EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2021-020
2021/02/10

CMS-BPH-20-004

Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$

The CMS Collaboration*

Abstract

The $\Xi_b^- \pi^+ \pi^-$ invariant mass spectrum is investigated with an event sample of proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$, collected by the CMS experiment at the LHC in 2016–2018 and corresponding to an integrated luminosity of $140\,\text{fb}^{-1}$. The ground state Ξ_b^- is reconstructed via its decays to $J/\psi\Xi^-$ and $J/\psi\Lambda K^-$. A narrow resonance, labeled $\Xi_b(6100)^-$, is observed at a $\Xi_b^- \pi^+ \pi^-$ invariant mass of $6100.3 \pm 0.2\,(\text{stat}) \pm 0.1\,(\text{syst}) \pm 0.6\,(\Xi_b^-)\,\text{MeV}$, where the last uncertainty reflects the precision of the Ξ_b^- baryon mass. The upper limit on the $\Xi_b(6100)^-$ natural width is determined to be 1.9 MeV at 95% confidence level. Following analogies with the established excited Ξ_c baryon states, the new $\Xi_b(6100)^-$ resonance and its decay sequence are consistent with the orbitally excited Ξ_b^- baryon, with spin and parity quantum numbers $J^P = 3/2^-$.

Submitted to Physical Review Letters

*See Appendix A for the list of collaboration members

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

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

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

Events of interest are selected using a two-tiered trigger system. The first level (L1), composed of custom hardware processors, uses information from the calorimeters and muon detectors [26]. The second level, known as the high-level trigger (HLT), consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing [27]. The events used in the analysis were selected at L1 by requiring the presence of at least two muons, and at HLT by requiring that the two muons have opposite sign (OS), with various thresholds on the pseudorapidity η and transverse momentum p_T, compatible with being produced in the dimuon decay of J/ψ mesons.

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

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

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

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

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

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

The invariant mass distributions of the selected Ξ_b^- candidates are shown in Fig. 1 for the $J/\psi\Xi^-$

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

The signal yields from the fits described above are 859 ± 36 and 815 ± 74 for the $\Xi_b^- \to J/\psi\Xi^-$ and fully reconstructed $\Xi_b^- \to J/\psi\Lambda K^-$ decay modes, respectively, with the uncertainties being statistical only. The fitted Ξ_b^- masses are consistent with each other and with the world-average value, $5797.0 \pm 0.6\,\text{MeV}$ [20]. The signal components corresponding to fully reconstructed Ξ_b^- candidates are shown by the solid green curves. The fitted yield of the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ contribution, reconstructed as $J/\psi\Lambda K^-$, is 820 ± 158, represented by the dotted-dashed curve in Fig. 1 (right). The Ξ_b^- fit results illustrate this part of the reconstruction procedure and provide the first confirmation of the $\Xi_b^- \to J/\psi\Lambda K^-$ decay observed by LHCb [24].

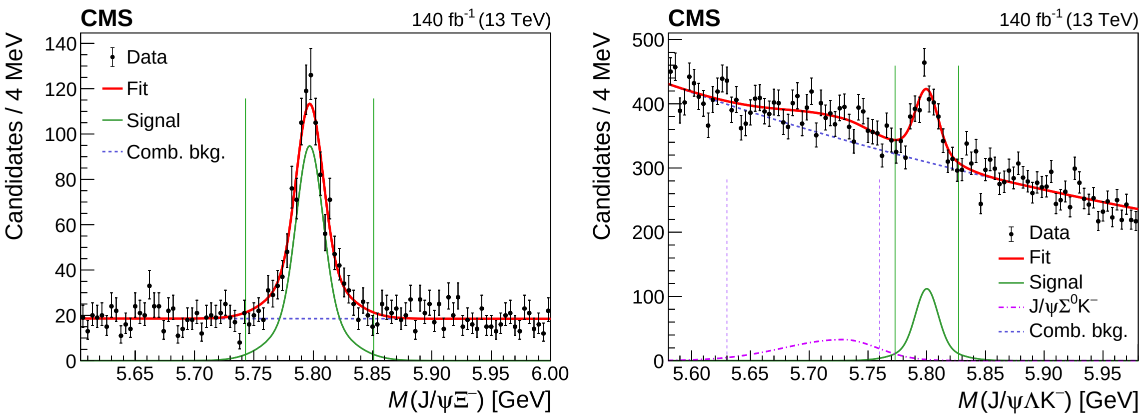

Figure 1: Invariant mass distributions of the selected Ξ_b^- candidates in the $J/\psi\Xi^-$ (left) and $J/\psi\Lambda K^-$ (right) decay channels with the fit results superimposed. The vertical solid (dashed) lines show the mass windows discussed in the text and used in the reconstruction of the $\Xi_b^-\pi^+\pi^-$ candidates in $J/\psi\Xi^-$ and $J/\psi\Lambda K^-$ ($J/\psi\Sigma^0 K^-$) channels.

