EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2018-125
2018/06/11

CMS-BPH-15-001

Angular analysis of the decay $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 8\,\mathrm{TeV}$

The CMS Collaboration*

Abstract

The angular distribution of the flavor-changing neutral current decay $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$ is studied in proton-proton collisions at a center-of-mass energy of 8 TeV. The analysis is based on data collected with the CMS detector at the LHC, corresponding to an integrated luminosity of $20.5\,\mathrm{fb}^{-1}$. The forward-backward asymmetry A_{FB} of the dimuon system and the contribution F_{H} from the pseudoscalar, scalar, and tensor amplitudes to the decay width are measured as a function of the dimuon mass squared. The measurements are consistent with the standard model expectations.

Submitted to Physical Review D

*See Appendix A for the list of collaboration members

1 Introduction

The decay $B^+ \to K^+\mu^+\mu^-$ is a manifestation of a flavor-changing neutral current process of the type $b \to s\ell^+\ell^-$, with ℓ denoting a charged lepton. In the standard model (SM), this decay is forbidden at tree level and occurs through higher-order processes. This makes the measurement of this process more sensitive to possible physics phenomena beyond the SM (BSM).

In the SM, three amplitudes contribute to $B^+ \to K^+\mu^+\mu^-$ via either electroweak Z/γ penguin diagrams or a W^+W^- box diagram, as shown in Fig. 1. Two independent parameters describe the decay rate for the $B^+ \to K^+\mu^+\mu^-$ process: the forward-backward asymmetry A_{FB} of the dimuon system and the contribution F_H from the pseudoscalar, scalar, and tensor amplitudes to the decay width. Theoretical predictions are available for both parameters [1–3]. In the SM, A_{FB} is zero up to small corrections, and F_H is also small. Because SM amplitudes may interfere with the contributions from BSM particles in loop diagrams, the decay can probe the presence of yet-unobserved particles and processes [4–9]. For example, a nonzero A_{FB} or large F_H would point to a BSM contribution [1, 10], which can be probed [11, 12] by comparing the experimental measurements with the theoretical predictions [6, 10, 13].

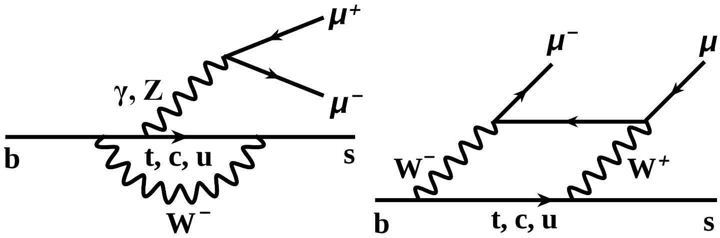

Figure 1: The SM electroweak Z/γ penguin (left) and W^+W^- box (right) diagrams for the decay process $B^+ \to K^+\mu^+\mu^-$.

In this paper, we report the measurement of A_{FB} and F_H as a function of the dimuon mass squared (q^2) based on an angular fit of the decay $B^+ \to K^+\mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 8\,\mathrm{TeV}$. Charge-conjugate decay modes are implied throughout this paper. The data, corresponding to an integrated luminosity of $20.5\,\mathrm{fb}^{-1}$ [14], were collected by the CMS experiment at the LHC in 2012. The angular distribution of this decay has previously been studied by the BABAR [15], Belle [16], CDF [17], and LHCb [18, 19] experiments, but no hints of BSM have been seen.

2 The CMS detector

The central feature of the CMS detector 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 a strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. A detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found elsewhere [20].

The events are selected online using a two-stage trigger system [21]. The first level is composed of custom hardware processors and uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a time interval of less than 4 μs. The second level, known as the high-level trigger (HLT), consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 1 kHz before data storage.

3 Event selection

The data for this analysis was recorded using a low-mass dimuon HLT with a displaced vertex. The trigger requires a pair of opposite-sign muons with a dimuon vertex displaced from the interaction point by more than three times the calculated uncertainty. The trigger also requires the dimuon candidate to have invariant mass in the range 1.0–4.8 GeV and $p_{\mathrm{T}} > 6.9\,\mathrm{GeV}$, and for each muon to have $p_{\mathrm{T}} > 3.5\,\mathrm{GeV}$ and $|\eta| < 2.2$.

Monte Carlo (MC) simulated event samples are widely used in the analysis. The number of simulated events for the signal sample $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$ corresponds to more than 160 times that of the data. Other simulated samples used in this analysis are $\mathrm{B}^+ \to \mathrm{K}^+\mathrm{J}/\psi(\mu^+\mu^-)$, $\mathrm{B}^+ \to \mathrm{K}^+\psi(2\mathrm{S})(\mu^+\mu^-)$, and $\mathrm{B}^+ \to \mu^+\mu^-\mathrm{X}$. In the last decay mode, the muon pairs come from J/ψ or $\psi(2\mathrm{S})$ decay, and X denotes all other final-state particles. The MC samples are produced using the PYTHIA generator [22] version 6.424. Decays of B^+ and J/ψ or $\psi(2\mathrm{S})$ mesons are processed by the EVTGEN [23] version 9.1 program (with the default matrix element for the signal). Particles are traced through a detailed model of the detector with GEANT4 [24], producing signals similar to the actual detector responses. Particles coming from other proton-proton collisions in the same or nearby beam crossings (pileup) are simulated according to the data-taking conditions, but their effects on this analysis are small.

The selected events are reconstructed through the decay into the fully charged final state of one charged hadron and a pair of oppositely charged muons. Events from the control channels $\mathrm{B}^+ \to \mathrm{K}^+\mathrm{J}/\psi(\mu^+\mu^-)$ and $\mathrm{B}^+ \to \mathrm{K}^+\psi(2\mathrm{S})(\mu^+\mu^-)$ have the same final state as the signal process $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$. The muons are reconstructed using information from the silicon tracker and muon detector systems [25]. They must satisfy the offline muon identification criteria that are optimized for low-p_{T} muons [26]. Dimuon candidates are formed from two oppositely charged muons matching the HLT criteria that triggered the event readout. To discriminate signal events from background, additional selection criteria on kinematic variables are used. The following selection criteria are determined through a maximization of the expected signal significance using MC signal events and the surviving data events in the final B^+ meson invariant mass fitting region, 5.1–5.6 GeV. The charged hadron track must have $p_{\mathrm{T}} > 1.3\,\mathrm{GeV}$ and the distance of closest approach in the transverse plane of the charged hadron trajectory to the interaction point, divided by its uncertainty, must be greater than 3.3. The B^+ meson candidate is formed by combining a dimuon candidate with the charged hadron track assumed to be a kaon. The event kinematic information is updated by fitting these three tracks to a common vertex. To further reduce the background, the chi-squared probability of the vertex fit for the B^+ candidate is required to be greater than 12%; the distance in the transverse plane between the B^+ vertex and the interaction point must be larger than 10.6 times its uncertainty; and the cosine of the angle in the transverse plane between the B^+ momentum and a vector from the interaction point to the B^+ meson vertex must be greater than 0.9997. After applying the selection criteria, less than 10% of the selected events contain multiple B^+ candidates. In these events, only the candidate with the highest B^+ decay vertex fit probability is retained.

Events with a dimuon invariant mass (q) close to the J/ψ or $\psi(2\mathrm{S})$ resonance region are rejected to remove this contamination from the control channels, as in Ref. [27]. The J/ψ and $\psi(2\mathrm{S})$ resonance regions are defined as $m_{\mathrm{J}/\psi}^{\mathrm{PDG}} - 5\sigma_q < q < m_{\mathrm{J}/\psi} + 3\sigma_q$ and $|q - m_{\psi(2\mathrm{S})}^{\mathrm{PDG}}| < 5\sigma_q$, respectively, where σ_q is the calculated uncertainty in q, and the PDG superscript indicates the world-average mass value [28] for each particle. We further suppress such events by requiring, $|(m - m_{\mathrm{B}^+}^{\mathrm{PDG}}) - (q - m_{\mathrm{J}/\psi}^{\mathrm{PDG}})| > 0.13\,\mathrm{GeV}$ and $|(m - m_{\mathrm{B}^+}^{\mathrm{PDG}}) - (q - m_{\psi(2\mathrm{S})}^{\mathrm{PDG}})| > 0.06\,\mathrm{GeV}$ in the B^+ meson invariant mass region of 5.1–5.6 GeV, where m is the B^+ candidate invariant mass. With these requirements, the maximum contribution of events containing a J/ψ or $\psi(2\mathrm{S})$ is less than 7% in any q^2, and the kinematic distributions of these events are similar to those of the combinatorial background.

4 Angular analysis

The measurement of A_{FB} and F_{H} is performed through angular analysis in seven q^2 ranges from 1 to 22 GeV^2. The q^2 ranges used in this analysis are the same as in previous measurements [16–18], facilitating the comparison. The J/ψ and $\psi(2\mathrm{S})$ regions, corresponding to q^2 ranges of 8.68–10.09 and 12.86–14.18 GeV^2, respectively, are used as control regions [27, 29]. Additionally, we define an inclusive low-q^2 range of 1.00–6.00 GeV^2 in order to compare the results to SM calculations with the best-controlled theoretical uncertainty, and a full inclusive q^2 range of 1.00–22.00 GeV^2, excluding the control regions. The analysis for these two ranges is performed with the same procedure as for the other ranges.

The decay rate for the process $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$ depends on $\cos\theta_\ell$, where θ_ℓ is the angle between the directions of the μ^- and K^+ in the dilepton rest frame. The $\cos\theta_\ell$ dependence of the decay width Γ_ℓ can be parametrized [1, 8, 9] in terms of the observables of interest A_{FB} and F_{H} as:

$$\frac{1}{\Gamma_\ell}\frac{\mathrm{d}\Gamma_\ell}{\mathrm{d}\cos\theta_\ell} = \frac{3}{4}(1 - F_{\mathrm{H}})(1 - \cos^2\theta_\ell) + \frac{1}{2}F_{\mathrm{H}} + A_{\mathrm{FB}}\cos\theta_\ell. \tag{1}$$

The requirement for the decay rate to remain positive over all possible lepton angles constrains the parameter space to the region $0 \le F_{\mathrm{H}} \le 3$ and $|A_{\mathrm{FB}}| \le \min(1, F_{\mathrm{H}}/2)$. The angular observables A_{FB} and F_{H} are extracted from a two-dimensional extended unbinned maximum-likelihood fit to the angular distribution of the selected B^+ meson candidates in each q^2 range. The unnormalized probability density function (pdf) used in the two-dimensional fit is:

$$\mathrm{pdf}(m, \cos\theta_\ell) = Y_{\mathrm{S}}S_{\mathrm{m}}(m)S_{\mathrm{a}}(\cos\theta_\ell)\epsilon(\cos\theta_\ell) + Y_{\mathrm{B}}B_{\mathrm{m}}(m)B_{\mathrm{a}}(\cos\theta_\ell), \tag{2}$$

where the two contributions on the righthand side correspond to the parametrization of the signal and background. The parameters Y_{S} and Y_{B} are the yields of signal and background events, respectively. The functions $S_{\mathrm{m}}(m)$ and $S_{\mathrm{a}}(\cos\theta_\ell)$ describe the signal invariant mass and angular distributions, while $B_{\mathrm{m}}(m)$ and $B_{\mathrm{a}}(\cos\theta_\ell)$ are similar functions describing the background. The function $\epsilon(\cos\theta_\ell)$ is the signal efficiency as a function of $\cos\theta_\ell$.

