam spot and the dimuon vertex, and σ_{xy} is the corresponding uncertainty. In addition, the two muons must have opposite charges, dimuon $p_{\mathrm{T}} > 6.9\,\mathrm{GeV}$, satisfy an invariant mass requirement $2.9 < m(\mu^+\mu^-) < 3.3\,\mathrm{GeV}$, and have a mutual distance of closest approach in the transverse plane of less than 0.5 cm. Trigger selection requirements on the χ^2 probability of the dimuon kinematic fit (P_{VTX}) and muon transverse momentum $p_{\mathrm{T}}(\mu)$ were made more restrictive as the luminosity increased and ranged from $P_{\mathrm{VTX}} > 0.5\%$ to 15% and up to $p_{\mathrm{T}}(\mu) > 4\,\mathrm{GeV}$, respectively. A requirement on the muon pseudorapidity, $|\eta(\mu)| < 2.2$, is also applied.

Monte Carlo (MC) simulations are employed to design the offline selection, assess the reconstruction efficiency, and study systematic effects. The B_c^+ signal events are simulated using a dedicated generator (BCVEGPY) [14, 15] interfaced with the PYTHIA simulation program (version 6.424, Z2 tune [16, 17]), which hadronizes the whole event. Unstable particle decays are simulated with EVTGEN [18] and the detector response with GEANT4 [19].

The offline selection starts from J/ψ candidates reconstructed from pairs of oppositely charged muons. Muons are identified through the standard CMS muon reconstruction procedure [20] and are required to have a track matched with at least one muon segment, a track fit χ^2 per degree of freedom less than 1.8, at least 11 hits in the tracker with at least 2 from the pixel detector, and a transverse (longitudinal) impact parameter less than 3 cm (30 cm). Offline requirements on the dimuon pair are tightened, with respect to those of the trigger, requiring a dimuon $p_{\mathrm{T}} > 7.1\,\mathrm{GeV}$ and $L_{xy}/\sigma_{xy} \geq 5$.

The $\mathrm{B}_c^+ \to \mathrm{J}/\psi\pi^+$ ($\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+$) candidates are formed by combining a J/ψ candidate with one track, assuming that it is a pion (kaon). The track must not be identified as a muon. The $\mathrm{B}_c^+ \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ candidates are analogously formed by combining a J/ψ candidate with three tracks, assuming that they are pions and requiring that the total charge is $+1$. The pion (kaon) candidates are required to have a track fit χ^2 less than three times the number of degrees of freedom; $\geq$6 tracker hits; $\geq$2 pixel hits; $|\eta| < 2.4$; and $p_{\mathrm{T}} > 0.9\,\mathrm{GeV}$. The three-dimensional impact parameter between each pion (kaon) and the J/ψ vertex is required to be less than 6 times its uncertainty to reduce combinatorial background and the effect of the number of simultaneous pp interactions per bunch crossing (pileup). The decay vertex is reconstructed using a kinematic vertex fit [21], which constrains the invariant mass of the two muons to the nominal J/ψ mass. After the vertex fit, the track parameters are re-estimated at the fitted vertex to improve the resolution of the track parameters. To reduce backgrounds, only the highest-transverse-momentum B_c^+ candidate is retained per event. This method has been studied using the MC samples and found to select the right candidate in 91% of the $\mathrm{B}_c^+ \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ events and 99.3% (99.2%) of the $\mathrm{B}_c^+ \to \mathrm{J}/\psi\pi^+$ ($\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+$) events. In the $\mathrm{B}_c^+ \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ data sample, this requirement reduces the background by more than a factor of four.

Additional topological requirements are made to improve the signal-to-background ratio, as discussed below.

4 $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ decay

The selection criteria have been optimized by maximizing $S/\sqrt{(S+B)}$ as a figure of merit, where S is the signal yield obtained from a Gaussian fit to the MC reconstructed events and B is the amount of background extrapolated from the $\mathrm{J}/\psi\pi^+\pi^+\pi^-$ invariant mass sidebands in the data. The two sideband regions are defined as being between $5\sigma_{m(\mathrm{B_c})}$ and $8\sigma_{m(\mathrm{B_c})}$ of the world-average $\mathrm{B_c}$ mass [22], where $\sigma_{m(\mathrm{B_c})}$ is the resolution of the signal as determined in simulation. The optimized selection requirements are: $p_\mathrm{T}(\mathrm{B_c}) > 15\,\mathrm{GeV}$; $|y(\mathrm{B_c})| < 1.6$; χ^2 probability of the five-track kinematic fit >20%; $\cos\alpha' > 0.99$, where α' is the angle between the candidate $\mathrm{B_c}$ momentum vector and the displacement between the beam spot and the decay vertex evaluated in the plane transverse to the beam; $p_\mathrm{T}(\pi_1) > 2.5\,\mathrm{GeV}$; $p_\mathrm{T}(\pi_2) > 1.7\,\mathrm{GeV}$; $p_\mathrm{T}(\pi_3) > 0.9\,\mathrm{GeV}$, where the three pions are referred to as π_1, π_2, and π_3 from highest to lowest p_T; and $\Delta R(\mathrm{J}/\psi, \pi_S) < 0.5$, where ΔR is the distance in the (η, ϕ) plane between the J/ψ momentum vector and the sum of the momentum vectors of the three pions (π_S). The resulting $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ invariant mass distribution is shown in Fig. 1. A fit is performed with an unbinned maximum likelihood estimator. The signal is parametrized as a Gaussian distribution and the background as a second-order Chebyshev polynomial. The signal yield is 92 ± 27 events and fitted mass and resolution values are $6.266 \pm 0.006\,\mathrm{GeV}$ and $0.021 \pm 0.006\,\mathrm{GeV}$, respectively, where the uncertainties are statistical only. Possible contamination from other $\mathrm{B_c^+}$ decay modes in the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ channel has been investigated. No $\mathrm{B_c^+} \to \mathrm{J}/\psi\mathrm{K^+K^-}\pi^+$ decays are observed in the data with the applied selection cuts. The effect from a possible undetected π^0 in the decay $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-\pi^0$ has been modeled with a dedicated MC sample. The partially reconstructed $\mathrm{J}/\psi\pi^+\pi^+\pi^-$ mass spectrum obtained from the simulated events has been fit with an ARGUS function [23] convolved with a Gaussian function describing the detector resolution. The resulting parametrization, added to a linear polynomial function, has been used to describe the background on the left of the signal peak in the fit of the $\mathrm{J}/\psi\pi^+\pi^+\pi^-$ mass spectrum in data. No significant variation in the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ signal yield is found.

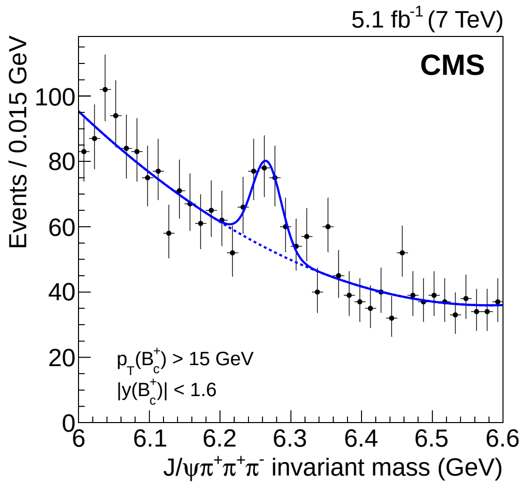

Figure 1: The $\mathrm{J}/\psi\pi^+\pi^+\pi^-$ invariant mass distribution. The result of the fit is superimposed; the lines represent the signal-plus-background fit (solid) and the background-only component (dashed).