When reconstructing $\Xi_b^-\pi^+\pi^-$ candidates, we select events with Ξ_b^- invariant mass within 54 (27) MeV of the fitted Ξ_b^- mass for the $J/\psi\Xi^-$ ($J/\psi\Lambda K^-$) channel, corresponding to approximately 2.8 (1.8) times the mass resolution, as shown by the vertical solid lines in Fig. 1. The $5.63 < M(J/\psi\Lambda K^-) < 5.76\,\text{GeV}$ mass region is used for the partially reconstructed $\Xi_b^- \to J/\psi\Sigma^0 K^-$ decay mode, shown by the dashed vertical lines in Fig. 1 (right). These mass ranges are selected through the same optimization procedure as used for the other selection criteria.

Since the lifetime of the excited Ξ_b states is expected to be negligible, the $\Xi_b^-\pi^+\pi^-$ candidates are formed by combining the selected Ξ_b^- candidates with two OS tracks originating from the PV, as in Refs. [37–40]. Combinations of a Ξ_b^- candidate with two SS pions from the PV are used as a control channel and form the SS control region. The analysis is performed using the mass difference variable $\Delta M = M(\Xi_b^-\pi^+\pi^-) - M(\Xi_b^-) - 2\,m_{\pi^\pm}^{\text{PDG}}$, which has a better mass resolution than $M(\Xi_b^-\pi^+\pi^-)$, where $M(\Xi_b^-)$ represents the reconstructed Ξ_b^- mass. According to the simulation studies, this variable also has the advantage of being insensitive to a potential mass shift caused by the fact that the photon emitted in the $\Xi_b^- \to J/\psi\Sigma^0 K^-$, $\Sigma^0 \to \Lambda\gamma$ decay sequence is not reconstructed. Following the technique developed in Ref. [40], the selected Ξ_b^- candidate and all tracks forming the PV are refit to a common vertex, further improving the $\Xi_b^-\pi^+\pi^-$ invariant mass resolution of the fully reconstructed channels from 1.39 ± 0.11 to 0.94 ± 0.06 MeV (statistical uncertainties only), as obtained from simulation studies.

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

The invariant mass distribution of the selected $\Xi_b^-\pi^+\pi^-$ candidates is shown in Fig. 2, using the mass difference variable ΔM. The left plot combines the data from the $\Xi_b^- \to \mathrm{J}/\psi\Xi^-$ and $\Xi_b^- \to \mathrm{J}/\psi\Lambda\mathrm{K}^-$ channels, which have identical mass resolutions, according to simulation studies (the Ξ_b^- is fully reconstructed in both channels). The right plot shows the events that use the partially reconstructed $\Xi_b^- \to \mathrm{J}/\psi\Sigma^0\mathrm{K}^-$ channel, with a 30% larger mass resolution. Given the definition of the ΔM variable, the mean mass of the signal peaks should not depend on the Ξ_b^- reconstruction channel.

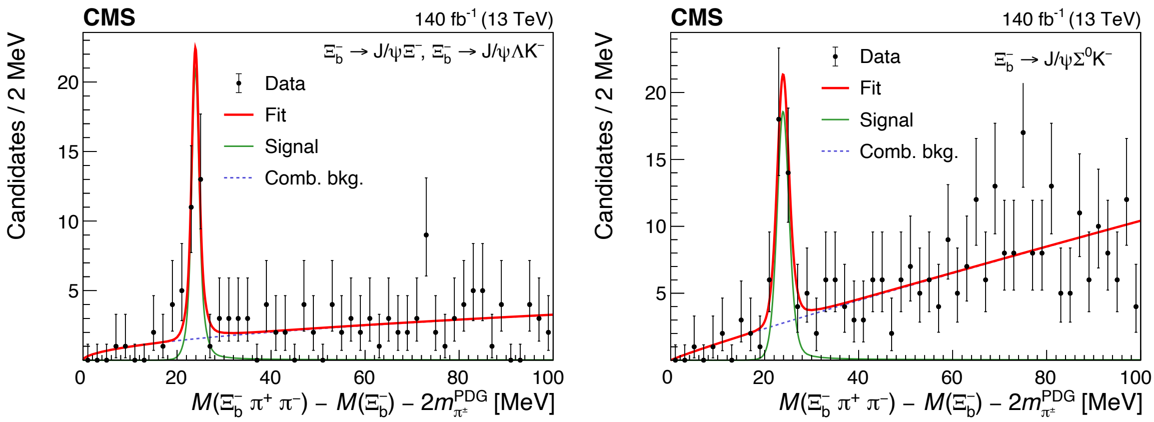

Figure 2: Distributions of the invariant mass difference ΔM for the selected $\Xi_b^-\pi^+\pi^-$ candidates, with the Ξ_b^- reconstructed in the $\mathrm{J}/\psi\Xi^-$ and $\mathrm{J}/\psi\Lambda\mathrm{K}^-$ channels (left) or partially reconstructed in the $\mathrm{J}/\psi\Sigma^0\mathrm{K}^-$ channel (right). The result of the simultaneous fit is also shown.