The signal distribution $S_{\mathrm{m}}(m)$ is modeled as the sum of two Gaussian functions with a common mean, and $S_{\mathrm{a}}(\cos\theta_\ell)$ is given in Eq. (1). The background distribution $B_{\mathrm{m}}(m)$ is modeled as a single exponential function, while $B_{\mathrm{a}}(\cos\theta_\ell)$ is parametrized as the sum of a Gaussian function and a third- or fourth-degree polynomial, depending on the particular q^2 range.

Many of the parameters in the final fit are set to a given value with a Gaussian constraint that reflects the input uncertainty of the value. For the $S_{\mathrm{m}}(m)$ function, the mean is constrained to the world-average B^+mass [28] and the widths and relative fraction of the two Gaussians are constrained to the values found from fitting simulated events. The parameters of the $B_{\mathrm{a}}(\cos\theta_\ell)$ function are obtained by fitting the events in the B^+meson invariant mass sideband regions of 5.10–5.21 and 5.35–5.46 GeV. The free parameters of the fit are Y_{S}, Y_{B}, A_{FB}, and F_{H}, as well as the exponential decay parameter of $B_{\mathrm{m}}(m)$.

The signal efficiency $\epsilon(\cos\theta_\ell)$ is factorized into an acceptance ϵ_{acc} times a reconstruction efficiency ϵ_{reco}, which are both functions of $\cos\theta_\ell$. The acceptance is obtained from generated events, before the particle propagation with GEANT4, and is calculated as the fraction of MC simulated signal events passing the muon requirement of $p_T > 3.5\,GeV$ and $|\eta| < 2.2$ relative to all generated events. It varies from 2 to 4% depending on q^2. The reconstruction efficiency is obtained from the ratio of the number of reconstructed MC events passing the final event selection to the number of events passing the single-muon selection at the generator level. It varies from 4 to 7% depending on q^2. The signal efficiency $\epsilon(\cos\theta_\ell)$ is parametrized and fit with a sixth-order polynomial, as shown in Fig. 2 for the nine different signal q^2 ranges used in this analysis.

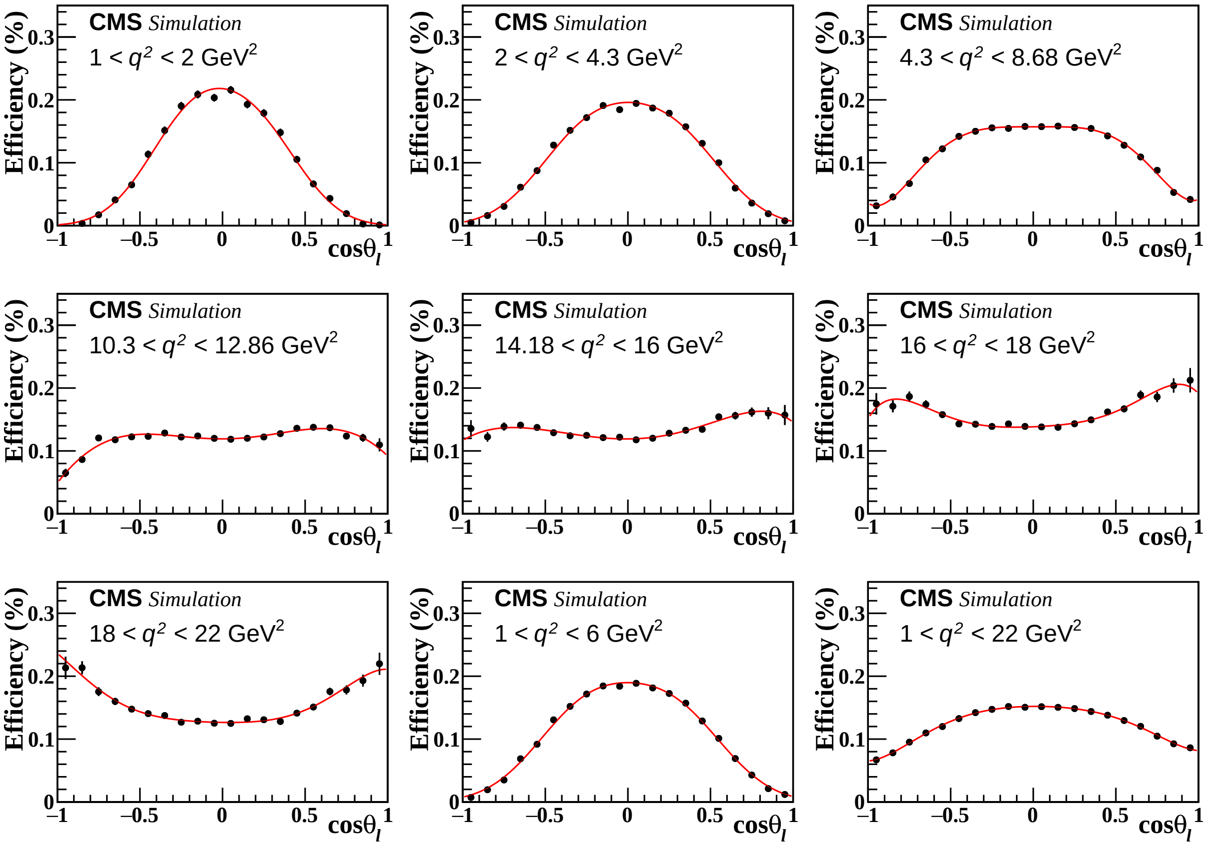

Figure 2: The signal efficiency determined from simulated events as a function of $\cos\theta_\ell$ for the different q^2 ranges (points). The vertical bars indicate the statistical uncertainty. The curves show the sixth-order polynomial fits to the points.

To validate the efficiency description derived from simulation, we check that the ratio of the branching fractions of the two control channels is consistent with the world-average value [28] within their uncertainties. The MC simulation samples are used to validate the fitting procedure in each q^2 range. The results of fitting the signal MC sample at the generator level and the standard signal simulation are consistent with each other. The large MC signal sample is divided into 20 subsamples and fits of these subsamples reveal no additional bias. In addition, we generate 200 pseudo-experiments of 100 times the size of data, using the pdf in Eq. (2), with parameters from fitting the data. The differences between the fitted values from these samples and the input parameters from data follow Gaussian distributions with the means consistent with zero and the widths smaller than the variations among the signal MC subsample fits in the same q^2 range.

The final fit is performed over the full B^+ meson invariant mass range and results in 2286 ± 73 signal events with q^2 from 1 to 22 GeV^2. Figures 3 and 4 show the $K^+\mu^+\mu^-$ invariant mass and the $\cos\theta_\ell$ projections, respectively, for each q^2 range from the two-dimensional fit to the data.

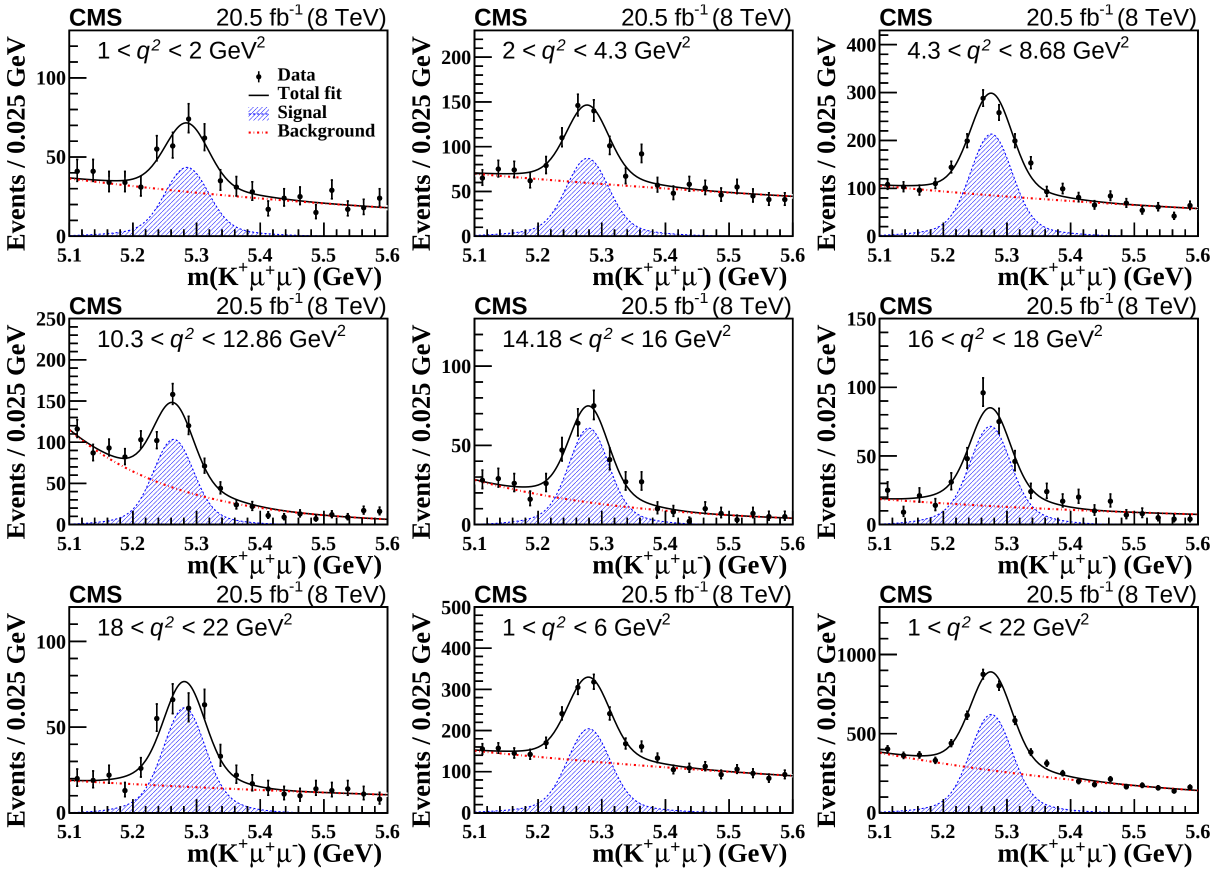

Figure 3: Projections of the $K^+\mu^+\mu^-$ invariant mass distributions for each q^2 range from the two-dimensional fit of data. The solid lines show the total fit, the shaded area the signal contribution, and the dash-dotted lines the background. The vertical bars on the points represent the statistical uncertainty in data.

5 Systematic uncertainties

Several sources of systematic uncertainty in the measured values of A_{FB} and F_H are considered, as summarized in Table 1. Varying the parameter values of $S_m(m)$ used to fit the signal invariant mass distribution within their uncertainties results in a negligible change in the measured values of A_{FB} and F_H.

The finite size of the simulated event samples can affect the accuracy of the efficiency determination. To estimate the uncertainty, 200 alternative efficiency functions are created by varying the parameters of the signal efficiency function $\epsilon(\cos\theta_\ell)$ within their uncertainties. These alternative efficiencies are independently used to fit the data. The standard deviations of the resulting A_{FB} and F_H fit values are taken as their systematic uncertainties from this source. The systematic uncertainty due to the efficiency description is estimated by changing the modeling of $\epsilon(\cos\theta_\ell)$. The fit to $\epsilon(\cos\theta_\ell)$ is modified from a sixth-order polynomial to the product of a Gaussian function and a sixth-order polynomial, where the Gaussian function parameters are the fit results from ϵ_{acc}, and the sixth-order polynomial parameters are the fit results from ϵ_{reco}. The differences in the results of A_{FB} and F_H are used as the systematic uncertainties.