5 $B_c^+ \to J/\psi\pi^+$ and $B^+ \to J/\psi K^+$ decays

The same figure of merit $S/\sqrt{(S+B)}$ is maximized in the selection of the $B_c^+ \to J/\psi\pi^+$ signal with the same kinematic phase space as defined for the $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ decay (i.e., $p_T(B_c) > 15\,\text{GeV}$ and $|y(B_c)| < 1.6$). The procedure results in the following requirements: B_c^+ vertex probability >6%, $\cos\alpha' > 0.9$, $p_T(\pi) > 2.7\,\text{GeV}$, and $\Delta R(J/\psi, \pi) < 1$. The $B_c^+ \to J/\psi\pi^+$ invariant mass distribution is shown in Fig. 2 (left). The $B^+ \to J/\psi K^+$ signal is obtained with the same selections and is shown in Fig. 2 (right). The $B_c^+ \to J/\psi\pi^+$ and the $B^+ \to J/\psi K^+$ invariant mass distributions are fit with an unbinned maximum likelihood estimator. The B_c^+ signal is fit with a Gaussian distribution and the background with a second-order Chebyshev polynomial. Contamination from other B_c^+ decay modes in the $B_c^+ \to J/\psi\pi^+$ channel has been investigated. A possible reflection of the Cabibbo-suppressed $B_c^+ \to J/\psi K^+$ mode in the $J/\psi\pi^+$ mass spectrum has been modeled with a simulated sample of $B_c^+ \to J/\psi K^+$ events and its contribution constrained using the value of the relative branching fraction to $J/\psi\pi^+$ [9]. Furthermore, the effect due to a possible undetected π^0 from $B_c^+ \to J/\psi\pi^+\pi^0$ decay has been modeled from a dedicated MC sample. The partially reconstructed $J/\psi\pi^+$ mass spectrum obtained from the simulated events has been fit with an ARGUS function convolved with a Gaussian function describing the detector resolution. The resulting parametrization, added to a linear polynomial function, has been used to describe the background on the left of the signal peak in the fit of the $J/\psi\pi^+$ mass spectrum in data. No significant variation of the $B_c^+ \to J/\psi\pi^+$ signal yield is found. The $B_c^+ \to J/\psi\pi^+$ signal yield is 176 ± 19, its mass $6.267 \pm 0.003\,\text{GeV}$, and its resolution $0.025 \pm 0.003\,\text{GeV}$ (statistical uncertainties only).

The B^+ invariant mass distribution is fit with a sum of two Gaussian distributions with a common mean for the signal and a second-order Chebyshev polynomial for the background. Additional contributions from partially reconstructed B^0 and B^+ decays are parametrized with functions determined from inclusive $B^+ \to J/\psi X$ and $B^0 \to J/\psi X$ MC samples.

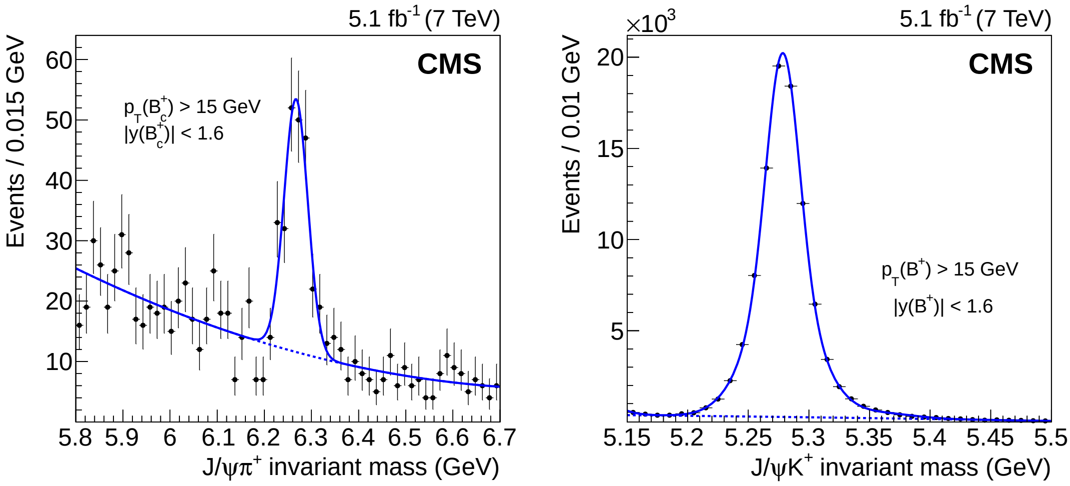

Figure 2: The $J/\psi\pi^+$ (left) and $J/\psi K^+$ (right) invariant mass distributions. The result of the fit is superimposed. The lines represent the signal-plus-background fit (solid) and the background-only component (dashed).

6 R_{B_c} measurement

The ratio R_{B_c} is defined as

$$R_{B_c} = \frac{\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)}{\mathcal{B}(B_c^+ \to J/\psi\pi^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+\pi^+\pi^-}}{Y_{B_c^+ \to J/\psi\pi^+}}, \tag{1}$$

where $Y_{B_c^+ \to J/\psi\pi^+\pi^+\pi^-}$ and $Y_{B_c^+ \to J/\psi\pi^+}$ are the signal yields extracted from the efficiency-corrected invariant mass distributions for the $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ and $B_c^+ \to J/\psi\pi^+$ channels, respectively, in the kinematic region $p_T > 15\,\text{GeV}$ and $|y| < 1.6$. Efficiency corrections of the $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ and $B_c^+ \to J/\psi\pi^+$ data include geometrical acceptance, reconstruction, selection, and trigger effects. The efficiencies for the two channels are evaluated from MC simulations.

The simulation of the two-body $B_c^+ \to J/\psi\pi^+$ decay takes into account the spins of the particles. The efficiency for this channel is evaluated as a function of the candidate's p_T and is computed in p_T bins, the size of which are determined by the number of available simulated events. Data are corrected event-by-event according to the candidate's p_T and the corresponding MC efficiency. The data efficiency-corrected invariant mass is fit with a function consisting of a Gaussian distribution for the signal and a second-order Chebyshev polynomial for the background. An unbinned maximum likelihood estimator is used to extract the $Y_{B_c^+ \to J/\psi\pi^+}$ yield.

The $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ decay can involve intermediate resonant states; indeed, the $\pi^+\pi^+\pi^-$ and $\pi^+\pi^-$ invariant mass projections from data show evidence for the presence of $a_1(1260)$ and $\rho(770)$ in the decay (Fig. 3). No hint of either $\psi(2S)(\to J/\psi\pi^+\pi^-)$ or $X(3872)(\to J/\psi\pi^+\pi^-)$ is detected in the $\mu^+\mu^-\pi^+\pi^-$ mass projections. The quantitative determination of the resonant contributions and their interferences in the decay requires a sophisticated amplitude analysis which is not feasible with the available amount of data. However, the reconstruction efficiency for this five-body decay could be affected by the decay dynamics; thus, a model-independent efficiency treatment is needed.