A narrow peak is seen near the threshold of the $\Xi_b^-\pi^+\pi^-$ system in both plots of Fig. 2. The excess is also visible in each of the two independent decay channels, $\mathrm{J}/\psi\Xi^-$ and $\mathrm{J}/\psi\Lambda\mathrm{K}^-$. We have also studied the OS and SS distributions in a wider range of ΔM (up to 280 MeV) and found no other significant peaks. A simultaneous unbinned extended maximum-likelihood fit is performed on the two data samples shown in Fig. 2, the result being represented by the red curves. The signal component is described with a relativistic Breit–Wigner (RBW) function [42, 43] for the $\Xi_b(6100)^- \to \Xi_b^{*0}\pi^-$ decay, convolved with a double-Gaussian resolution function. The mass and natural width of the signal function are the two parameters of interest in the fit. The normalization and background parameters are different for the fully and partially reconstructed channels, as are the resolution parameters, which are fixed from the simulation studies. The background component is modeled with the threshold function $(\Delta M)^\alpha$, where α is a free parameter.

The fitted mass difference of the new $\Xi_b(6100)^-$ state is $\Delta M_{\Xi_b(6100)^-} = 24.14 \pm 0.22\,\mathrm{MeV}$, where the uncertainty is statistical only. The fitted signal yields are 26 ± 7 and 34 ± 9 for the fully reconstructed and the $\Xi_b^- \to J/\psi \Sigma^0 K^-$ channels, respectively. The natural width of the $\Xi_b(6100)^-$ is too small to be measured with the present data sample and experimental resolution. An upper limit on $\Gamma(\Xi_b(6100)^-)$ has been obtained through a scan of the profiled likelihood, assuming an asymptotic distribution. The measured upper limit, at 95% confidence level, is $\Gamma(\Xi_b(6100)^-) < 1.9\,\mathrm{MeV}$, where the systematic uncertainties, discussed below, are taken into account.

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

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

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

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

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

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

The total systematic uncertainty in the measured mass difference $\Delta M_{\Xi_b(6100)^-}$, calculated as the sum in quadrature of the partial terms, is 0.05 MeV.

In summary, we report the observation of a new excited beauty strange baryon, decaying to $\Xi_b^- \pi^+ \pi^-$. The analysis uses proton-proton collision data collected by the CMS experiment at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of $140\,\mathrm{fb}^{-1}$. The measured mass difference of this state is $M(\Xi_b(6100)^-) - M(\Xi_b^-) - 2\,m_{\pi^\pm}^{PDG} = 24.14 \pm 0.22\,(stat) \pm 0.05\,(syst)$ MeV. The known Ξ_b^- mass of 5797.0 ± 0.6 MeV [20] is used to obtain $M(\Xi_b(6100)^-) = 6100.3 \pm 0.2\,(stat) \pm 0.1\,(syst) \pm 0.6\,(\Xi_b^-)$ MeV. It is particularly remarkable that if the $\Xi_b(6100)^-$ baryon were only 13 MeV heavier, it would be above the $\Lambda_b^0 K^-$ mass threshold and could decay to this final state. The natural width of this resonance is compatible with zero and a 95% confidence level upper limit of 1.9 MeV has been determined.

Following analogies with the established excited Ξ_c baryon states [20], and considering several theoretical predictions [12, 13, 21], the new $\Xi_b(6100)^-$ resonance and its decay sequence are consistent with the orbitally excited Ξ_b^- baryon, with the light diquark spin $j_{qs} = 1$ and $J^P = 3/2^-$. This suggests that it is the beauty analogue of the $\Xi_c(2815)$ baryon [41]. The observation of this baryon and the measurement of its properties provide information that should help to distinguish between different theoretical models used to calculate the properties of the excited Ξ_b states.

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 and other centers for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC, the CMS detector, and the supporting computing infrastructure provided by the following funding agencies: BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); MoER, ERC PUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); NKFIA (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, RosAtom, RAS, RFBR, and NRC KI (Russia); MESTD (Serbia); SEIDI, CPAN, PCTI, and FEDER (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR, and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Individuals have received support from the Marie-Curie program and the European Research Council and Horizon 2020 Grant, contract Nos. 675440, 724704, 752730, and 765710 (European Union); the Leventis Foundation; the Alfred P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the F.R.S.-FNRS and FWO (Belgium) under the "Excellence of Science – EOS" – be.h project n. 30820817; the Beijing Municipal Science & Technology Commission, No. Z191100007219010; the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Deutsche Forschungsgemeinschaft (DFG), under Germany's Excellence Strategy – EXC 2121 "Quantum Universe" – 390833306, and under project number 400140256 - GRK2497; the Lendület ("Momentum") Program and the János Bolyai Research Scholarship of the Hungarian

Academy of Sciences, the New National Excellence Program ÚNKP, the NKFIA research grants 123842, 123959, 124845, 124850, 125105, 128713, 128786, and 129058 (Hungary); the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus program of the Ministry of Science and Higher Education, the National Science Center (Poland), contracts Harmonia 2014/14/M/ST2/00428, Opus 2014/13/B/ST2/02543, 2014/15/B/ST2/03998, and 2015/19/B/ST2/02861, Sonata-bis 2012/07/E/ST2/01406; the National Priorities Research Program by Qatar National Research Fund; the Ministry of Science and Higher Education, project no. 14.W03.31.0026 (Russia); the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia María de Maeztu, grant MDM-2015-0509 and the Programa Severo Ochoa del Principado de Asturias; the Thalis and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); the Kavli Foundation; the Nvidia Corporation; the SuperMicro Corporation; the Welch Foundation, contract C-1845; and the Weston Havens Foundation (USA).