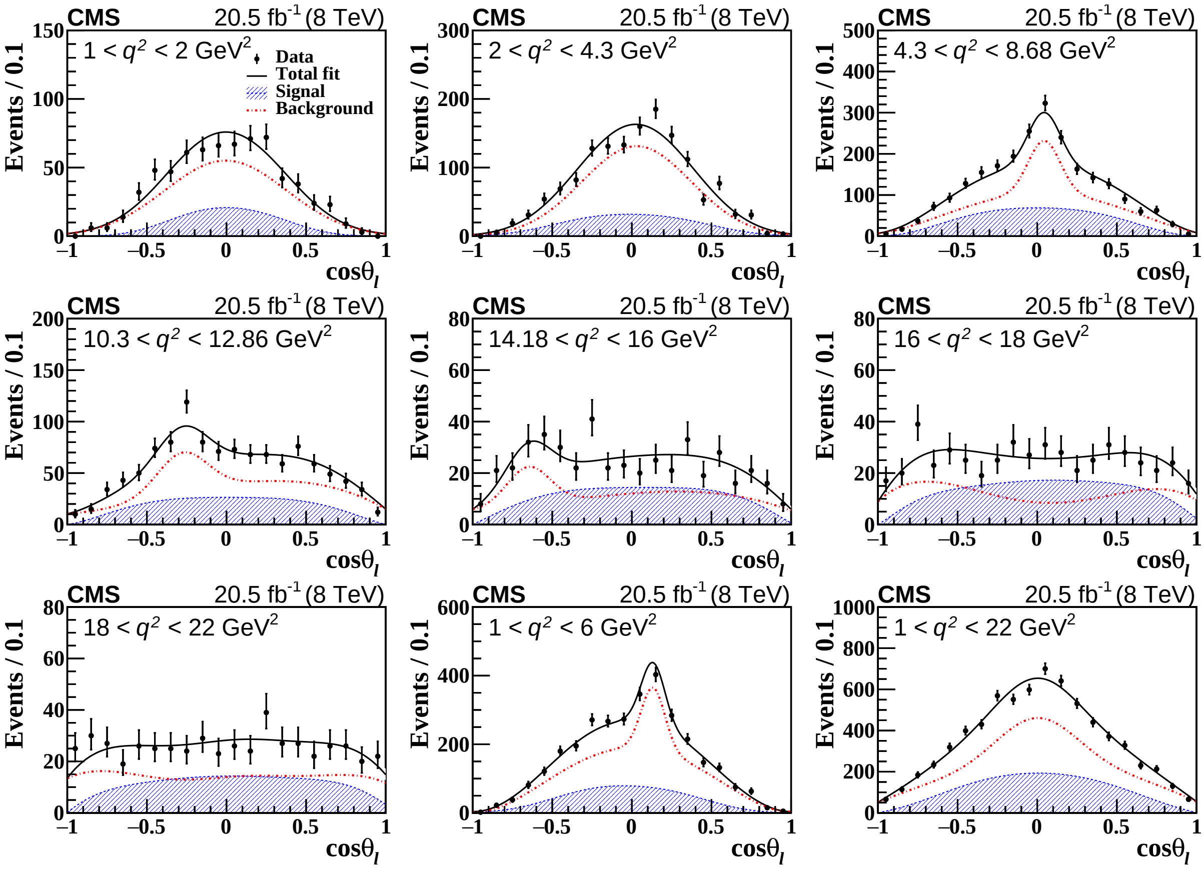

Figure 4: Projections of the $\cos\theta_\ell$ distributions for each q^2 range from the two-dimensional fit of data. The solid lines show the total fit, the shaded area the signal contribution, and the dash-dotted lines the background. The vertical bars on the points represent the statistical uncertainty in data.

Table 1: Absolute values of the uncertainty contributions in the measurements of A_{FB} and F_H. For each item, the range indicates the variation of the uncertainty in the signal q^2 ranges.

Systematic uncertainty	A_{FB} $(\times 10^{-2})$	F_H $(\times 10^{-2})$
Finite size of MC samples	0.4–1.8	0.9–5.0
Efficiency description	0.1–1.5	0.1–7.8
Simulation mismodeling	0.1–2.8	0.1–1.4
Background parametrization model	0.1–1.0	0.1–5.1
Angular resolution	0.1–1.7	0.1–3.3
Dimuon mass resolution	0.1–1.0	0.1–1.5
Fitting procedure	0.1–3.2	0.4–25
Background distribution	0.1–7.2	0.1–29
Total systematic uncertainty	1.6–7.5	4.4–39

The simulated signal sample is used to evaluate the effects of any simulation mismodeling. The difference in the fitted values of A_{FB} and F_H between a simulated sample at the generator level without the detector simulation and reconstruction steps, and the standard signal simulation sample is assigned as the systematic uncertainty. The specific parametrization of the function used to fit the backgrounds can cause the results to change. To evaluate the effect of fitting the background $\cos\theta_\ell$ distribution, the degrees of the polynomials used to describe the angular shapes of the combinatorial background are decreased by one. After fitting with the alternative background parametrization, the differences in the A_{FB} and F_H results are taken as the systematic uncertainties from the background parametrization model. The systematic uncertainties coming from the experimental resolution in $\cos\theta_\ell$ and q^2 are estimated by comparing the values of A_{FB} and F_H obtained from the reconstructed MC events with those found using the generated values of $\cos\theta_\ell$ and q^2 in the fit.

An estimate of the systematic uncertainty from the fitting procedure is calculated using two different methods. In the first method, we divide the large simulated signal sample into multiple subsamples, each with a size similar to that of the data. The difference between the average of the fitted values of A_{FB} and F_H from the subsamples and the fitted value from the full sample is taken as an estimate of the systematic uncertainty from the modeling of the signal. In the second method, we generate many pseudo-experiments in which each of the mass and $\cos\theta_\ell$ distributions are obtained from combining a signal and background distribution. The signal distribution is obtained by selecting signal events from the simulated sample, with the number of events determined by the fit to the data. The background distribution is obtained from sampling a parent distribution that comes from subtracting the fitted signal distributions from the data. The mean value of the differences from these pseudo-experiments and the measurements from the reconstruction-level simulated signal sample is taken as an estimate of the fitting uncertainty due to the presence of background. The estimates from the two methods are then added in quadrature to obtain the overall systematic uncertainty from the fitting procedure.

In some q^2 ranges there are visible structures in the background $\cos\theta_\ell$ distributions, as seen in Fig. 4. We have investigated many possible contributions to these structures, and no single source has been identified. This uncertainty is estimated using the "second" method from the fitting procedure systematic uncertainty calculation with the $\cos\theta_\ell$ distribution for the background obtained separately from the lower- and higher-mass sideband regions, 5.10–5.21 and 5.35–5.60 GeV. The larger of the two differences between these alternative fits and the nominal fit is taken as the systematic uncertainty from fitting the background $\cos\theta_\ell$ distribution.

The systematic uncertainties are estimated for each q^2 range independently. As the systematic uncertainty sources are considered to be independent, they are added in quadrature to obtain the total systematic uncertainties, as shown in the last row of Table 1.

6 Results

To evaluate the statistical uncertainties, the 68.3% confidence level intervals on A_{FB} and F_H are estimated using the profiled Feldman–Cousins technique [30]. When estimating the uncertainty in A_{FB} and F_H, the other variable is treated as a nuisance parameter and profiled. A large number of pseudo-experiments are generated with the maximum-likelihood estimate of the nuisance parameter. The correlation between the two variables is ignored by setting the confidence interval after using this profiling method. The systematic and statistical uncertainties are added in quadrature to obtain the total uncertainty.

The measured values of A_{FB} and F_H for each q^2 range are shown in Fig. 5. The numerical results are summarized in Table 2, including the two special q^2 ranges. The measured values of A_{FB} are consistent with the SM expectation of no asymmetry. Table 2 also includes three SM predictions for F_H with different input parameters and different handling of higher-order corrections, one of which is also shown in Fig. 5. There is generally good agreement between the predictions and our results, as well as between our results and previous measurements [15–19].

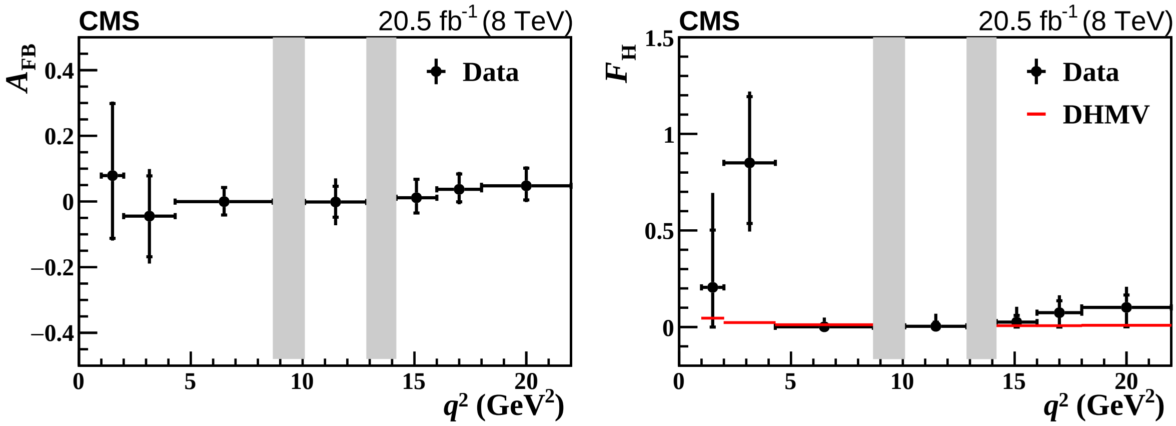

Figure 5: Results of the A_{FB} (left) and F_{H} (right) measurements in ranges of q^2. The statistical uncertainties are shown by the inner vertical bars, while the outer vertical bars give the total uncertainties. The horizontal bars show the q^2 range widths. The vertical shaded regions are 8.68–10.09 and 12.86–14.18 GeV^2, corresponding to the J/ψ- and ψ(2S)-dominated control regions, respectively. The horizontal lines in the right plot show the DHMV SM theoretical predictions [31, 32], whose uncertainties are smaller than the line width.