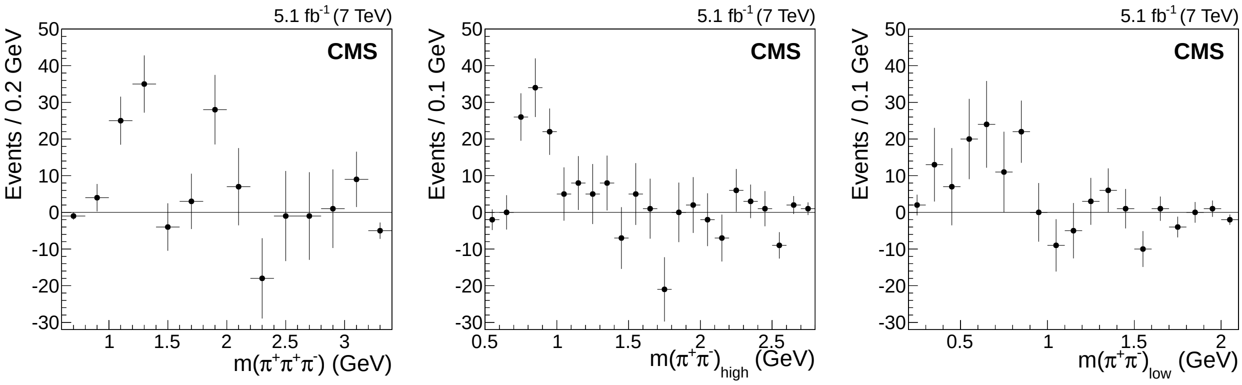

Figure 3: Background-subtracted invariant mass projections for $\pi^+\pi^+\pi^-$ (left), $(\pi^+\pi^-)_{\text{high}}$ (center), and $(\pi^+\pi^-)_{\text{low}}$ (right) from the $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ candidate events. Since two same-sign pions are present in the final state, we indicate with $(\pi^+\pi^-)_{\text{low}}$ the $\pi^+\pi^-$ pair with the lower invariant mass and with $(\pi^+\pi^-)_{\text{high}}$ the higher invariant mass combination.

A five-body decay of a spinless particle can be fully described in its center-of-mass frame by eight independent mass combinations of the type m_{ij}^2 ($i \neq j$), where m_{ij}^2 is the squared invariant mass of the pair of particles i and j in the final state (Dalitz plot representation). In the present case, the additional J/ψ mass constraint reduces the number of independent m^2_{ij} to seven. The following seven mass combinations have been chosen: $x = m^2(\mu^+\pi^+)_{\mathrm{low}}$, $y = m^2(\pi^+\pi^-)_{\mathrm{high}}$, $z = m^2(\mu^+\pi^-)$, $w = m^2(\pi^+\pi^+)$, $r = m^2(\mu^-\pi^+)_{\mathrm{low}}$, $t = m^2(\mu^-\pi^+)_{\mathrm{high}}$, and $v = m^2(\mu^-\pi^-)$; the "low" and "high" subscripts refer to the lower and higher invariant mass combination where a π^+ is involved. A $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ nonresonant MC has been produced to access all the phase-space configurations. The efficiency is parametrized as a linear function of these seven mass combinations:

$$\epsilon = |p_0 + p_1 \cdot x + p_2 \cdot y + p_3 \cdot z + p_4 \cdot w + p_5 \cdot r + p_6 \cdot t + p_7 \cdot v|, \tag{2}$$

where p_i are free parameters to be determined via an unbinned maximum likelihood fit to the generated events in the seven-dimensional space using a binomial probability density function. The absolute value is required to prevent the function from assuming negative values. The resulting efficiency function is used to weight the data event-by-event. The data efficiency-corrected invariant mass is fit with a function consisting of a Gaussian distribution for the signal and a second-order Chebyshev polynomial for the background. An unbinned maximum likelihood estimator is used to extract the $Y_{\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-}$ yield. The resulting measurement of the branching fraction ratio is $R_{\mathrm{B_c}} = 2.55 \pm 0.80$, where the uncertainty is statistical only.

Possible systematic uncertainties introduced by different trigger and pileup conditions and analysis selections have been investigated by dividing the data and evaluating the statistical consistency [22] of the independent samples; the resulting systematic uncertainties are found to be insignificant. Uncertainties from the different signal and background fit functions and fit ranges have been evaluated through a "fit variant" approach [24] and account for a 9.4% uncertainty. The finite size of the MC samples introduces a systematic uncertainty of 4.1%. The efficiency for the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ channel is computed as a function of the $\mathrm{B_c^+}$ candidate p_{T}; the choice of the p_{T} binning gives a systematic uncertainty of 1.9%.

An additional contribution is considered coming from the choice of the seven-dimensional efficiency parametrization of Eq. (2). To estimate this contribution, data are alternatively weighted according to the efficiency distribution directly obtained from the MC samples, binned in the seven two-body submasses. The difference between the ratio measured using the binned efficiency distribution and the function in Eq. (2) is taken as a systematic uncertainty (1.0%). In the evaluation of $R_{\mathrm{B_c}}$, two different multiplicity final states are compared. Assuming a tracking efficiency uncertainty for each pion track of 3.9% [25], a global 7.8% uncertainty is included in the final systematic evaluation. The total systematic uncertainty in the ratio, obtained by adding all the contributions in quadrature, is 13.1%.

Recently, the LHCb Collaboration published a new, more precise $\mathrm{B_c^+}$ lifetime measurement [26], which is significantly higher than the previous world average [22]. The $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ and $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ reconstruction efficiencies have a dependence on the $\mathrm{B_c^+}$ lifetime. To determine the systematic uncertainty associated with the uncertainty in the $\mathrm{B_c^+}$ lifetime, the efficiencies are evaluated while changing the $\mathrm{B_c^+}$ lifetime in the simulation to cover the range from the world average minus its one standard deviation uncertainty, to the new LHCb measurement. The resulting variation in the $R_{\mathrm{B_c}}$ ratio is quoted separately as a lifetime systematic uncertainty ($\sigma(\tau_{\mathrm{B_c}})$) and is $^{+1.6}_{-0.4}$%. The sources of systematic uncertainty are summarized in Table 1.