References

[1] D. Ebert, T. Feldmann, C. Kettner, and H. Reinhardt, "A diquark model for baryons containing one heavy quark", *Z. Phys. C* **71** (1996) 329, doi:10.1007/BF02906991, arXiv:hep-ph/9506298.

[2] D. Ebert, R. N. Faustov, and V. O. Galkin, "Masses of excited heavy baryons in the relativistic quark model", *Phys. Lett. B* **659** (2008) 612, doi:10.1016/j.physletb.2007.11.037, arXiv:0705.2957.

[3] E. E. Jenkins, "Model-independent bottom baryon mass predictions in the 1/N(*c*) expansion", *Phys. Rev. D* **77** (2008) 034012, doi:10.1103/PhysRevD.77.034012, arXiv:0712.0406.

[4] M. Karliner, B. Keren-Zur, H. J. Lipkin, and J. L. Rosner, "The quark model and b baryons", *Annals Phys.* **324** (2009) 2, doi:10.1016/j.aop.2008.05.003, arXiv:0804.1575.

[5] W. Roberts and M. Pervin, "Heavy baryons in a quark model", *Int. J. Mod. Phys. A* **23** (2008) 2817, doi:10.1142/S0217751X08041219, arXiv:0711.2492.

[6] D. Ebert, R. N. Faustov, and V. O. Galkin, "Spectroscopy and Regge trajectories of heavy baryons in the relativistic quark-diquark picture", *Phys. Rev. D* **84** (2011) 014025, doi:10.1103/PhysRevD.84.014025, arXiv:1105.0583.

[7] H. Garcilazo, J. Vijande, and A. Valcarce, "Faddeev study of heavy baryon spectroscopy", *J. Phys. G* **34** (2007) 961, doi:10.1088/0954-3899/34/5/014, arXiv:hep-ph/0703257.

[8] B. Chen, K.-W. Wei, and A. Zhang, "Assignments of Λ_Q and Ξ_Q baryons in the heavy quark-light diquark picture", *Eur. Phys. J. A* **51** (2015) 82, doi:10.1140/epja/i2015-15082-3, arXiv:1406.6561.

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

[10] Q. Mao et al., "QCD sum rule calculation for P-wave bottom baryons", *Phys. Rev. D* **92** (2015) 114007, doi:10.1103/PhysRevD.92.114007, arXiv:1510.05267.

[11] Z.-G. Wang, "Analysis of the $1/2^-$ and $3/2^-$ heavy and doubly heavy baryon states with QCD sum rules", *Eur. Phys. J. A* **47** (2011) 81, doi:10.1140/epja/i2011-11081-8, arXiv:1003.2838.

[12] K.-L. Wang, Y.-X. Yao, X.-H. Zhong, and Q. Zhao, "Strong and radiative decays of the low-lying *S*- and *P*-wave singly heavy baryons", *Phys. Rev. D* **96** (2017) 116016, doi:10.1103/PhysRevD.96.116016, arXiv:1709.04268.

[13] Y. Kawakami and M. Harada, "Singly heavy baryons with chiral partner structure in a three-flavor chiral model", *Phys. Rev. D* **99** (2019) 094016, doi:10.1103/PhysRevD.99.094016, arXiv:1902.06774.

[14] Z.-Y. Wang, J.-J. Qi, X.-H. Guo, and K.-W. Wei, "Spectra of charmed and bottom baryons with hyperfine interaction", *Chin. Phys. C* **41** (2017) 093103, doi:10.1088/1674-1137/41/9/093103, arXiv:1701.04524.

[15] K. Thakkar, Z. Shah, A. K. Rai, and P. C. Vinodkumar, "Excited state mass spectra and Regge trajectories of bottom baryons", *Nucl. Phys. A* **965** (2017) 57, doi:10.1016/j.nuclphysa.2017.05.087, arXiv:1610.00411.

[16] K.-W. Wei et al., "Spectroscopy of singly, doubly, and triply bottom baryons", *Phys. Rev. D* **95** (2017) 116005, doi:10.1103/PhysRevD.95.116005, arXiv:1609.02512.

[17] CMS Collaboration, "Observation of a new Ξ_b baryon", *Phys. Rev. Lett.* **108** (2012) 252002, doi:10.1103/PhysRevLett.108.252002, arXiv:1204.5955.

[18] LHCb Collaboration, "Measurement of the properties of the Ξ_b^{*0} baryon", *JHEP* **05** (2016) 161, doi:10.1007/JHEP05(2016)161, arXiv:1604.03896.