Table 2: Results of the fit for each q^2 range, together with several SM predictions. The inclusive $q^2 = 1.00$–22.00 GeV^2 range in the bottom line does not include events from the J/ψ and ψ(2S) resonance regions. The signal yield Y_{S} is given, along with its statistical uncertainty. The measured values of A_{FB} and F_{H} are presented, where the first uncertainties are statistical and the second are systematic. The fifth column is a theoretical prediction by C. Bobeth et al. [1, 3] using the EOS package [33] with the form factors from Refs. [2, 34, 35]. The sixth column is the calculation from S. Descotes-Genon et al. (DHMV) based on Refs. [31, 32]. The last column is the prediction using the FLAVIO package [36] with the form factors from Ref. [37]. Only the central values of the theoretical predictions are shown, since their uncertainties are insignificant compared to those in the measurements.

q^2 (GeV^2)	Y_{S}	A_{FB}	F_{H}	F_{H}(EOS)	F_{H}(DHMV)	F_{H}(FLAVIO)
1.00–2.00	169 ± 22	$0.08\,^{+0.22}_{-0.19} \pm 0.05$	$0.21\,^{+0.29}_{-0.21} \pm 0.39$	0.047	0.046	0.045
2.00–4.30	331 ± 32	$-0.04\,^{+0.12}_{-0.12} \pm 0.07$	$0.85\,^{+0.34}_{-0.31} \pm 0.14$	0.024	0.023	0.022
4.30–8.68	785 ± 42	$0.00\,^{+0.04}_{-0.04} \pm 0.02$	$0.01\,^{+0.02}_{-0.01} \pm 0.04$	—	0.012	0.011
10.09–12.86	365 ± 29	$0.00\,^{+0.05}_{-0.05} \pm 0.05$	$0.01\,^{+0.02}_{-0.01} \pm 0.06$	—	—	—
14.18–16.00	215 ± 19	$0.01\,^{+0.06}_{-0.05} \pm 0.02$	$0.03\,^{+0.03}_{-0.03} \pm 0.07$	0.007	0.007	0.006
16.00–18.00	262 ± 21	$0.04\,^{+0.05}_{-0.04} \pm 0.03$	$0.07\,^{+0.06}_{-0.07} \pm 0.07$	0.007	0.007	0.006
18.00–22.00	226 ± 20	$0.05\,^{+0.05}_{-0.04} \pm 0.02$	$0.10\,^{+0.06}_{-0.10} \pm 0.09$	0.008	0.009	0.008
1.00–6.00	778 ± 47	$-0.14\,^{+0.07}_{-0.06} \pm 0.03$	$0.38\,^{+0.17}_{-0.21} \pm 0.09$	0.025	0.025	0.020
1.00–22.00	2286 ± 73	$0.00\,^{+0.02}_{-0.02} \pm 0.03$	$0.01\,^{+0.01}_{-0.01} \pm 0.06$	—	—	—

7 Summary

An angular analysis of the decay $\mathrm{B}^+ \to \mathrm{K}^+\mu^+\mu^-$ has been performed using a data sample of proton-proton collisions corresponding to an integrated luminosity of 20.5 fb^{-1} recorded with the CMS detector at $\sqrt{s} = 8$ TeV. The forward-backward asymmetry A_{FB} of the muon system and the contribution F_{H} of the pseudoscalar, scalar, and tensor amplitudes to the decay width are measured as a function of the dimuon mass squared. The results are consistent with previous measurements, and are also compatible with three different standard model predictions.

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); SENESCYT (Ecuador); 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); NKFIA (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, 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, CPAN, PCTI and FEDER (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 program and the European Research Council and Horizon 2020 Grant, contract No. 675440 (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 n. 30820817; the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; 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 123842, 123959, 124845, 124850 and 125105 (Hungary); the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus program of the Ministry of Science and Higher Education, the National Science Center (Poland), contracts Harmonia 2014/14/M/ST2/00428, Opus 2014/13/B/ST2/02543, 2014/15/B/ST2/03998, and 2015/19/B/ST2/02861, Sonata-bis 2012/07/E/ST2/01406; the National Priorities Research Program by Qatar National Research Fund; the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, grant MDM-2015-0509 and the Programa Severo Ochoa del Principado de Asturias; the Thalis and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); the Welch Foundation, contract C-1845; and the Weston Havens Foundation (USA).

References

[1] C. Bobeth, G. Hiller, and G. Piranishvili, “Angular distributions of $B \to K\ell^+\ell^-$ decays”, *JHEP* **12** (2007) 040, doi:10.1088/1126-6708/2007/12/040, arXiv:0709.4174.

[2] A. Khodjamirian, T. Mannel, A. A. Pivovarov, and Y. M. Wang, “Charm-loop effect in $B \to K^{(*)}\ell^+\ell^-$ and $B \to K^*\gamma$”, *JHEP* **09** (2010) 089, doi:10.1007/JHEP09(2010)089, arXiv:1006.4945.

[3] C. Bobeth, G. Hiller, D. van Dyk, and C. Wacker, “The decay $B \to K\ell^+\ell^-$ at low hadronic recoil and model-independent $\delta B = 1$ constraints”, *JHEP* **01** (2012) 107, doi:10.1007/JHEP01(2012)107, arXiv:1111.2558.

[4] A. Ali, T. Mannel, and T. Morozumi, “Forward-backward asymmetry of dilepton angular distribution in the decay $b \to s\ell^+\ell^-$”, *Phys. Lett. B* **273** (1991) 505, doi:10.1016/0370-2693(91)90306-B.

[5] F. Beaujean, C. Bobeth, and S. Jahn, “Constraints on tensor and scalar couplings from $B \to K\overline{\mu}\mu$ and $B_s \to \overline{\mu}\mu$”, *Eur. Phys. J. C* **75** (2015) 456, doi:10.1140/epjc/s10052-015-3676-2, arXiv:1508.01526.

[6] W. Altmannshofer, C. Niehoff, P. Stangl, and D. M. Straub, “Status of the $B \to K^*\mu^+\mu^-$ anomaly after Moriond 2017”, *Eur. Phys. J. C* **77** (2017) 377, doi:10.1140/epjc/s10052-017-4952-0, arXiv:1703.09189.

[7] W. Altmannshofer, P. Paradisi, and D. M. Straub, “Model-independent constraints on new physics in $b \to s$ transitions”, *JHEP* **04** (2012) 008, doi:10.1007/JHEP04(2012)008, arXiv:1111.1257.

[8] A. Ali, P. Ball, L. T. Handoko, and G. Hiller, “A comparative study of the decays $B \to K^{(*)}\ell^+\ell^-$ in standard model and supersymmetric theories”, *Phys. Rev. D* **61** (2000) 074024, doi:10.1103/PhysRevD.61.074024, arXiv:hep-ph/9910221.

[9] C. Bobeth, T. Ewerth, F. Kruger, and J. Urban, “Analysis of neutral Higgs-boson contributions to the decays $B_s \to \ell^+\ell^-$ and $B \to K\ell^+\ell^-$”, *Phys. Rev. D* **64** (2001) 074014, doi:10.1103/PhysRevD.64.074014, arXiv:hep-ph/0104284.

[10] A. K. Alok, A. Dighe, and S. U. Sankar, “Large forward-backward asymmetry in $B \to K\mu^+\mu^-$ from new physics tensor operators”, *Phys. Rev. D* **78** (2008) 114025, doi:10.1103/PhysRevD.78.114025, arXiv:0810.3779.

[11] F. Sala and D. M. Straub, “A new light particle in B decays?”, *Phys. Lett. B* **774** (2017) 205, doi:10.1016/j.physletb.2017.09.072, arXiv:1704.06188.

[12] W. Altmannshofer and D. M. Straub, “New physics in $b \to s$ transitions after LHC run 1”, *Eur. Phys. J. C* **75** (2015) 382, doi:10.1140/epjc/s10052-015-3602-7, arXiv:1411.3161.

[13] D. Ghosh, M. Nardecchia, and S. A. Renner, “Hint of lepton flavour non-universality in B meson decays”, *JHEP* **12** (2014) 131, doi:10.1007/JHEP12(2014)131, arXiv:1408.4097.

[14] CMS Collaboration, “CMS luminosity based on pixel cluster counting—summer 2013 update”, CMS Physics Analysis Summary CMS–PAS–LUM–13–001, CERN, 2013.

[15] BABAR Collaboration, "Measurements of branching fractions, rate asymmetries, and angular distributions in the rare decays $B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$", *Phys. Rev. D* **73** (2006) 092001, doi:10.1103/PhysRevD.73.092001, arXiv:hep-ex/0604007.

[16] Belle Collaboration, "Measurement of the differential branching fraction and forward-backward asymmetry for $B \to K^{(*)}\ell^+\ell^-$", *Phys. Rev. Lett.* **103** (2009) 171801, doi:10.1103/PhysRevLett.103.171801, arXiv:0904.0770.

[17] CDF Collaboration, "Measurements of the angular distributions in the decays $B \to K^{(*)}\mu^+\mu^-$ at CDF", *Phys. Rev. Lett.* **108** (2012) 081807, doi:10.1103/PhysRevLett.108.081807, arXiv:1108.0695.

[18] LHCb Collaboration, "Differential branching fraction and angular analysis of the $B^+ \to K^+\mu^+\mu^-$ decay", *JHEP* **02** (2013) 105, doi:10.1007/JHEP02(2013)105, arXiv:1209.4284.

[19] LHCb Collaboration, "Angular analysis of charged and neutral $B \to K\mu^+\mu^-$ decays", *JHEP* **05** (2014) 082, doi:10.1007/JHEP05(2014)082, arXiv:1403.8045.

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

[21] CMS Collaboration, "The CMS trigger system", *JINST* **12** (2017) P01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.

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

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

[24] GEANT4 Collaboration, "GEANT4—a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[25] 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.

[26] CMS Collaboration, "Muon ID performance: low-p_t muon efficiencies", CMS Detector Performance Report CMS–DP–2014–020, CERN, 2014.

[27] CMS Collaboration, "Angular analysis and branching fraction measurement of the decay $B^0 \to K^{*0}\mu^+\mu^-$", *Phys. Lett. B* **727** (2013) 77, doi:10.1016/j.physletb.2013.10.017, arXiv:1308.3409.

[28] Particle Data Group, C. Patrignani et al., "Review of particle physics", *Chin. Phys. C* **40** (2016) 100001, doi:10.1088/1674-1137/40/10/100001.

[29] CMS Collaboration, "Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$ from pp collisions at $\sqrt{s} = 8$ TeV", *Phys. Lett. B* **753** (2016) 424, doi:10.1016/j.physletb.2015.12.020, arXiv:1507.08126.

[30] G. J. Feldman and R. D. Cousins, "A unified approach to the classical statistical analysis of small signals", *Phys. Rev. D* **57** (1998) 3873, doi:10.1103/PhysRevD.57.3873, arXiv:physics/9711021.

[31] S. Descotes-Genon, L. Hofer, J. Matias, and J. Virto, "On the impact of power corrections in the prediction of $B \to K^{*}\mu^{+}\mu^{-}$ observables", *JHEP* **12** (2014) 125, doi:10.1007/JHEP12(2014)125, arXiv:1407.8526.

[32] S. Descotes-Genon, L. Hofer, J. Matias, and J. Virto, "Global analysis of $b \to s\ell\ell$ anomalies", *JHEP* **06** (2016) 092, doi:10.1007/JHEP06(2016)092, arXiv:1510.04239.

[33] D. van Dyk, C. Bobeth, F. Beaujean, and T. Blake, "EOS (lambda-polarised release)", 2017. doi:10.5281/zenodo.886055.

[34] HPQCD Collaboration, "Rare decay $B \to K\ell^{+}\ell^{-}$ form factors from lattice QCD", *Phys. Rev. D* **88** (2013) 054509, doi:10.1103/PhysRevD.88.054509, arXiv:1306.2384. [Erratum: doi:10.1103/PhysRevD.88.079901].

[35] P. Ball and R. Zwicky, "New results on $B \to \pi, K, \eta$ decay form factors from light-cone sum rules", *Phys. Rev. D* **71** (2005) 014015, doi:10.1103/PhysRevD.71.014015, arXiv:hep-ph/0406232.

[36] D. Straub et al., "flav-io/flavio v0.15.1", 2016. doi:10.5281/zenodo.167380.