The resulting ratio, including all uncertainties, is

$$R_{\mathrm{B_c}} = 2.55 \pm 0.80\,(\mathrm{stat}) \pm 0.33\,(\mathrm{syst})\,^{+0.04}_{-0.01}\,(\tau_{\mathrm{B_c}}). \tag{3}$$

Table 1: Systematic uncertainties in the measurement of $R_{\mathrm{B_c}}$

Systematic source	%
Fit variant	9.4
MC sample size	4.1
Efficiency fit function	1.0
Efficiency binning	1.9
Tracking efficiency	7.8
Total uncertainty	13.1
Lifetime	$^{+1.6}_{-0.4}$

7 $R_{\mathrm{c/u}}$ measurement

The ratio $R_{\mathrm{c/u}}$ of the production cross sections times branching fractions is obtained from the relation

$$R_{\mathrm{c/u}} = \frac{\sigma(\mathrm{B_c^+})\mathcal{B}(\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+)}{\sigma(\mathrm{B^+})\mathcal{B}(\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+})} = \frac{Y_{\mathrm{B_c^+}\to\mathrm{J}/\psi\pi^+}}{Y_{\mathrm{B^+}\to\mathrm{J}/\psi\mathrm{K^+}}}, \tag{4}$$

where $Y_{\mathrm{B_c^+}\to\mathrm{J}/\psi\pi^+}$ and $Y_{\mathrm{B^+}\to\mathrm{J}/\psi\mathrm{K^+}}$ are the signal yields extracted from the efficiency-corrected invariant mass distributions for the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ and $\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+}$ channels, respectively, in the kinematic region $p_{\mathrm{T}} > 15\,\mathrm{GeV}$ and $|y| < 1.6$. The efficiencies for the two channels are evaluated from MC simulations and include geometrical acceptance, reconstruction, selection, and trigger effects.

The efficiencies are evaluated as a function of the $\mathrm{B^+}$ or $\mathrm{B_c^+}$ candidate's p_{T} and computed in p_{T} bins, whose sizes are determined by the available size of the two-body $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ and $\mathrm{B^+} \to \mathrm{J}/\psi\mathrm{K^+}$ MC samples. Data are corrected event-by-event according to the candidate's p_{T} and the efficiency determined using the simulation.

The same sources of systematic uncertainties considered in Section 6, have been evaluated for this measurement and yield a total systematic uncertainty of 6.5% in the ratio. The systematic uncertainty from the $\mathrm{B_c^+}$ lifetime uncertainty is quoted separately in the result; it is estimated by varying the $\mathrm{B_c^+}$ lifetime in the simulation from the world average value [22] minus its one standard deviation uncertainty, to the new LHCb measurement [26], resulting in a value of 10.4%. The different contributions to the systematic uncertainty are listed in Table 2.

Table 2: Systematic uncertainties in the measurement of $R_{\mathrm{c/u}}$.

Systematic source	%
Fit variant	5.3
MC sample size	2.1
Efficiency binning	3.1
Total uncertainty	6.5
$\mathrm{B_c}$ lifetime	10.4

The measurement of the ratio, including all the uncertainties, is

$$R_{\mathrm{c/u}} = [0.48 \pm 0.05\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst}) \pm 0.05\,(\tau_{\mathrm{B_c}})]\%. \tag{5}$$

8 Summary

An analysis of the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ decay mode has been presented based on pp collision data at a center-of-mass energy of 7 TeV collected by the CMS experiment and corresponding to an integrated luminosity of 5.1 fb^{-1}. The ratio of the $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+\pi^+\pi^-$ and $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ branching fractions has been measured to be

$$R_{\mathrm{B_c}} = 2.55 \pm 0.80\,(\mathrm{stat}) \pm 0.33\,(\mathrm{syst})^{+0.04}_{-0.01}\,(\tau_{\mathrm{B_c}}), \tag{6}$$

which is in good agreement with the result from the LHCb experiment, $2.41 \pm 0.30\,(\mathrm{stat}) \pm 0.33\,(\mathrm{syst})$ [10]. This measurement can be compared with the theoretical predictions, which assume factorization into $\mathrm{B_c^+} \to \mathrm{J}/\psi\mathrm{W}^{+*}$ and $\mathrm{W}^{+*} \to n\pi^+$ ($n = 1, 2, 3, 4$). In particular, Ref. [27] predicts 1.5 for the ratio, whereas Ref. [28] predicts three different values, 1.9, 2.0, and 2.3, depending on the chosen set of $\mathrm{B_c^+}$ meson form factors. More precise measurements are needed to determine if one of the predictions is favored by the data.

A measurement of the ratio of the cross sections times branching fractions for $\mathrm{B_c^+} \to \mathrm{J}/\psi\pi^+$ and $\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+$

$$R_{\mathrm{c/u}} = [0.48 \pm 0.05\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst}) \pm 0.05\,(\tau_{\mathrm{B_c}})]\%, \tag{7}$$

has been presented for $\mathrm{B_c^+}$ and B^+ mesons with $p_{\mathrm{T}} > 15\,\mathrm{GeV}$ and in the central rapidity region $|y| < 1.6$. A similar measurement from LHCb in the kinematic region $p_{\mathrm{T}} > 4\,\mathrm{GeV}$, $2.5 < \eta < 4.5$ gives $[0.68 \pm 0.10\,(\mathrm{stat}) \pm 0.03\,(\mathrm{syst}) \pm 0.05\,(\tau_{\mathrm{B_c}})]\%$ [29]. The two measurements, performed in different kinematic regions, are expected to vary because of the softer p_{T} distribution of the $\mathrm{B_c^+}$ with respect to that of the B^+, implying a lower value of the ratio at higher p_{T}. The measurements are consistent with this expectation. Measurements of the production cross section times branching fraction for $\mathrm{B_c^+} \to \mathrm{J}/\psi\ell^+\nu$ relative to that for $\mathrm{B}^+ \to \mathrm{J}/\psi\mathrm{K}^+$ are also available from the CDF experiment [4] in the kinematic region $p_{\mathrm{T}} > 4\,\mathrm{GeV}$ and $|y| < 1$. With the present $\mathrm{B_c^+}$ (p_{T},$|y|$) coverage, these experimental results can give guidance to improve the theoretical calculations still affected by large uncertainties and constrain the various $\mathrm{B_c^+}$ production models.

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

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (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 Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund; the Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalis and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; and the National Priorities Research Program by Qatar National Research Fund.

References

[1] Quarkonium Working Group Collaboration, "Heavy quarkonium physics", (2004). arXiv:hep-ph/0412158.

[2] I. P. Gouz et al., "Prospects for the B_c studies at LHCb", *Phys. Atom. Nucl* **67** (2004) 1559, doi:10.1134/1.1788046, arXiv:hep-ph/0211432.

[3] H.-M. Choi and C.-R. Ji, "Non leptonic two-body decays of the B_c meson in the light-front quark model and the QCD factorization approach", *Phys. Rev. D* **80** (2009) 114003, doi:10.1103/PhysRevD.80.114003, arXiv:0909.5028.

[4] CDF Collaboration, "Observation of the B_c meson in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **81** (1998) 2432, doi:10.1103/PhysRevLett.81.2432, arXiv:hep-ex/9805034.

[5] LHCb Collaboration, "Observation of the decay $B_c^+ \to J/\psi\, K^+K^-\pi^+$", *JHEP* **11** (2013) 094, doi:10.1007/JHEP11(2013)094, arXiv:1309.0587.

[6] LHCb Collaboration, "Observation of the decay $B_c^+ \to B_s^0\, \pi^+$", *Phys. Rev. Lett.* **111** (2013) 181801, doi:10.1103/PhysRevLett.111.181801, arXiv:1308.4544.