[19] LHCb Collaboration, "Observation of two new Ξ_b^- baryon resonances", *Phys. Rev. Lett.* **114** (2015) 062004, doi:10.1103/PhysRevLett.114.062004, arXiv:1411.4849.

[20] Particle Data Group, P. A. Zyla et al., "Review of particle physics", *Prog. Theor. Exp. Phys.* **2020** (2020) 083C01, doi:10.1093/ptep/ptaa104.

[21] B. Chen, K.-W. Wei, X. Liu, and A. Zhang, "Role of newly discovered $\Xi_b(6227)^-$ for constructing excited bottom baryon family", *Phys. Rev. D* **98** (2018) 031502, doi:10.1103/PhysRevD.98.031502, arXiv:1805.10826.

[22] LHCb Collaboration, "Observation of a new Ξ_b^- resonance", *Phys. Rev. Lett.* **121** (2018) 072002, doi:10.1103/PhysRevLett.121.072002, arXiv:1805.09418.

[23] LHCb Collaboration, "Observation of a new Ξ_b^0 state", *Phys. Rev. D* **103** (2021) 012004, doi:10.1103/PhysRevD.103.012004, arXiv:2010.14485.

[24] LHCb Collaboration, "Observation of the $\Xi_b^- \to J/\psi \Lambda K^-$ decay", *Phys. Lett. B* **772** (2017) 265, doi:10.1016/j.physletb.2017.06.045, arXiv:1701.05274.

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

[26] CMS Collaboration, "Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$", *JINST* **15** (2020) P10017, doi:10.1088/1748-0221/15/10/P10017, arXiv:2006.10165.

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

[28] T. Sjöstrand et al., "An introduction to PYTHIA 8.2", *Comput. Phys. Commun.* **191** (2015) 159, doi:10.1016/j.cpc.2015.01.024, arXiv:1410.3012.

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

[30] E. Barberio, B. van Eijk, and Z. Wąs, "PHOTOS: A universal Monte Carlo for QED radiative corrections in decays", *Comput. Phys. Commun.* **66** (1991) 115, doi:10.1016/0010-4655(91)90012-A.

[31] E. Barberio and Z. Wąs, "PHOTOS: A universal Monte Carlo for QED radiative corrections. Version 2.0", *Comput. Phys. Commun.* **79** (1994) 291, doi:10.1016/0010-4655(94)90074-4.

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

[33] G. Punzi, "Sensitivity of searches for new signals and its optimization", in *Proceedings of PHYSTAT 2003, Statistical problems in particle physics, astrophysics and cosmology*, p. MODT002. 2003. arXiv:physics/0308063. eConf C030908.

[34] CMS Collaboration, "Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV", *JINST* **13** (2018) P06015, doi:10.1088/1748-0221/13/06/P06015, arXiv:1804.04528.

[35] CMS Collaboration, "CMS tracking performance results from early LHC operation", *Eur. Phys. J. C* **70** (2010) 1165, doi:10.1140/epjc/s10052-010-1491-3, arXiv:1007.1988.

[36] CMS Collaboration, "Description and performance of track and primary-vertex reconstruction with the CMS tracker", *JINST* **9** (2014) P10009, doi:10.1088/1748-0221/9/10/P10009, arXiv:1405.6569.

[37] CMS Collaboration, "Search for the X(5568) state decaying into $\mathrm{B_s^0}\pi^{\pm}$ in proton-proton collisions at $\sqrt{s} = 8$ TeV", *Phys. Rev. Lett.* **120** (2018) 202005, doi:10.1103/PhysRevLett.120.202005, arXiv:1712.06144.

[38] CMS Collaboration, "Studies of $\mathrm{B_{s2}^*}(5840)^0$ and $\mathrm{B_{s1}}(5830)^0$ mesons including the observation of the $\mathrm{B_{s2}^*}(5840)^0 \to \mathrm{B^0 K_S^0}$ decay in proton-proton collisions at $\sqrt{s} = 8$ TeV", *Eur. Phys. J. C* **78** (2018) 939, doi:10.1140/epjc/s10052-018-6390-z, arXiv:1809.03578.

[39] CMS Collaboration, "Observation of two excited $\mathrm{B_c^+}$ states and measurement of the $\mathrm{B_c^+}$(2S) mass in pp collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **122** (2019) 132001, doi:10.1103/PhysRevLett.122.132001, arXiv:1902.00571.

[40] CMS Collaboration, “Study of excited Λ_b^0 states decaying to $\Lambda_b^0\pi^+\pi^-$ in proton-proton collisions at $\sqrt{s} = 13$ TeV”, *Phys. Lett. B* **803** (2020) 135345, doi:10.1016/j.physletb.2020.135345, arXiv:2001.06533.

[41] CLEO Collaboration, “Evidence of new states decaying into $\Xi_c^*\pi$”, *Phys. Rev. Lett.* **83** (1999) 3390, doi:10.1103/PhysRevLett.83.3390, arXiv:hep-ex/9906013.