[37] Fermilab Lattice and MILC Collaborations, "$B \to K\ell^{+}\ell^{-}$ decay form factors from three-flavor lattice QCD", *Phys. Rev. D* **93** (2016) 025, doi:10.1103/PhysRevD.93.025026, arXiv:1509.06235.

A The CMS Collaboration

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

Institut für Hochenergiephysik, Wien, Austria
W. Adam, F. Ambrogi, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, A. Escalante Del Valle, M. Flechl, R. Frühwirth[1], V.M. Ghete, J. Hrubec, M. Jeitler[1], N. Krammer, I. Krätschmer, D. Liko, T. Madlener, I. Mikulec, N. Rad, H. Rohringer, J. Schieck[1], R. Schöfbeck, M. Spanring, D. Spitzbart, A. Taurok, W. Waltenberger, J. Wittmann, C.-E. Wulz[1], M. Zarucki

Institute for Nuclear Problems, Minsk, Belarus
V. Chekhovsky, V. Mossolov, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium
E.A. De Wolf, D. Di Croce, X. Janssen, J. Lauwers, M. Pieters, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium
S. Abu Zeid, F. Blekman, J. D'Hondt, I. De Bruyn, J. De Clercq, K. Deroover, G. Flouris, D. Lontkovskyi, S. Lowette, I. Marchesini, S. Moortgat, L. Moreels, Q. Python, K. Skovpen, S. Tavernier, W. Van Doninck, P. Van Mulders, I. Van Parijs

Université Libre de Bruxelles, Bruxelles, Belgium
D. Beghin, B. Bilin, H. Brun, B. Clerbaux, G. De Lentdecker, H. Delannoy, B. Dorney, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, A.K. Kalsi, T. Lenzi, J. Luetic, N. Postiau, E. Starling, L. Thomas, C. Vander Velde, P. Vanlaer, D. Vannerom, Q. Wang

Ghent University, Ghent, Belgium
T. Cornelis, D. Dobur, A. Fagot, M. Gul, I. Khvastunov[2], D. Poyraz, C. Roskas, D. Trocino, M. Tytgat, W. Verbeke, B. Vermassen, M. Vit, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
H. Bakhshiansohi, O. Bondu, S. Brochet, G. Bruno, C. Caputo, P. David, C. Delaere, M. Delcourt, B. Francois, A. Giammanco, G. Krintiras, V. Lemaitre, A. Magitteri, A. Mertens, M. Musich, K. Piotrzkowski, A. Saggio, M. Vidal Marono, S. Wertz, J. Zobec

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
F.L. Alves, G.A. Alves, L. Brito, G. Correia Silva, C. Hensel, A. Moraes, M.E. Pol, P. Rebello Teles

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato[3], E. Coelho, E.M. Da Costa, G.G. Da Silveira[4], D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, D. Matos Figueiredo, M. Melo De Almeida, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, L.J. Sanchez Rosas, A. Santoro, A. Sznajder, M. Thiel, E.J. Tonelli Manganote[3], F. Torres Da Silva De Araujo, A. Vilela Pereira

Universidade Estadual Paulista [a], Universidade Federal do ABC [b], São Paulo, Brazil
S. Ahuja[a], C.A. Bernardes[a], L. Calligaris[a], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], P.G. Mercadante[b], S.F. Novaes[a], SandraS. Padula[a], D. Romero Abad[b]

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia,

Bulgaria
A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, A. Marinov, M. Misheva, M. Rodozov, M. Shopova, G. Sultanov

University of Sofia, Sofia, Bulgaria
A. Dimitrov, L. Litov, B. Pavlov, P. Petkov

Beihang University, Beijing, China
W. Fang[5], X. Gao[5], L. Yuan

Institute of High Energy Physics, Beijing, China
M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, Y. Chen, C.H. Jiang, D. Leggat, H. Liao, Z. Liu, F. Romeo, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, E. Yazgan, H. Zhang, J. Zhao

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
Y. Ban, G. Chen, A. Levin, J. Li, L. Li, Q. Li, Y. Mao, S.J. Qian, D. Wang, Z. Xu

Tsinghua University, Beijing, China
Y. Wang

Universidad de Los Andes, Bogota, Colombia
C. Avila, A. Cabrera, C.A. Carrillo Montoya, L.F. Chaparro Sierra, C. Florez, C.F. González Hernández, M.A. Segura Delgado

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
B. Courbon, N. Godinovic, D. Lelas, I. Puljak, T. Sculac

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

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, D. Ferencek, K. Kadija, B. Mesic, A. Starodumov[6], T. Susa

University of Cyprus, Nicosia, Cyprus
M.W. Ather, A. Attikis, M. Kolosova, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

Charles University, Prague, Czech Republic
M. Finger[7], M. Finger Jr.[7]

Escuela Politecnica Nacional, Quito, Ecuador
E. Ayala

Universidad San Francisco de Quito, Quito, Ecuador
E. Carrera Jarrin

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
A. Mahrous[8], Y. Mohammed[9], E. Salama[10,11]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
S. Bhowmik, A. Carvalho Antunes De Oliveira, R.K. Dewanjee, K. Ehataht, M. Kadastik, M. Raidal, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, H. Kirschenmann, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Havukainen, J.K. Heikkilä, T. Järvinen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Laurila, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, H. Siikonen, E. Tuominen, J. Tuominiemi

Lappeenranta University of Technology, Lappeenranta, Finland
T. Tuuva

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
M. Besancon, F. Couderc, M. Dejardin, D. Denegri, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, C. Leloup, E. Locci, J. Malcles, G. Negro, J. Rander, A. Rosowsky, M.Ö. Sahin, M. Titov

Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3, Université Paris-Saclay, Palaiseau, France
A. Abdulsalam[12], C. Amendola, I. Antropov, F. Beaudette, P. Busson, C. Charlot, R. Granier de Cassagnac, I. Kucher, S. Lisniak, A. Lobanov, J. Martin Blanco, M. Nguyen, C. Ochando, G. Ortona, P. Pigard, R. Salerno, J.B. Sauvan, Y. Sirois, A.G. Stahl Leiton, A. Zabi, A. Zghiche

Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
J.-L. Agram[13], J. Andrea, D. Bloch, J.-M. Brom, E.C. Chabert, V. Cherepanov, C. Collard, E. Conte[13], J.-C. Fontaine[13], D. Gelé, U. Goerlach, M. Jansová, A.-C. Le Bihan, N. Tonon, 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, C. Bernet, G. Boudoul, N. Chanon, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, L. Finco, S. Gascon, M. Gouzevitch, G. Grenier, B. Ille, F. Lagarde, I.B. Laktineh, H. Lattaud, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, A. Popov[14], V. Sordini, M. Vander Donckt, S. Viret, S. Zhang

Georgian Technical University, Tbilisi, Georgia
T. Toriashvili[15]

Tbilisi State University, Tbilisi, Georgia
I. Bagaturia[16]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, L. Feld, M.K. Kiesel, K. Klein, M. Lipinski, M. Preuten, M.P. Rauch, C. Schomakers, J. Schulz, M. Teroerde, B. Wittmer, V. Zhukov[14]

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
A. Albert, D. Duchardt, M. Endres, M. Erdmann, T. Esch, R. Fischer, S. Ghosh, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, H. Keller, S. Knutzen, L. Mastrolorenzo, M. Merschmeyer, A. Meyer, P. Millet, S. Mukherjee, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, A. Schmidt, D. Teyssier

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
G. Flügge, O. Hlushchenko, B. Kargoll, T. Kress, A. Künsken, T. Müller, A. Nehrkorn, A. Nowack, C. Pistone, O. Pooth, H. Sert, A. Stahl[17]

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, I. Babounikau, K. Beernaert, O. Behnke, U. Behrens, A. Bermúdez Martínez, D. Bertsche, A.A. Bin Anuar, K. Borras[18], V. Botta, A. Campbell, P. Connor, C. Contreras-Campana, F. Costanza, V. Danilov, A. De Wit, M.M. Defranchis, C. Diez Pardos, D. Domínguez Damiani, G. Eckerlin, T. Eichhorn, A. Elwood, E. Eren, E. Gallo[19], A. Geiser, J.M. Grados Luyando, A. Grohsjean, P. Gunnellini, M. Guthoff, M. Haranko, A. Harb, J. Hauk, H. Jung, M. Kasemann, J. Keaveney, C. Kleinwort, J. Knolle, D. Krücker, W. Lange, A. Lelek, T. Lenz, K. Lipka, W. Lohmann[20], R. Mankel, I.-A. Melzer-Pellmann, A.B. Meyer, M. Meyer, M. Missiroli, G. Mittag, J. Mnich, V. Myronenko, S.K. Pflitsch, D. Pitzl, A. Raspereza, M. Savitskyi, P. Saxena, P. Schütze, C. Schwanenberger, R. Shevchenko, A. Singh, N. Stefaniuk, H. Tholen, O. Turkot, A. Vagnerini, G.P. Van Onsem, R. Walsh, Y. Wen, K. Wichmann, C. Wissing, O. Zenaiev

University of Hamburg, Hamburg, Germany
R. Aggleton, S. Bein, L. Benato, A. Benecke, V. Blobel, M. Centis Vignali, T. Dreyer, E. Garutti, D. Gonzalez, J. Haller, A. Hinzmann, A. Karavdina, G. Kasieczka, R. Klanner, R. Kogler, N. Kovalchuk, S. Kurz, V. Kutzner, J. Lange, D. Marconi, J. Multhaup, M. Niedziela, D. Nowatschin, A. Perieanu, A. Reimers, O. Rieger, C. Scharf, P. Schleper, S. Schumann, J. Schwandt, J. Sonneveld, H. Stadie, G. Steinbrück, F.M. Stober, M. Stöver, D. Troendle, A. Vanhoefer, B. Vormwald

Karlsruher Institut fuer Technology
M. Akbiyik, C. Barth, M. Baselga, S. Baur, E. Butz, R. Caspart, T. Chwalek, F. Colombo, W. De Boer, A. Dierlamm, N. Faltermann, B. Freund, M. Giffels, M.A. Harrendorf, F. Hartmann[17], S.M. Heindl, U. Husemann, F. Kassel[17], I. Katkov[14], S. Kudella, H. Mildner, S. Mitra, M.U. Mozer, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, M. Schröder, I. Shvetsov, G. Sieber, H.J. Simonis, R. Ulrich, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

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

National and Kapodistrian University of Athens, Athens, Greece
G. Karathanasis, S. Kesisoglou, P. Kontaxakis, A. Panagiotou, N. Saoulidou, E. Tziaferi, K. Vellidis

National Technical University of Athens, Athens, Greece
K. Kousouris, I. Papakrivopoulos, G. Tsipolitis

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Gianneios, P. Katsoulis, P. Kokkas, S. Mallios, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas, F.A. Triantis, D. Tsitsonis

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
M. Bartók[21], M. Csanad, N. Filipovic, P. Major, M.I. Nagy, G. Pasztor, O. Surányi, G.I. Veres

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, D. Horvath[22], Á. Hunyadi, F. Sikler, T.Á. Vámi, V. Veszpremi, G. Vesztergombi[†]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Karancsi[23], A. Makovec, J. Molnar, Z. Szillasi

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

Indian Institute of Science (IISc), Bangalore, India
S. Choudhury, J.R. Komaragiri, P.C. Tiwari

National Institute of Science Education and Research, HBNI, Bhubaneswar, India
S. Bahinipati[24], C. Kar, P. Mal, K. Mandal, A. Nayak[25], D.K. Sahoo[24], S.K. Swain