[7] LHCb Collaboration, "Observation of $B_c^+ \to J/\psi\, D_s^+$and $B_c^+ \to J/\psi\, D_s^{*+}$", *Phys. Rev. D* **87** (2013) 112012, doi:10.1103/PhysRevD.87.112012, arXiv:1304.4530.

[8] LHCb Collaboration, "Observation of the decay $B_c^+ \to \psi(2S)\pi^+$", *Phys. Rev. D* **87** (2013) 071103, doi:10.1103/PhysRevD.87.071103, arXiv:1303.1737.

[9] LHCb Collaboration, "First observation of the decay $B_c^+ \to J/\psi\, K^+$", *JHEP* **09** (2013) 075, doi:10.1007/JHEP09(2013)075, arXiv:1306.6723.

[10] LHCb Collaboration, "First observation of the decay $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$", *Phys. Rev. Lett.* **108** (2012) 251802, doi:10.1103/PhysRevLett.108.251802, arXiv:1204.0079.

[11] LHCb Collaboration, "Evidence for the decay $B_c^+ \to J/\psi 3\pi^+ 2\pi^-$", *JHEP* **05** (2014) 198, doi:10.1007/JHEP05(2014)148, arXiv:1404.0287.

[12] ATLAS Collaboration, "Observation of an Excited $B_c^{\pm}$ Meson State with the ATLAS Detector", (2014). arXiv:1407.1032.

[13] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[14] C. Chang, C. Driouchi, P. Eerola, and X. Wu, "BCVEGPY: an event generator for hadronic production of the B_c meson", *Comput. Phys. Comm.* **159** (2004) 192, doi:10.1016/j.cpc.2004.02.005, arXiv:hep-ph/0309120.

[15] C. Chang, J. Wang, and X. Wu, "BCVEGPY2.0: An upgraded version of the generator BCVEGPY with the addition of hadroproduction of the P-wave B_c states", *Comput. Phys. Comm.* **174** (2006) 241, doi:10.1016/j.cpc.2005.09.008, arXiv:hep-ph/0504017.

[16] T. Sjöstrand, S. Mrenna, and P. K. Skands, "Pythia 6.4 physics and manual", *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[17] R. Field, "Early LHC underlying event data-findings and surprises", (2010). arXiv:hep-ph/1010.3558.

[18] D. J. Lange, "The EvtGen particle decay simulation package", *Nucl. Instrum. Meth. A* **462** (2001) 152, doi:10.1016/S0168-9002(01)00089-4.

[19] Geant4 Collaboration, "Geant4 toolkit for simulation of HEP experiments", *Nucl. Instrum. Meth. A* **502** (2003) 666, doi:10.1016/S0168-9002(03)00538-2.

[20] CMS Collaboration, "Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV", *JINST* **7** (2012) P10002, doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.

[21] G. E. Forden and D. H. Saxon, "Improving vertex position determination using a kinematic fit", *Nucl. Instrum. Meth. A* **248** (1986) 439, doi:10.1016/0168-9002(86)91031-4.

[22] Particle Data Group, "Review of Particle Physics", *Phys. Rev. D* **86** (2012) 010001 and the 2013 partial update for the 2014 edition (URL: http://pdg.lbl.gov) doi:10.1103/PhysRevD.86.010001.

[23] ARGUS Collaboration, "Search for hadronic $b \to u$ decays", *Phys. Lett. B* **241** (1990) 278, doi:10.1016/0370-2693(90)91293-K.

[24] FOCUS Collaboration, "Study of the Cabibbo-suppressed decay modes $D^0 \to \pi^-\pi^+$ and $D^0 \to K^-K^+$", *Phys. Lett. B* **555** (2003) 167, doi:10.1016/S0370-2693(03)00053-4, arXiv:hep-ex/0212058.

[25] CMS Collaboration, "Measurement of Tracking Efficiency", CMS Physics Analysis Summary CMS-PAS-TRK-10-002, 2010.

[26] LHCb Collaboration, "Measurement of the B_c^+ meson lifetime using $B_c^+ \to J/\psi\, \mu^+\nu_\mu X$ decays", *Eur. Phys. J. C* **74** (2014) 2839, doi:10.1140/epjc/s10052-014-2839-x, arXiv:1401.6932.

[27] A. Rakitin and S. Koshkavev, "Hadronic B_c decays as a test of B_c cross section", *Phys. Rev. D* **81** (2010) 014005, doi:10.1103/PhysRevD.81.014005, arXiv:0911.3287.

[28] A. K. Likhoded and A. V. Luchinsky, "Light hadron production in $B_c \to J/\psi + X$ decays.", *Phys. Rev. D* **81** (2010) 014015, doi:10.1103/PhysRevD.81.014015, arXiv:0910.3089.

[29] LHCb Collaboration, "Measurement of B_c^+ production and mass with the $B_c^+ \to J/\psi$ π^+decay", *Phys. Rev. Lett.* **109** (2012) 232001, doi:10.1103/PhysRevLett.109.232001, arXiv:1209.5634.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria
W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan[1], M. Friedl, R. Frühwirth[1], V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer, V. Knünz, M. Krammer[1], I. Krätschmer, D. Liko, I. Mikulec, D. Rabady[2], B. Rahbaran, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz[1]

National Centre for Particle and High Energy Physics, Minsk, Belarus
V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium
S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, S. Luyckx, S. Ochesanu, R. Rougny, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, S. Blyweert, J. D'Hondt, N. Daci, N. Heracleous, J. Keaveney, S. Lowette, M. Maes, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium
C. Caillol, B. Clerbaux, G. De Lentdecker, D. Dobur, L. Favart, A.P.R. Gay, A. Grebenyuk, A. Léonard, A. Mohammadi, L. Perniè[2], T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang, F. Zenoni

Ghent University, Ghent, Belgium
V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Crucy, S. Dildick, A. Fagot, G. Garcia, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, S. Salva Diblen, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, C. Beluffi[3], G. Bruno, R. Castello, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[4], J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaitre, C. Nuttens, D. Pagano, L. Perrini, A. Pin, K. Piotrzkowski, A. Popov[5], L. Quertenmont, M. Selvaggi, M. Vidal Marono, J.M. Vizan Garcia

Université de Mons, Mons, Belgium
N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, T. Dos Reis Martins, C. Mora Herrera, M.E. Pol

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W. Carvalho, J. Chinellato[6], A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, J. Santaolalla, A. Santoro, A. Sznajder, E.J. Tonelli Manganote[6], A. Vilela Pereira

Universidade Estadual Paulista [a], Universidade Federal do ABC [b], São Paulo, Brazil
C.A. Bernardes[b], S. Dogra[a], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], P.G. Mercadante[b], S.F. Novaes[a], Sandra S. Padula[a]

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
A. Aleksandrov, V. Genchev[2], P. Iaydjiev, A. Marinov, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria
A. Dimitrov, I. Glushkov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, R. Du, C.H. Jiang, R. Plestina[7], F. Romeo, J. Tao, Z. Wang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
C. Asawatangtrakuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, W. Zou

Universidad de Los Andes, Bogota, Colombia
C. Avila, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
N. Godinovic, D. Lelas, D. Polic, I. Puljak

University of Split, Faculty of Science, Split, Croatia
Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, K. Kadija, J. Luetic, D. Mekterovic, L. Sudic