[42] J. D. Jackson, “Remarks on the phenomenological analysis of resonances”, *Nuovo Cim.* **34** (1964) 1644, doi:10.1007/BF02750563.

[43] J. M. Blatt and V. F. Weisskopf, “Theoretical nuclear physics”. Springer, New York, 1952. doi:10.1007/978-1-4612-9959-2, ISBN 978-0-471-08019-0.

[44] S. S. Wilks, “The large-sample distribution of the likelihood ratio for testing composite hypotheses”, *Annals Math. Statist.* **9** (1938) 60, doi:10.1214/aoms/1177732360.

[45] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, “Asymptotic formulae for likelihood-based tests of new physics”, *Eur. Phys. J. C* **71** (2011) 1554, doi:10.1140/epjc/s10052-011-1554-0, arXiv:1007.1727. [Erratum: doi:10.1140/epjc/s10052-013-2501-z].

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
A.M. Sirunyan[†], A. Tumasyan

Institut für Hochenergiephysik, Wien, Austria
W. Adam, J.W. Andrejkovic, T. Bergauer, S. Chatterjee, M. Dragicevic, A. Escalante Del Valle, R. Frühwirth[1], M. Jeitler[1], N. Krammer, L. Lechner, D. Liko, I. Mikulec, F.M. Pitters, J. Schieck[1], R. Schöfbeck, M. Spanring, S. Templ, W. Waltenberger, C.-E. Wulz[1]

Institute for Nuclear Problems, Minsk, Belarus
V. Chekhovsky, A. Litomin, V. Makarenko

Universiteit Antwerpen, Antwerpen, Belgium
M.R. Darwish[2], E.A. De Wolf, X. Janssen, T. Kello[3], A. Lelek, H. Rejeb Sfar, P. Van Mechelen, S. Van Putte, N. Van Remortel

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, E.S. Bols, J. D'Hondt, J. De Clercq, M. Delcourt, S. Lowette, S. Moortgat, A. Morton, D. Müller, A.R. Sahasransu, S. Tavernier, W. Van Doninck, P. Van Mulders

Université Libre de Bruxelles, Bruxelles, Belgium
D. Beghin, B. Bilin, B. Clerbaux, G. De Lentdecker, L. Favart, A. Grebenyuk, A.K. Kalsi, K. Lee, M. Mahdavikhorrami, I. Makarenko, L. Moureaux, L. Pétré, A. Popov, N. Postiau, E. Starling, L. Thomas, M. Vanden Bemden, C. Vander Velde, P. Vanlaer, D. Vannerom, L. Wezenbeek

Ghent University, Ghent, Belgium
T. Cornelis, D. Dobur, M. Gruchala, L. Lambrecht, G. Mestdach, M. Niedziela, C. Roskas, K. Skovpen, T.T. Tran, M. Tytgat, W. Verbeke, B. Vermassen, M. Vit

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
A. Bethani, G. Bruno, F. Bury, C. Caputo, P. David, C. Delaere, I.S. Donertas, A. Giammanco, K. Jaffel, V. Lemaitre, K. Mondal, J. Prisciandaro, A. Taliercio, M. Teklishyn, P. Vischia, S. Wertz, S. Wuyckens

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, C. Hensel, A. Moraes

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, M. Barroso Ferreira Filho, H. BRANDAO MALBOUISSON, W. Carvalho, J. Chinellato[4], E.M. Da Costa, G.G. Da Silveira[5], D. De Jesus Damiao, S. Fonseca De Souza, D. Matos Figueiredo, C. Mora Herrera, K. Mota Amarilo, L. Mundim, H. Nogima, P. Rebello Teles, L.J. Sanchez Rosas, A. Santoro, S.M. Silva Do Amaral, A. Sznajder, M. Thiel, F. Torres Da Silva De Araujo, A. Vilela Pereira

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

Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria
A. Aleksandrov, G. Antchev, I. Atanasov, R. Hadjiiska, P. Iaydjiev, M. Misheva, M. Rodozov, M. Shopova, G. Sultanov

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

Beihang University, Beijing, China
T. Cheng, W. Fang[3], Q. Guo, T. Javaid[6], M. Mittal, H. Wang, L. Yuan

Department of Physics, Tsinghua University, Beijing, China
M. Ahmad, G. Bauer, C. Dozen[7], Z. Hu, J. Martins[8], Y. Wang, K. Yi[9,10]

Institute of High Energy Physics, Beijing, China
E. Chapon, G.M. Chen[6], H.S. Chen[6], M. Chen, F. Iemmi, A. Kapoor, D. Leggat, H. Liao, Z.-A. LIU[6], R. Sharma, A. Spiezia, J. Tao, J. Thomas-wilsker, J. Wang, H. Zhang, S. Zhang[6], J. Zhao

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
A. Agapitos, Y. Ban, C. Chen, Q. Huang, A. Levin, Q. Li, M. Lu, X. Lyu, Y. Mao, S.J. Qian, D. Wang, Q. Wang, J. Xiao