Panjab University, Chandigarh, India
S. Bansal, S.B. Beri, V. Bhatnagar, S. Chauhan, R. Chawla, N. Dhingra, R. Gupta, A. Kaur, A. Kaur, M. Kaur, S. Kaur, R. Kumar, P. Kumari, M. Lohan, A. Mehta, K. Sandeep, S. Sharma, J.B. Singh, G. Walia

University of Delhi, Delhi, India
A. Bhardwaj, B.C. Choudhary, R.B. Garg, M. Gola, S. Keshri, Ashok Kumar, S. Malhotra, M. Naimuddin, P. Priyanka, K. Ranjan, Aashaq Shah, R. Sharma

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
R. Bhardwaj[26], M. Bharti, R. Bhattacharya, S. Bhattacharya, U. Bhawandeep[26], D. Bhowmik, S. Dey, S. Dutt[26], S. Dutta, S. Ghosh, K. Mondal, S. Nandan, A. Purohit, P.K. Rout, A. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan, B. Singh, S. Thakur[26]

Indian Institute of Technology Madras, Madras, India
P.K. Behera

Bhabha Atomic Research Centre, Mumbai, India
R. Chudasama, D. Dutta, V. Jha, V. Kumar, P.K. Netrakanti, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research-A, Mumbai, India
T. Aziz, M.A. Bhat, S. Dugad, G.B. Mohanty, N. Sur, B. Sutar, RavindraKumar Verma

Tata Institute of Fundamental Research-B, Mumbai, India
S. Banerjee, S. Bhattacharya, S. Chatterjee, P. Das, M. Guchait, Sa. Jain, S. Karmakar, S. Kumar, M. Maity[27], G. Majumder, K. Mazumdar, N. Sahoo, T. Sarkar[27]

Indian Institute of Science Education and Research (IISER), Pune, India
S. Chauhan, S. Dube, V. Hegde, A. Kapoor, K. Kothekar, S. Pandey, A. Rane, S. Sharma

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
S. Chenarani[28], E. Eskandari Tadavani, S.M. Etesami[28], M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, F. Rezaei Hosseinabadi, B. Safarzadeh[29], 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], C. Calabria[a,b], A. Colaleo[a], D. Creanza[a,c], L. Cristella[a,b], N. De Filippis[a,c], M. De Palma[a,b], A. Di Florio[a,b], F. Errico[a,b], L. Fiore[a], A. Gelmi[a,b], G. Iaselli[a,c], S. Lezki[a,b], G. Maggi[a,c], M. Maggi[a], G. Miniello[a,b], S. My[a,b], S. Nuzzo[a,b], A. Pompili[a,b], G. Pugliese[a,c], R. Radogna[a], A. Ranieri[a], G. Selvaggi[a,b], A. Sharma[a], L. Silvestris[a,17], R. Venditti[a], P. Verwilligen[a], G. Zito[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], C. Battilana[a,b], D. Bonacorsi[a,b], L. Borgonovi[a,b], S. Braibant-Giacomelli[a,b], R. Campanini[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], S.S. Chhibra[a,b], C. Ciocca[a], G. Codispoti[a,b], M. Cuffiani[a,b], G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], P. Giacomelli[a], C. Grandi[a], L. Guiducci[a,b], F. Iemmi[a,b], S. Marcellini[a], G. Masetti[a], A. Montanari[a], F.L. Navarria[a,b], A. Perrotta[a], F. Primavera[a,b,17], A.M. Rossi[a,b], T. Rovelli[a,b], G.P. Siroli[a,b], N. Tosi[a]

INFN Sezione di Catania [a], Università di Catania [b], Catania, Italy
S. Albergo[a,b], A. Di Mattia[a], 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], K. Chatterjee[a,b], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], G. Latino, P. Lenzi[a,b], M. Meschini[a], S. Paoletti[a], L. Russo[a,30], G. Sguazzoni[a], D. Strom[a], L. Viliani[a]

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
F. Ferro[a], F. Ravera[a,b], E. Robutti[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a], A. Beschi[b], L. Brianza[a,b], F. Brivio[a,b], V. Ciriolo[a,b,17], S. Di Guida[a,d,17], M.E. Dinardo[a,b], S. Fiorendi[a,b], S. Gennai[a], A. Ghezzi[a,b], P. Govoni[a,b], M. Malberti[a,b], S. Malvezzi[a], A. Massironi[a,b], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli 'Federico II' [b], Napoli, Italy, Università della Basilicata [c], Potenza, Italy, Università G. Marconi [d], Roma, Italy
S. Buontempo[a], N. Cavallo[a,c], A. Di Crescenzo[a,b], F. Fabozzi[a,c], F. Fienga[a], G. Galati[a], A.O.M. Iorio[a,b], W.A. Khan[a], L. Lista[a], S. Meola[a,d,17], P. Paolucci[a,17], C. Sciacca[a,b], E. Voevodina[a,b]

INFN Sezione di Padova [a], Università di Padova [b], Padova, Italy, Università di Trento [c], Trento, Italy
P. Azzi[a], N. Bacchetta[a], D. Bisello[a,b], A. Boletti[a,b], A. Bragagnolo, R. Carlin[a,b], P. Checchia[a], M. Dall'Osso[a,b], P. De Castro Manzano[a], T. Dorigo[a], F. Gasparini[a,b], U. Gasparini[a,b], S. Lacaprara[a], P. Lujan, M. Margoni[a,b], A.T. Meneguzzo[a,b], N. Pozzobon[a,b], P. Ronchese[a,b], R. Rossin[a,b], F. Simonetto[a,b], A. Tiko, E. Torassa[a], S. Ventura[a], M. Zanetti[a,b], P. Zotto[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
A. Braghieri[a], A. Magnani[a], P. Montagna[a,b], S.P. Ratti[a,b], V. Re[a], M. Ressegotti[a,b], C. Riccardi[a,b], P. Salvini[a], I. Vai[a,b], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
L. Alunni Solestizi[a,b], M. Biasini[a,b], G.M. Bilei[a], C. Cecchi[a,b], D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], E. Manoni[a], G. Mantovani[a,b], V. Mariani[a,b], M. Menichelli[a], A. Rossi[a,b], A. Santocchia[a,b], D. Spiga[a]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
K. Androsov[a], P. Azzurri[a], G. Bagliesi[a], L. Bianchini[a], T. Boccali[a], L. Borrello, R. Castaldi[a], M.A. Ciocci[a,b], R. Dell'Orso[a], G. Fedi[a], F. Fiori[a,c], L. Giannini[a,c], A. Giassi[a], M.T. Grippo[a],

F. Ligabue[a,c], E. Manca[a,c], G. Mandorli[a,c], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Sapienza Università di Roma [b], Rome, Italy
L. Barone[a,b], F. Cavallari[a], M. Cipriani[a,b], N. Daci[a], D. Del Re[a,b], E. Di Marco[a,b], M. Diemoz[a], S. Gelli[a,b], E. Longo[a,b], B. Marzocchi[a,b], P. Meridiani[a], G. Organtini[a,b], F. Pandolfi[a], R. Paramatti[a,b], F. Preiato[a,b], S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b]

INFN Sezione di Torino [a], Università di Torino [b], Torino, Italy, Università del Piemonte Orientale [c], Novara, Italy
N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], N. Bartosik[a], R. Bellan[a,b], C. Biino[a], N. Cartiglia[a], F. Cenna[a,b], S. Cometti, M. Costa[a,b], R. Covarelli[a,b], N. Demaria[a], B. Kiani[a,b], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], E. Monteil[a,b], M. Monteno[a], M.M. Obertino[a,b], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], K. Shchelina[a,b], V. Sola[a], A. Solano[a,b], D. Soldi, A. Staiano[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], F. Vazzoler[a,b], A. Zanetti[a]

Kyungpook National University
D.H. Kim, G.N. Kim, M.S. Kim, J. Lee, S. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, S. Sekmen, D.C. Son, Y.C. Yang

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
H. Kim, D.H. Moon, G. Oh

Hanyang University, Seoul, Korea
J. Goh, T.J. Kim

Korea University, Seoul, Korea
S. Cho, S. Choi, Y. Go, D. Gyun, S. Ha, B. Hong, Y. Jo, K. Lee, K.S. Lee, S. Lee, J. Lim, S.K. Park, Y. Roh

Sejong University, Seoul, Korea
H.S. Kim

Seoul National University, Seoul, Korea
J. Almond, J. Kim, J.S. Kim, H. Lee, K. Lee, K. Nam, S.B. Oh, B.C. Radburn-Smith, S.h. Seo, U.K. Yang, H.D. Yoo, G.B. Yu

University of Seoul, Seoul, Korea
D. Jeon, H. Kim, J.H. Kim, J.S.H. Lee, I.C. Park

Sungkyunkwan University, Suwon, Korea
Y. Choi, C. Hwang, J. Lee, I. Yu

Vilnius University, Vilnius, Lithuania
V. Dudenas, A. Juodagalvis, J. Vaitkus

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
I. Ahmed, Z.A. Ibrahim, M.A.B. Md Ali[31], F. Mohamad Idris[32], W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

Universidad de Sonora (UNISON), Hermosillo, Mexico
A. Castaneda Hernandez, J.A. Murillo Quijada

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, M.C. Duran-Osuna, I. Heredia-De La Cruz[33], R. Lopez-Fernandez, J. Mejia Guisao, R.I. Rabadan-Trejo, G. Ramirez-Sanchez, R Reyes-Almanza, A. Sanchez-Hernandez

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

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
J. Eysermans, I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

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

University of Auckland, Auckland, New Zealand
D. Krofcheck

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

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
A. Ahmad, M. Ahmad, M.I. Asghar, Q. Hassan, H.R. Hoorani, A. Saddique, M.A. Shah, M. Shoaib, M. Waqas

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

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
K. Bunkowski, A. Byszuk[34], K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, A. Pyskir, M. Walczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, B. Galinhas, M. Gallinaro, J. Hollar, N. Leonardo, L. Lloret Iglesias, M.V. Nemallapudi, J. Seixas, G. Strong, O. Toldaiev, D. Vadruccio, J. Varela

Joint Institute for Nuclear Research, Dubna, Russia
A. Baginyan, I. Golutvin, V. Karjavin, I. Kashunin, V. Korenkov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev[35,36], V.V. Mitsyn, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, N. Skatchkov, V. Smirnov, V. Trofimov, A. Zarubin, V. Zhiltsov

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
V. Golovtsov, Y. Ivanov, V. Kim[37], E. Kuznetsova[38], P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, D. Sosnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, 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, I. Pozdnyakov, G. Safronov, A. Spiridonov, A. Stepennov, V. Stolin, M. Toms, E. Vlasov, A. Zhokin

Moscow Institute of Physics and Technology, Moscow, Russia
T. Aushev

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
R. Chistov[39], M. Danilov[39], P. Parygin, D. Philippov, S. Polikarpov[39], E. Tarkovskii

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin[36], I. Dremin[36], M. Kirakosyan[36], S.V. Rusakov, A. Terkulov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Baskakov, A. Belyaev, E. Boos, M. Dubinin[40], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

Novosibirsk State University (NSU), Novosibirsk, Russia
V. Blinov[41], T. Dimova[41], L. Kardapoltsev[41], D. Shtol[41], Y. Skovpen[41]