University of Cyprus, Nicosia, Cyprus
A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic
M. Bodlak, M. Finger, M. Finger Jr.[8]

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[9], A. Ellithi Kamel[10], M.A. Mahmoud[11], A. Radi[12,13]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
M. Kadastik, M. Murumaa, M. Raidal, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland
J. Talvitie, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri,

S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, P. Busson, C. Charlot, T. Dahms, M. Dalchenko, L. Dobrzynski, N. Filipovic, A. Florent, R. Granier de Cassagnac, L. Mastrolorenzo, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, C. Veelken, Y. Yilmaz, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram[14], J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte[14], J.-C. Fontaine[14], D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, N. Beaupere, G. Boudoul[2], E. Bouvier, S. Brochet, C.A. Carrillo Montoya, J. Chasserat, R. Chierici, D. Contardo[2], P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret, H. Xiao

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[8]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, S. Beranek, M. Bontenackels, M. Edelhoff, L. Feld, O. Hindrichs, K. Klein, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, H. Weber, B. Wittmer, V. Zhukov[5]

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, H. Reithler, S.A. Schmitz, L. Sonnenschein, D. Teyssier, S. Thüer, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, A. Heister, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann[2], A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany
I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, A.J. Bell, M. Bergholz[15], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, J. Garay Garcia, A. Geiser, P. Gunnellini, J. Hauk, M. Hempel[15], D. Horton, H. Jung, A. Kalogeropoulos, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, D. Krücker, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann[15], B. Lutz, R. Mankel, I. Marfin[15], I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, O. Novgorodova, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, B. Roland, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, P. Saxena, R. Schmidt[15],

T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, A.D.R. Vargas Trevino, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
M. Aldaya Martin, V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, H. Kirschenmann, R. Klanner, R. Kogler, J. Lange, T. Lapsien, T. Lenz, I. Marchesini, J. Ott, T. Peiffer, N. Pietsch, J. Poehlsen, T. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, F. Frensch, M. Giffels, F. Hartmann[2], T. Hauth[2], U. Husemann, I. Katkov[5], A. Kornmayer[2], E. Kuznetsova, P. Lobelle Pardo, M.U. Mozer, Th. Müller, A. Nürnberg, G. Quast, K. Rabbertz, F. Ratnikov, S. Röcker, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, R. Wolf

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. Geralis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, A. Psallidas, I. Topsis-Giotis

University of Athens, Athens, Greece
A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Stiliaris

University of Ioánnina, Ioánnina, Greece
X. Aslanoglou, I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos, E. Paradas

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath[16], F. Sikler, V. Veszpremi, G. Vesztergombi[17], A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Karancsi[18], J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary
P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India
S.K. Swain

Panjab University, Chandigarh, India
S.B. Beri, V. Bhatnagar, R. Gupta, U.Bhawandeep, A.K. Kalsi, M. Kaur, R. Kumar, M. Mittal, N. Nishu, J.B. Singh

University of Delhi, Delhi, India
Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma

Saha Institute of Nuclear Physics, Kolkata, India
S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India
A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty[2], L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research, Mumbai, India
T. Aziz, S. Banerjee, S. Bhowmik[19], R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu[20], G. Kole, S. Kumar, M. Maity[19], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage[21]

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Bakhshiansohi, H. Behnamian, S.M. Etesami[22], A. Fahim[23], R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh[24], M. Zeinali

University College Dublin, Dublin, Ireland
M. Felcini, M. Grunewald

INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], L. Barbone[a,b], C. Calabria[a,b], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], G. Maggi[a,c], M. Maggi[a], S. My[a,c], S. Nuzzo[a,b], A. Pompili[a,b], G. Pugliese[a,c], R. Radogna[a,b,2], G. Selvaggi[a,b], A. Sharma, L. Silvestris[a,2], R. Venditti[a,b], G. Zito[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b], R. Campanini[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], G. Codispoti[a,b], M. Cuffiani[a,b], G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a,b], P. Giacomelli[a], C. Grandi[a], L. Guiducci[a,b], S. Marcellini[a], G. Masetti[a], A. Montanari[a], F.L. Navarria[a,b], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], T. Rovelli[a,b], G.P. Siroli[a,b], N. Tosi[a,b], R. Travaglini[a,b]

INFN Sezione di Catania [a], Università di Catania [b], CSFNSM [c], Catania, Italy
S. Albergo[a,b], G. Cappello[a], M. Chiorboli[a,b], S. Costa[a,b], F. Giordano[a,2], R. Potenza[a,b], A. Tricomi[a,b], C. Tuve[a,b]

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], E. Gallo[a], S. Gonzi[a,b], V. Gori[a,b,2], P. Lenzi[a,b], M. Meschini[a], S. Paoletti[a], G. Sguazzoni[a], A. Tropiano[a,b]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, F. Fabbri, D. Piccolo

INFN Sezione di Genova [a], Università di Genova [b], Genova, Italy
R. Ferretti[a,b], F. Ferro[a], M. Lo Vetere[a,b], E. Robutti[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
M.E. Dinardo[a,b], P. Dini[a], S. Fiorendi[a,b,2], S. Gennai[a,2], R. Gerosa[a,b,2], A. Ghezzi[a,b], P. Govoni[a,b], M.T. Lucchini[a,b,2], S. Malvezzi[a], R.A. Manzoni[a,b], A. Martelli[a,b], B. Marzocchi[a,b], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], N. Redaelli[a], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli 'Federico II' [b], Università della Basilicata (Potenza) [c], Università G. Marconi (Roma) [d], Napoli, Italy
S. Buontempo[a], N. Cavallo[a,c], S. Di Guida[a,d,2], F. Fabozzi[a,c], A.O.M. Iorio[a,b], L. Lista[a], S. Meola[a,d,2], M. Merola[a], P. Paolucci[a,2]

INFN Sezione di Padova [a], Università di Padova [b], Università di Trento (Trento) [c], Padova, Italy
P. Azzi[a], N. Bacchetta[a], D. Bisello[a,b], A. Branca[a,b], R. Carlin[a,b], P. Checchia[a], M. Dall'Osso[a,b], T. Dorigo[a], U. Dosselli[a], M. Galanti[a,b], U. Gasparini[a,b], P. Giubilato[a,b], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a], M. Margoni[a,b], A.T. Meneguzzo[a,b], F. Montecassiano[a],

M. Passaseo[a], J. Pazzini[a,b], N. Pozzobon[a,b], P. Ronchese[a,b], F. Simonetto[a,b], E. Torassa[a], M. Tosi[a,b], P. Zotto[a,b], A. Zucchetta[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
M. Gabusi[a,b], S.P. Ratti[a,b], V. Re[a], C. Riccardi[a,b], P. Salvini[a], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
M. Biasini[a,b], G.M. Bilei[a], D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], G. Mantovani[a,b], M. Menichelli[a], A. Saha[a], A. Santocchia[a,b], A. Spiezia[a,b,2]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
K. Androsov[a,25], P. Azzurri[a], G. Bagliesi[a], J. Bernardini[a], T. Boccali[a], G. Broccolo[a,c], R. Castaldi[a], M.A. Ciocci[a,25], R. Dell'Orso[a], S. Donato[a,c], F. Fiori[a,c], L. Foà[a,c], A. Giassi[a], M.T. Grippo[a,25], F. Ligabue[a,c], T. Lomtadze[a], L. Martini[a,b], A. Messineo[a,b], C.S. Moon[a,26], F. Palla[a,2], A. Rizzi[a,b], A. Savoy-Navarro[a,27], A.T. Serban[a], P. Spagnolo[a], P. Squillacioti[a,25], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a], C. Vernieri[a,c,2]