Sun Yat-Sen University, Guangzhou, China
Z. You

Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China
X. Gao[3], H. Okawa

Zhejiang University, Hangzhou, China
M. Xiao

Universidad de Los Andes, Bogota, Colombia
C. Avila, A. Cabrera, C. Florez, J. Fraga, A. Sarkar, M.A. Segura Delgado

Universidad de Antioquia, Medellin, Colombia
J. Jaramillo, J. Mejia Guisao, F. Ramirez, J.D. Ruiz Alvarez, C.A. Salazar González, N. Vanegas Arbelaez

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

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

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, D. Ferencek, D. Majumder, M. Roguljic, A. Starodumov[11], T. Susa

University of Cyprus, Nicosia, Cyprus
A. Attikis, E. Erodotou, A. Ioannou, G. Kole, M. Kolosova, S. Konstantinou, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski, H. Saka

Charles University, Prague, Czech Republic
M. Finger[12], M. Finger Jr.[12], A. Kveton

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
S. Abu Zeid[13], S. Khalil[14], E. Salama[15,13]

Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt
A. Lotfy, M.A. Mahmoud

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

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, L. Forthomme, H. Kirschenmann, K. Osterberg, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
E. Brücken, F. Garcia, J. Havukainen, V. Karimäki, M.S. Kim, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, M. Lotti, L. Martikainen, H. Siikonen, E. Tuominen, J. Tuominiemi

Lappeenranta University of Technology, Lappeenranta, Finland
P. Luukka, H. Petrow, T. Tuuva

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
C. Amendola, 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, B. Lenzi, E. Locci, J. Malcles, J. Rander, A. Rosowsky, M.Ö. Sahin, A. Savoy-Navarro[16], M. Titov, G.B. Yu

Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France
S. Ahuja, F. Beaudette, M. Bonanomi, A. Buchot Perraguin, P. Busson, A. Cappati, C. Charlot, O. Davignon, B. Diab, G. Falmagne, S. Ghosh, R. Granier de Cassagnac, A. Hakimi, I. Kucher, A. Lobanov, M. Nguyen, C. Ochando, P. Paganini, J. Rembser, R. Salerno, J.B. Sauvan, Y. Sirois, A. Zabi, A. Zghiche

Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France
J.-L. Agram[17], J. Andrea, D. Apparu, D. Bloch, G. Bourgatte, J.-M. Brom, E.C. Chabert, C. Collard, D. Darej, J.-C. Fontaine[17], U. Goerlach, C. Grimault, A.-C. Le Bihan, P. Van Hove

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
E. Asilar, S. Beauceron, C. Bernet, G. Boudoul, C. Camen, A. Carle, N. Chanon, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, Sa. Jain, I.B. Laktineh, H. Lattaud, A. Lesauvage, M. Lethuillier, L. Mirabito, K. Shchablo, L. Torterotot, G. Touquet, M. Vander Donckt, S. Viret

Georgian Technical University, Tbilisi, Georgia
I. Lomidze, T. Toriashvili[18], Z. Tsamalaidze[12]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
L. Feld, K. Klein, M. Lipinski, D. Meuser, A. Pauls, M.P. Rauch, M. Teroerde

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
D. Eliseev, M. Erdmann, P. Fackeldey, B. Fischer, S. Ghosh, T. Hebbeker, K. Hoepfner, F. Ivone, H. Keller, L. Mastrolorenzo, M. Merschmeyer, A. Meyer, G. Mocellin, S. Mondal, S. Mukherjee, D. Noll, A. Novak, T. Pook, A. Pozdnyakov, Y. Rath, H. Reithler, J. Roemer, A. Schmidt, S.C. Schuler, A. Sharma, S. Wiedenbeck, S. Zaleski

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
C. Dziwok, G. Flügge, W. Haj Ahmad[19], O. Hlushchenko, T. Kress, A. Nowack, C. Pistone, O. Pooth, D. Roy, H. Sert, A. Stahl[20], T. Ziemons

Deutsches Elektronen-Synchrotron, Hamburg, Germany
H. Aarup Petersen, M. Aldaya Martin, P. Asmuss, I. Babounikau, S. Baxter, O. Behnke, A. Bermúdez Martínez, A.A. Bin Anuar, K. Borras[21], V. Botta, D. Brunner, A. Campbell, A. Cardini, C. Cheng, P. Connor, S. Consuegra Rodríguez, V. Danilov, M.M. Defranchis, L. Didukh, G. Eckerlin, D. Eckstein, L.I. Estevez Banos, O. Filatov, E. Gallo[22], A. Geiser, A. Giraldi, A. Grohsjean, M. Guthoff, A. Jafari[23], N.Z. Jomhari, H. Jung, A. Kasem[21], M. Kasemann, H. Kaveh, C. Kleinwort, J. Knolle, D. Krücker, W. Lange, T. Lenz, J. Lidrych, K. Lipka, W. Lohmann[24], T. Madlener, R. Mankel, I.-A. Melzer-Pellmann, J. Metwally, A.B. Meyer, M. Meyer, J. Mnich, A. Mussgiller, V. Myronenko, Y. Otarid, D. Pérez Adán, D. Pitzl, A. Raspereza, B. Ribeiro Lopes, J. Rübenach, A. Saggio, A. Saibel, M. Savitskyi, V. Scheurer, C. Schwanenberger[22], A. Singh, R.E. Sosa Ricardo, D. Stafford, N. Tonon, O. Turkot, A. Vagnerini, M. Van De Klundert, R. Walsh, D. Walter, Y. Wen, K. Wichmann, C. Wissing, S. Wuchterl, R. Zlebcik