State Research Center of Russian Federation, Institute for High Energy Physics of NRC "Kurchatov Institute", Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, D. Elumakhov, A. Godizov, V. Kachanov, A. Kalinin, D. Konstantinov, P. Mandrik, V. Petrov, R. Ryutin, S. Slabospitskii, A. Sobol, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

National Research Tomsk Polytechnic University, Tomsk, Russia
A. Babaev, S. Baidali

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[42], P. Cirkovic, D. Devetak, M. Dordevic, J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
J. Alcaraz Maestre, A. Álvarez Fernández, I. Bachiller, M. Barrio Luna, J.A. Brochero Cifuentes, M. Cerrada, N. Colino, B. De La Cruz, A. Delgado Peris, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, D. Moran, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, I. Redondo, L. Romero, M.S. Soares, A. Triossi

Universidad Autónoma de Madrid, Madrid, Spain
C. Albajar, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain
J. Cuevas, C. Erice, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, J.R. González Fernández, E. Palencia Cortezon, V. Rodríguez Bouza, S. Sanchez Cruz, P. Vischia, J.M. Vizan Garcia

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
I.J. Cabrillo, A. Calderon, B. Chazin Quero, J. Duarte Campderros, M. Fernandez, P.J. Fernández Manteca, A. García Alonso, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, C. Martinez Rivero, P. Martinez Ruiz del Arbol, F. Matorras, J. Piedra Gomez, C. Prieels, T. Rodrigo, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, B. Akgun, E. Auffray, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, M. Bianco, A. Bocci, C. Botta, T. Camporesi, M. Cepeda, G. Cerminara, E. Chapon, Y. Chen, G. Cucciati, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, A. De Roeck, N. Deelen, M. Dobson, T. du Pree, M. Dünser, N. Dupont, A. Elliott-Peisert, P. Everaerts, F. Fallavollita[43], D. Fasanella, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, A. Gilbert, K. Gill, F. Glege, M. Guilbaud, D. Gulhan, J. Hegeman, V. Innocente, A. Jafari, P. Janot, O. Karacheban[20], J. Kieseler, A. Kornmayer, M. Krammer[1], C. Lange, P. Lecoq, C. Lourenço, L. Malgeri, M. Mannelli, F. Meijers, J.A. Merlin, S. Mersi, E. Meschi, P. Milenovic[44], F. Moortgat, M. Mulders, J. Ngadiuba, S. Orfanelli, L. Orsini, F. Pantaleo[17], L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, F.M. Pitters, D. Rabady, A. Racz, T. Reis, G. Rolandi[45], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, M. Selvaggi, A. Sharma, P. Silva, P. Sphicas[46], A. Stakia, J. Steggemann, M. Tosi, D. Treille, A. Tsirou, V. Veckalns[47], W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
L. Caminada[48], K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, T. Rohe, S.A. Wiederkehr

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
M. Backhaus, L. Bäni, P. Berger, N. Chernyavskaya, G. Dissertori, M. Dittmar, M. Donegà, C. Dorfer, C. Grab, C. Heidegger, D. Hits, J. Hoss, T. Klijnsma, W. Lustermann, R.A. Manzoni, M. Marionneau, M.T. Meinhard, F. Micheli, P. Musella, F. Nessi-Tedaldi, J. Pata, F. Pauss, G. Perrin, L. Perrozzi, S. Pigazzini, M. Quittnat, D. Ruini, D.A. Sanz Becerra, M. Schönenberger, L. Shchutska, V.R. Tavolaro, K. Theofilatos, M.L. Vesterbacka Olsson, R. Wallny, D.H. Zhu

Universität Zürich, Zurich, Switzerland
T.K. Aarrestad, C. Amsler[49], D. Brzhechko, M.F. Canelli, A. De Cosa, R. Del Burgo, S. Donato, C. Galloni, T. Hreus, B. Kilminster, I. Neutelings, D. Pinna, G. Rauco, P. Robmann, D. Salerno, K. Schweiger, C. Seitz, Y. Takahashi, A. Zucchetta

National Central University, Chung-Li, Taiwan
Y.H. Chang, K.y. Cheng, T.H. Doan, Sh. Jain, R. Khurana, C.M. Kuo, W. Lin, A. Pozdnyakov, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
P. Chang, Y. Chao, K.F. Chen, P.H. Chen, W.-S. Hou, Arun Kumar, Y.y. Li, R.-S. Lu, E. Paganis, A. Psallidas, A. Steen, J.f. Tsai

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

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
A. Bat, F. Boran, S. Cerci[50], S. Damarseckin, Z.S. Demiroglu, F. Dolek, C. Dozen, I. Dumanoglu, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos[51], C. Isik, E.E. Kangal[52], O. Kara, A. Kayis Topaksu, U. Kiminsu, M. Oglakci, G. Onengut, K. Ozdemir[53], S. Ozturk[54], D. Sunar Cerci[50], B. Tali[50], U.G. Tok, S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
B. Isildak[55], G. Karapinar[56], M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
I.O. Atakisi, E. Gülmez, M. Kaya[57], O. Kaya[58], S. Tekten, E.A. Yetkin[59]

Istanbul Technical University, Istanbul, Turkey
M.N. Agaras, S. Atay, A. Cakir, K. Cankocak, Y. Komurcu, S. Sen[60]

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine
B. Grynyov

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

University of Bristol, Bristol, United Kingdom
F. Ball, L. Beck, J.J. Brooke, D. Burns, E. Clement, D. Cussans, O. Davignon, H. Flacher, J. Goldstein, G.P. Heath, H.F. Heath, L. Kreczko, D.M. Newbold[61], S. Paramesvaran, B. Penning, T. Sakuma, D. Smith, V.J. Smith, J. Taylor, A. Titterton

Rutherford Appleton Laboratory, Didcot, United Kingdom
K.W. Bell, A. Belyaev[62], C. Brew, R.M. Brown, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Linacre, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, W.J. Womersley

Imperial College, London, United Kingdom
G. Auzinger, R. Bainbridge, P. Bloch, J. Borg, S. Breeze, O. Buchmuller, A. Bundock, S. Casasso, D. Colling, L. Corpe, P. Dauncey, G. Davies, M. Della Negra, R. Di Maria, Y. Haddad, G. Hall, G. Iles, T. James, M. Komm, C. Laner, L. Lyons, A.-M. Magnan, S. Malik, A. Martelli, J. Nash[63], A. Nikitenko[6], V. Palladino, M. Pesaresi, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, G. Singh, M. Stoye, T. Strebler, S. Summers, A. Tapper, K. Uchida, T. Virdee[17], N. Wardle, D. Winterbottom, J. Wright, S.C. Zenz

Brunel University, Uxbridge, United Kingdom
J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, C.K. Mackay, A. Morton, I.D. Reid, L. Teodorescu, S. Zahid

Baylor University, Waco, USA
K. Call, J. Dittmann, K. Hatakeyama, H. Liu, C. Madrid, B. Mcmaster, N. Pastika, C. Smith

Catholic University of America, Washington DC, USA
R. Bartek, A. Dominguez

The University of Alabama, Tuscaloosa, USA
A. Buccilli, S.I. Cooper, C. Henderson, P. Rumerio, C. West

Boston University, Boston, USA
D. Arcaro, T. Bose, D. Gastler, D. Rankin, C. Richardson, J. Rohlf, L. Sulak, D. Zou

Brown University, Providence, USA
G. Benelli, X. Coubez, D. Cutts, M. Hadley, J. Hakala, U. Heintz, J.M. Hogan[64], K.H.M. Kwok, E. Laird, G. Landsberg, J. Lee, Z. Mao, M. Narain, J. Pazzini, S. Piperov, S. Sagir[65], R. Syarif, E. Usai, D. Yu

University of California, Davis, Davis, USA
R. Band, C. Brainerd, R. Breedon, D. Burns, M. Calderon De La Barca Sanchez, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, C. Flores, G. Funk, W. Ko, O. Kukral, R. Lander, C. Mclean, M. Mulhearn, D. Pellett, J. Pilot, S. Shalhout, M. Shi, D. Stolp, D. Taylor, K. Tos, M. Tripathi, Z. Wang, F. Zhang

University of California, Los Angeles, USA
M. Bachtis, C. Bravo, R. Cousins, A. Dasgupta, A. Florent, J. Hauser, M. Ignatenko, N. Mccoll, S. Regnard, D. Saltzberg, C. Schnaible, V. Valuev

University of California, Riverside, Riverside, USA
E. Bouvier, K. Burt, R. Clare, J.W. Gary, S.M.A. Ghiasi Shirazi, G. Hanson, G. Karapostoli, E. Kennedy, F. Lacroix, O.R. Long, M. Olmedo Negrete, M.I. Paneva, W. Si, L. Wang, H. Wei, S. Wimpenny, B.R. Yates

University of California, San Diego, La Jolla, USA
J.G. Branson, S. Cittolin, M. Derdzinski, R. Gerosa, D. Gilbert, B. Hashemi, A. Holzner, D. Klein, G. Kole, V. Krutelyov, J. Letts, M. Masciovecchio, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech[66], J. Wood, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara - Department of Physics, Santa Barbara, USA
N. Amin, R. Bhandari, J. Bradmiller-Feld, C. Campagnari, M. Citron, A. Dishaw, V. Dutta, M. Franco Sevilla, L. Gouskos, R. Heller, J. Incandela, A. Ovcharova, H. Qu, J. Richman, D. Stuart, I. Suarez, S. Wang, J. Yoo

California Institute of Technology, Pasadena, USA
D. Anderson, A. Bornheim, J.M. Lawhorn, H.B. Newman, T.Q. Nguyen, M. Spiropulu, J.R. Vlimant, R. Wilkinson, S. Xie, Z. Zhang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
M.B. Andrews, T. Ferguson, T. Mudholkar, M. Paulini, M. Sun, I. Vorobiev, M. Weinberg

University of Colorado Boulder, Boulder, USA
J.P. Cumalat, W.T. Ford, F. Jensen, A. Johnson, M. Krohn, S. Leontsinis, E. MacDonald, T. Mulholland, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, J. Chaves, Y. Cheng, J. Chu, A. Datta, K. Mcdermott, N. Mirman, J.R. Patterson, D. Quach, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, S.M. Tan, Z. Tao, J. Thom, J. Tucker, P. Wittich, M. Zientek

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, M. Alyari, G. Apollinari, A. Apresyan, A. Apyan, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla[†], K. Burkett, J.N. Butler, A. Canepa, G.B. Cerati, H.W.K. Cheung, F. Chlebana, M. Cremonesi, J. Duarte, V.D. Elvira, J. Freeman, Z. Gecse, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, M.J. Kortelainen, B. Kreis, S. Lammel, D. Lincoln, R. Lipton, M. Liu, T. Liu, J. Lykken, K. Maeshima, J.M. Marraffino, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, V. O'Dell, K. Pedro, C. Pena, O. Prokofyev, G. Rakness, L. Ristori, A. Savoy-Navarro[67], B. Schneider, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, S. Stoynev, J. Strait, N. Strobbe, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, M. Wang, H.A. Weber, A. Whitbeck

University of Florida, Gainesville, USA
D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Brinkerhoff, L. Cadamuro, A. Carnes, M. Carver, D. Curry, R.D. Field, S.V. Gleyzer, B.M. Joshi, J. Konigsberg, A. Korytov, P. Ma, K. Matchev, H. Mei, G. Mitselmakher, K. Shi, D. Sperka, J. Wang, S. Wang