INFN Sezione di Roma [a], Università di Roma [b], Roma, Italy
L. Barone[a,b], F. Cavallari[a], G. D'imperio[a,b], D. Del Re[a,b], M. Diemoz[a], M. Grassi[a,b], C. Jorda[a], E. Longo[a,b], F. Margaroli[a,b], P. Meridiani[a], F. Micheli[a,b,2], S. Nourbakhsh[a,b], G. Organtini[a,b], R. Paramatti[a], S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b], L. Soffi[a,b,2], P. Traczyk[a,b]

INFN Sezione di Torino [a], Università di Torino [b], Università del Piemonte Orientale (Novara) [c], Torino, Italy
N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], R. Bellan[a,b], C. Biino[a], N. Cartiglia[a], S. Casasso[a,b,2], M. Costa[a,b], A. Degano[a,b], N. Demaria[a], L. Finco[a,b], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a], M.M. Obertino[a,c,2], G. Ortona[a,b], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], A. Solano[a,b], A. Staiano[a], U. Tamponi[a]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a], G. Della Ricca[a,b], B. Gobbo[a], C. La Licata[a,b], M. Marone[a,b], A. Schizzi[a,b], T. Umer[a,b], A. Zanetti[a]

Kangwon National University, Chunchon, Korea
S. Chang, A. Kropivnitskaya, S.K. Nam

Kyungpook National University, Daegu, Korea
D.H. Kim, G.N. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, H. Park, A. Sakharov, D.C. Son

Chonbuk National University, Jeonju, Korea
T.J. Kim

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
J.Y. Kim, S. Song

Korea University, Seoul, Korea
S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, B. Lee, K.S. Lee, S.K. Park, Y. Roh

University of Seoul, Seoul, Korea
M. Choi, J.H. Kim, I.C. Park, G. Ryu, M.S. Ryu

Sungkyunkwan University, Suwon, Korea
Y. Choi, Y.K. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania
A. Juodagalvis

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
J.R. Komaragiri, M.A.B. Md Ali

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz[28], A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico
S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
I. Pedraza, H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
E. Casimiro Linares, A. Morelos Pineda

University of Auckland, Auckland, New Zealand
D. Krofcheck

University of Canterbury, Christchurch, New Zealand
P.H. Butler, S. Reucroft

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, W. Wolszczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
P. Bargassa, C. Beirão Da Cruz E Silva, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev[29], P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, N. Skatchkov, V. Smirnov, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
V. Golovtsov, Y. Ivanov, V. Kim[30], P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, A. Spiridonov, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, M. Dubinin[31], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[32], M. Ekmedzic, J. Milosevic, V. Rekovic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, A. Escalante Del Valle, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares

Universidad Autónoma de Madrid, Madrid, Spain
C. Albajar, J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad de Oviedo, Oviedo, Spain
H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, J. Duarte Campderros, M. Fernandez, G. Gomez, A. Graziano, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, C. Bernet[7], P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, S. Colafranceschi[33], M. D'Alfonso, D. d'Enterria, A. Dabrowski, A. David, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson, M. Dordevic, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer, M. Hansen, P. Harris, J. Hegeman, V. Innocente, P. Janot, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, N. Magini, L. Malgeri, M. Mannelli, J. Marrouche, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, P. Musella, L. Orsini, L. Pape, E. Perez, L. Perrozzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, M. Plagge, A. Racz, G. Rolandi[34], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[35], D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Tsirou, G.I. Veres[17], N. Wardle, H.K. Wöhri, H. Wollny, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, N. Chanon, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, C. Grab, D. Hits, J. Hoss, W. Lustermann, B. Mangano, A.C. Marini, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, N. Mohr, C. Nägeli[36], F. Nessi-Tedaldi, F. Pandolfi, F. Pauss, M. Peruzzi, M. Quittnat, L. Rebane, M. Rossini, A. Starodumov[37], M. Takahashi, K. Theofilatos, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland
C. Amsler[38], M.F. Canelli, V. Chiochia, A. De Cosa, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, B. Millan Mejias, J. Ngadiuba, P. Robmann, F.J. Ronga, S. Taroni, M. Verzetti, Y. Yang

National Central University, Chung-Li, Taiwan
M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, W. Lin, Y.J. Lu, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, U. Grundler, W.-S. Hou, K.Y. Kao, Y.J. Lei, Y.F. Liu, R.-S. Lu, D. Majumder, E. Petrakou, Y.M. Tzeng, R. Wilken

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
B. Asavapibhop, G. Singh, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[39], S. Cerci[40], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut[41], K. Ozdemir, S. Ozturk[39], A. Polatoz, D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, B. Bilin, S. Bilmis, H. Gamsizkan[42], G. Karapinar[43], K. Ocalan[44], S. Sekmen, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, B. Isildak[45], M. Kaya[46], O. Kaya[47]

Istanbul Technical University, Istanbul, Turkey
K. Cankocak, F.I. Vardarlı

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
L. Levchuk, P. Sorokin

University of Bristol, Bristol, United Kingdom
J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold[48], S. Paramesvaran, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
K.W. Bell, A. Belyaev[49], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, W.J. Womersley, S.D. Worm

Imperial College, London, United Kingdom
M. Baber, R. Bainbridge, O. Buchmuller, D. Burton, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, P. Dunne, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert,

G. Hall, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, R. Lane, R. Lucas[48], L. Lyons, A.-M. Magnan, S. Malik, B. Mathias, J. Nash, A. Nikitenko[37], J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Tapper, M. Vazquez Acosta, T. Virdee, S.C. Zenz

Brunel University, Uxbridge, United Kingdom
J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, W. Martin, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA
J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA
O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA
A. Avetisyan, T. Bose, C. Fantasia, P. Lawson, C. Richardson, J. Rohlf, J. St. John, L. Sulak

Brown University, Providence, USA
J. Alimena, E. Berry, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, N. Dhingra, A. Ferapontov, A. Garabedian, U. Heintz, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer, J. Swanson

University of California, Davis, Davis, USA
R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, R. Lander, T. Miceli, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, M. Searle, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, USA
R. Cousins, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, G. Rakness, E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA
K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Ivova Rikova, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, H. Nguyen, M. Olmedo Negrete, A. Shrinivas, S. Sumowidagdo, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D'Agnolo, D. Evans, A. Holzner, R. Kelley, D. Klein, M. Lebourgeois, J. Letts, I. Macneill, D. Olivito, S. Padhi, C. Palmer, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, C. Welke, F. Würthwein, A. Yagil

University of California, Santa Barbara, Santa Barbara, USA
D. Barge, J. Bradmiller-Feld, C. Campagnari, T. Danielson, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Incandela, C. Justus, N. Mccoll, J. Richman, D. Stuart, W. To, C. West, J. Yoo

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, C. Rogan, M. Spiropulu, V. Timciuc, J.R. Vlimant, R. Wilkinson, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, Y. Iiyama, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA
J.P. Cumalat, W.T. Ford, A. Gaz, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, A. Chatterjee, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, L. Skinnari, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA
D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, K. Kaadze, B. Klima, B. Kreis, S. Kwan, J. Linacre, D. Lincoln, R. Lipton, T. Liu, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, Y. Musienko[29], S. Nahn, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, A. Whitbeck, J. Whitmore, F. Yang

University of Florida, Gainesville, USA
D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, M. Carver, T. Cheng, D. Curry, S. Das, M. De Gruttola, G.P. Di Giovanni, R.D. Field, M. Fisher, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[50], G. Mitselmakher, L. Muniz, A. Rinkevicius, L. Shchutska, M. Snowball, D. Sperka, J. Yelton, M. Zakaria

Florida International University, Miami, USA
S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA
T. Adams, A. Askew, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, M. Hohlmann, H. Kalakhety, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, L. Apanasevich, V.E. Bazterra, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, D.H. Moon, C. O'Brien, C. Silkworth, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA
E.A. Albayrak[51], B. Bilki[52], W. Clarida, K. Dilsiz, F. Duru, M. Haytmyradov, J.-P. Merlo, H. Mermerkaya[53], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok[51], A. Penzo, R. Rahmat, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin[54], K. Yi

Johns Hopkins University, Baltimore, USA
B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, A.V. Gritsan, P. Maksimovic, C. Martin, M. Swartz

The University of Kansas, Lawrence, USA
P. Baringer, A. Bean, G. Benelli, C. Bruner, R.P. Kenny III, M. Malek, M. Murray, D. Noonan, S. Sanders, J. Sekaric, R. Stringer, Q. Wang, J.S. Wood

Kansas State University, Manhattan, USA
I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, L.K. Saini, S. Shrestha, N. Skhirtladze, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA
J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA
A. Baden, A. Belloni, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Skuja, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA
A. Apyan, R. Barbieri, G. Bauer, W. Busza, I.A. Cali, M. Chan, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, M. Klute, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, T. Ma, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, D. Velicanu, J. Veverka, B. Wyslouch, M. Yang, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA
B. Dahmes, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA
J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, USA
E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, R. Gonzalez Suarez, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, S. Malik, F. Meier, G.R. Snow, M. Zvada

State University of New York at Buffalo, Buffalo, USA
J. Dolen, A. Godshalk, I. Iashvili, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, USA
G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

Northwestern University, Evanston, USA
K.A. Hahn, A. Kubik, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA
A. Brinkerhoff, K.M. Chan, A. Drozdetskiy, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, W. Luo, S. Lynch, N. Marinelli, T. Pearson, M. Planer, R. Ruchti, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA
L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, B.L. Winer, H. Wolfe, H.W. Wulsin

Princeton University, Princeton, USA
O. Driga, P. Elmer, P. Hebda, A. Hunt, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, H. Saka, D. Stickland[2], C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA
E. Brownson, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA
V.E. Barnes, D. Benedetti, D. Bortoletto, M. De Mattia, L. Gutay, Z. Hu, M.K. Jha, M. Jones, K. Jung, M. Kress, N. Leonardo, D. Lopes Pegna, V. Maroussov, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
N. Parashar, J. Stupak

Rice University, Houston, USA
A. Adair, B. Akgun, K.M. Ecklund, F.J.M. Geurts, W. Li, B. Michlin, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA
B. Betchart, A. Bodek, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, A. Khukhunaishvili, G. Petrillo, D. Vishnevskiy

The Rockefeller University, New York, USA
R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, C. Mesropian

Rutgers, The State University of New Jersey, Piscataway, USA
S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, S. Kaplan, A. Lath, S. Panwalkar, M. Park, R. Patel, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA
K. Rose, S. Spanier, A. York

Texas A&M University, College Station, USA
O. Bouhali[55], A. Castaneda Hernandez, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[56], V. Khotilovich, V. Krutelyov, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Rose, A. Safonov, T. Sakuma, I. Suarez, A. Tatarinov

Texas Tech University, Lubbock, USA
N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Dudero, J. Faulkner, K. Kovitanggoon, S. Kunori, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, USA
E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, J. Wood

Wayne State University, Detroit, USA
C. Clarke, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

University of Wisconsin, Madison, USA
D.A. Belknap, D. Carlsmith, M. Cepeda, S. Dasu, L. Dodd, S. Duric, E. Friis, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, C. Lazaridis, A. Levine, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, I. Ross, T. Sarangi, A. Savin, W.H. Smith, D. Taylor, P. Verwilligen, C. Vuosalo, N. Woods

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
3: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
6: Also at Universidade Estadual de Campinas, Campinas, Brazil
7: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
8: Also at Joint Institute for Nuclear Research, Dubna, Russia
9: Also at Suez University, Suez, Egypt
10: Also at Cairo University, Cairo, Egypt
11: Also at Fayoum University, El-Fayoum, Egypt
12: Also at Ain Shams University, Cairo, Egypt
13: Now at Sultan Qaboos University, Muscat, Oman
14: Also at Université de Haute Alsace, Mulhouse, France
15: Also at Brandenburg University of Technology, Cottbus, Germany
16: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
17: Also at Eötvös Loránd University, Budapest, Hungary
18: Also at University of Debrecen, Debrecen, Hungary
19: Also at University of Visva-Bharati, Santiniketan, India
20: Now at King Abdulaziz University, Jeddah, Saudi Arabia
21: Also at University of Ruhuna, Matara, Sri Lanka
22: Also at Isfahan University of Technology, Isfahan, Iran
23: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
24: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
25: Also at Università degli Studi di Siena, Siena, Italy
26: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France
27: Also at Purdue University, West Lafayette, USA
28: Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico
29: Also at Institute for Nuclear Research, Moscow, Russia
30: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
31: Also at California Institute of Technology, Pasadena, USA
32: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
33: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
34: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
35: Also at University of Athens, Athens, Greece
36: Also at Paul Scherrer Institut, Villigen, Switzerland
37: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
38: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
39: Also at Gaziosmanpasa University, Tokat, Turkey
40: Also at Adiyaman University, Adiyaman, Turkey

41: Also at Cag University, Mersin, Turkey
42: Also at Anadolu University, Eskisehir, Turkey
43: Also at Izmir Institute of Technology, Izmir, Turkey
44: Also at Necmettin Erbakan University, Konya, Turkey
45: Also at Ozyegin University, Istanbul, Turkey
46: Also at Marmara University, Istanbul, Turkey
47: Also at Kafkas University, Kars, Turkey
48: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
49: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
50: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
51: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
52: Also at Argonne National Laboratory, Argonne, USA
53: Also at Erzincan University, Erzincan, Turkey
54: Also at Yildiz Technical University, Istanbul, Turkey
55: Also at Texas A&M University at Qatar, Doha, Qatar
56: Also at Kyungpook National University, Daegu, Korea