Florida International University, Miami, USA
Y.R. Joshi, S. Linn

Florida State University, Tallahassee, USA
A. Ackert, T. Adams, A. Askew, S. Hagopian, V. Hagopian, K.F. Johnson, T. Kolberg, G. Martinez, T. Perry, H. Prosper, A. Saha, A. Santra, V. Sharma, R. Yohay

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, V. Bhopatkar, S. Colafranceschi, M. Hohlmann, D. Noonan, M. Rahmani, T. Roy, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, R. Cavanaugh, X. Chen, S. Dittmer, O. Evdokimov, C.E. Gerber, D.A. Hangal, D.J. Hofman, K. Jung, J. Kamin, C. Mills, I.D. Sandoval Gonzalez, M.B. Tonjes, N. Varelas, H. Wang, X. Wang, Z. Wu, J. Zhang

The University of Iowa, Iowa City, USA
M. Alhusseini, B. Bilki[68], W. Clarida, K. Dilsiz[69], S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul[70], Y. Onel, F. Ozok[71], A. Penzo, C. Snyder, E. Tiras, J. Wetzel

Johns Hopkins University, Baltimore, USA
B. Blumenfeld, A. Cocoros, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, W.T. Hung, P. Maksimovic, J. Roskes, U. Sarica, M. Swartz, M. Xiao, C. You

The University of Kansas, Lawrence, USA
A. Al-bataineh, P. Baringer, A. Bean, S. Boren, J. Bowen, A. Bylinkin, J. Castle, S. Khalil, A. Kropivnitskaya, D. Majumder, W. Mcbrayer, M. Murray, C. Rogan, S. Sanders, E. Schmitz, J.D. Tapia Takaki, Q. Wang

Kansas State University, Manhattan, USA
A. Ivanov, K. Kaadze, D. Kim, Y. Maravin, D.R. Mendis, T. Mitchell, A. Modak, A. Mohammadi, L.K. Saini, N. Skhirtladze

Lawrence Livermore National Laboratory, Livermore, USA
F. Rebassoo, D. Wright

University of Maryland, College Park, USA
A. Baden, O. Baron, A. Belloni, S.C. Eno, Y. Feng, C. Ferraioli, N.J. Hadley, S. Jabeen, G.Y. Jeng, R.G. Kellogg, J. Kunkle, A.C. Mignerey, F. Ricci-Tam, Y.H. Shin, A. Skuja, S.C. Tonwar, K. Wong

Massachusetts Institute of Technology, Cambridge, USA
D. Abercrombie, B. Allen, V. Azzolini, A. Baty, G. Bauer, R. Bi, S. Brandt, W. Busza, I.A. Cali, M. D'Alfonso, Z. Demiragli, G. Gomez Ceballos, M. Goncharov, P. Harris, D. Hsu, M. Hu, Y. Iiyama, G.M. Innocenti, M. Klute, D. Kovalskyi, Y.-J. Lee, P.D. Luckey, B. Maier, A.C. Marini, C. Mcginn, C. Mironov, S. Narayanan, X. Niu, C. Paus, C. Roland, G. Roland, G.S.F. Stephans, K. Sumorok, K. Tatar, D. Velicanu, J. Wang, T.W. Wang, B. Wyslouch, S. Zhaozhong

University of Minnesota, Minneapolis, USA
A.C. Benvenuti, R.M. Chatterjee, A. Evans, P. Hansen, S. Kalafut, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, J. Turkewitz, M.A. Wadud

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

University of Nebraska-Lincoln, Lincoln, USA
E. Avdeeva, K. Bloom, D.R. Claes, C. Fangmeier, F. Golf, R. Gonzalez Suarez, R. Kamalieddin, I. Kravchenko, J. Monroy, J.E. Siado, G.R. Snow, B. Stieger

State University of New York at Buffalo, Buffalo, USA
A. Godshalk, C. Harrington, I. Iashvili, A. Kharchilava, D. Nguyen, A. Parker, S. Rappoccio, B. Roozbahani

Northeastern University, Boston, USA
G. Alverson, E. Barberis, C. Freer, A. Hortiangtham, D.M. Morse, T. Orimoto, R. Teixeira De Lima, T. Wamorkar, B. Wang, A. Wisecarver, D. Wood

Northwestern University, Evanston, USA
S. Bhattacharya, O. Charaf, K.A. Hahn, N. Mucia, N. Odell, M.H. Schmitt, K. Sung, M. Trovato, M. Velasco

University of Notre Dame, Notre Dame, USA
R. Bucci, N. Dev, M. Hildreth, K. Hurtado Anampa, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, W. Li, N. Loukas, N. Marinelli, F. Meng, C. Mueller, Y. Musienko[35], M. Planer, A. Reinsvold, R. Ruchti, P. Siddireddy, G. Smith, S. Taroni, M. Wayne, A. Wightman, M. Wolf, A. Woodard

The Ohio State University, Columbus, USA
J. Alimena, L. Antonelli, B. Bylsma, L.S. Durkin, S. Flowers, B. Francis, A. Hart, C. Hill, W. Ji, T.Y. Ling, W. Luo, B.L. Winer, H.W. Wulsin

Princeton University, Princeton, USA
S. Cooperstein, P. Elmer, J. Hardenbrook, P. Hebda, S. Higginbotham, A. Kalogeropoulos, D. Lange, M.T. Lucchini, J. Luo, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, P. Piroué, J. Salfeld-Nebgen, D. Stickland, C. Tully

University of Puerto Rico, Mayaguez, USA
S. Malik, S. Norberg

Purdue University, West Lafayette, USA
A. Barker, V.E. Barnes, S. Das, L. Gutay, M. Jones, A.W. Jung, A. Khatiwada, B. Mahakud, D.H. Miller, N. Neumeister, C.C. Peng, H. Qiu, J.F. Schulte, J. Sun, F. Wang, R. Xiao, W. Xie

Purdue University Northwest, Hammond, USA
T. Cheng, J. Dolen, N. Parashar

Rice University, Houston, USA
Z. Chen, K.M. Ecklund, S. Freed, F.J.M. Geurts, M. Kilpatrick, W. Li, B. Michlin, B.P. Padley, J. Roberts, J. Rorie, W. Shi, Z. Tu, J. Zabel, A. Zhang

University of Rochester, Rochester, USA
A. Bodek, P. de Barbaro, R. Demina, Y.t. Duh, J.L. Dulemba, C. Fallon, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, O. Hindrichs, A. Khukhunaishvili, K.H. Lo, P. Tan, R. Taus, M. Verzetti

Rutgers, The State University of New Jersey, Piscataway, USA
A. Agapitos, J.P. Chou, Y. Gershtein, T.A. Gómez Espinosa, E. Halkiadakis, M. Heindl, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, S. Kyriacou, A. Lath, R. Montalvo, K. Nash, M. Osherson, H. Saka, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, USA
A.G. Delannoy, J. Heideman, G. Riley, K. Rose, S. Spanier, K. Thapa

Texas A&M University, College Station, USA
O. Bouhali[72], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon[73], S. Luo, R. Mueller, Y. Pakhotin, R. Patel, A. Perloff, L. Perniè, D. Rathjens, A. Safonov, A. Tatarinov

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, F. De Guio, P.R. Dudero, S. Kunori, K. Lamichhane, S.W. Lee, T. Mengke, S. Muthumuni, T. Peltola, S. Undleeb, I. Volobouev, Z. Wang

Vanderbilt University, Nashville, USA
S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, A. Melo, H. Ni, K. Padeken, J.D. Ruiz Alvarez, P. Sheldon, S. Tuo, J. Velkovska, M. Verweij, Q. Xu

University of Virginia, Charlottesville, USA
M.W. Arenton, P. Barria, B. Cox, R. Hirosky, M. Joyce, A. Ledovskoy, H. Li, C. Neu, T. Sinthuprasith, Y. Wang, E. Wolfe, F. Xia

Wayne State University, Detroit, USA
R. Harr, P.E. Karchin, N. Poudyal, J. Sturdy, P. Thapa, S. Zaleski

University of Wisconsin - Madison, Madison, WI, USA
M. Brodski, J. Buchanan, C. Caillol, D. Carlsmith, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe, M. Herndon, A. Hervé, U. Hussain, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, T. Ruggles, A. Savin, N. Smith, W.H. Smith, N. Woods

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
3: Also at Universidade Estadual de Campinas, Campinas, Brazil
4: Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
5: Also at Université Libre de Bruxelles, Bruxelles, Belgium
6: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
7: Also at Joint Institute for Nuclear Research, Dubna, Russia
8: Now at Helwan University, Cairo, Egypt
9: Now at Fayoum University, El-Fayoum, Egypt
10: Also at British University in Egypt, Cairo, Egypt
11: Now at Ain Shams University, Cairo, Egypt
12: Also at Department of Physics, King Abdulaziz University, Jeddah, Saudi Arabia
13: Also at Université de Haute Alsace, Mulhouse, France
14: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
15: Also at Tbilisi State University, Tbilisi, Georgia
16: Also at Ilia State University, Tbilisi, Georgia
17: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
18: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
19: Also at University of Hamburg, Hamburg, Germany
20: Also at Brandenburg University of Technology, Cottbus, Germany
21: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
22: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary

23: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary
24: Also at Indian Institute of Technology Bhubaneswar, Bhubaneswar, India
25: Also at Institute of Physics, Bhubaneswar, India
26: Also at Shoolini University, Solan, India
27: Also at University of Visva-Bharati, Santiniketan, India
28: Also at Isfahan University of Technology, Isfahan, Iran
29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
30: Also at Università degli Studi di Siena, Siena, Italy
31: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
32: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
33: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
34: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
35: Also at Institute for Nuclear Research, Moscow, Russia
36: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
37: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
38: Also at University of Florida, Gainesville, USA
39: Also at P.N. Lebedev Physical Institute, Moscow, Russia
40: Also at California Institute of Technology, Pasadena, USA
41: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
42: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
43: Also at INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
44: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
45: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
46: Also at National and Kapodistrian University of Athens, Athens, Greece
47: Also at Riga Technical University, Riga, Latvia
48: Also at Universität Zürich, Zurich, Switzerland
49: Also at Stefan Meyer Institute for Subatomic Physics (SMI), Vienna, Austria
50: Also at Adiyaman University, Adiyaman, Turkey
51: Also at Istanbul Aydin University, Istanbul, Turkey
52: Also at Mersin University, Mersin, Turkey
53: Also at Piri Reis University, Istanbul, Turkey
54: Also at Gaziosmanpasa University, Tokat, Turkey
55: Also at Ozyegin University, Istanbul, Turkey
56: Also at Izmir Institute of Technology, Izmir, Turkey
57: Also at Marmara University, Istanbul, Turkey
58: Also at Kafkas University, Kars, Turkey
59: Also at Istanbul Bilgi University, Istanbul, Turkey
60: Also at Hacettepe University, Ankara, Turkey
61: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
62: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
63: Also at Monash University, Faculty of Science, Clayton, Australia
64: Also at Bethel University, St. Paul, USA
65: Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
66: Also at Utah Valley University, Orem, USA
67: Also at Purdue University, West Lafayette, USA

68: Also at Beykent University, Istanbul, Turkey
69: Also at Bingol University, Bingol, Turkey
70: Also at Sinop University, Sinop, Turkey
71: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
72: Also at Texas A&M University at Qatar, Doha, Qatar
73: Also at Kyungpook National University, Daegu, Korea