University of Hamburg, Hamburg, Germany
R. Aggleton, S. Bein, L. Benato, A. Benecke, K. De Leo, T. Dreyer, M. Eich, F. Feindt, A. Fröhlich, C. Garbers, E. Garutti, P. Gunnellini, J. Haller, A. Hinzmann, A. Karavdina, G. Kasieczka, R. Klanner, R. Kogler, V. Kutzner, J. Lange, T. Lange, A. Malara, A. Nigamova, K.J. Pena Rodriguez, O. Rieger, P. Schleper, M. Schröder, J. Schwandt, D. Schwarz, J. Sonneveld, H. Stadie, G. Steinbrück, A. Tews, B. Vormwald, I. Zoi

Karlsruher Institut fuer Technologie, Karlsruhe, Germany
J. Bechtel, T. Berger, E. Butz, R. Caspart, T. Chwalek, W. De Boer[†], A. Dierlamm, A. Droll, K. El Morabit, N. Faltermann, K. Flöh, M. Giffels, J.o. Gosewisch, A. Gottmann, F. Hartmann[20], C. Heidecker, U. Husemann, I. Katkov[25], P. Keicher, R. Koppenhöfer, S. Maier, M. Metzler, S. Mitra, Th. Müller, M. Neukum, G. Quast, K. Rabbertz, J. Rauser, D. Savoiu, D. Schäfer, M. Schnepf, D. Seith, I. Shvetsov, H.J. Simonis, R. Ulrich, J. Van Der Linden, R.F. Von Cube, M. Wassmer, M. Weber, S. Wieland, R. Wolf, S. Wozniewski, S. Wunsch

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
G. Anagnostou, P. Asenov, G. Daskalakis, T. Geralis, A. Kyriakis, D. Loukas, A. Stakia

National and Kapodistrian University of Athens, Athens, Greece
M. Diamantopoulou, D. Karasavvas, G. Karathanasis, P. Kontaxakis, C.K. Koraka, A. Manousakis-katsikakis, A. Panagiotou, I. Papavergou, N. Saoulidou, K. Theofilatos, E. Tziaferi, K. Vellidis, E. Vourliotis

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

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Gianneios, P. Katsoulis, P. Kokkas, N. Manthos, I. Papadopoulos, J. Strologas

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
M. Csanad, K. Farkas, M.M.A. Gadallah[26], S. Lökös[27], P. Major, K. Mandal, A. Mehta, G. Pasztor, A.J. Rádl, O. Surányi, G.I. Veres

Wigner Research Centre for Physics, Budapest, Hungary
M. Bartók[28], G. Bencze, C. Hajdu, D. Horvath[29], F. Sikler, V. Veszpremi, G. Vesztergombi[†]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
S. Czellar, J. Karancsi[28], J. Molnar, Z. Szillasi, D. Teyssier

Institute of Physics, University of Debrecen, Debrecen, Hungary
P. Raics, Z.L. Trocsanyi[30], B. Ujvari

Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary
T. Csorgo[31], F. Nemes[31], T. Novak

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

National Institute of Science Education and Research, HBNI, Bhubaneswar, India
S. Bahinipati[32], D. Dash, C. Kar, P. Mal, T. Mishra, V.K. Muraleedharan Nair Bindhu[33], A. Nayak[33], P. Saha, N. Sur, S.K. Swain

Panjab University, Chandigarh, India
S. Bansal, S.B. Beri, V. Bhatnagar, G. Chaudhary, S. Chauhan, N. Dhingra[34], R. Gupta, A. Kaur, S. Kaur, P. Kumari, M. Meena, K. Sandeep, J.B. Singh, A.K. Virdi

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

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
M. Bharti[35], R. Bhattacharya, S. Bhattacharya, D. Bhowmik, S. Dutta, B. Gomber[36], M. Maity[37], S. Nandan, P. Palit, P.K. Rout, G. Saha, B. Sahu, S. Sarkar, M. Sharan, B. Singh[35], S. Thakur[35]

Indian Institute of Technology Madras, Madras, India
P.K. Behera, S.C. Behera, P. Kalbhor, A. Muhammad, R. Pradhan, P.R. Pujahari, A. Sharma, A.K. Sikdar

Bhabha Atomic Research Centre, Mumbai, India
D. Dutta, V. Jha, V. Kumar, D.K. Mishra, K. Naskar[38], P.K. Netrakanti, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research-A, Mumbai, India
T. Aziz, S. Dugad, M. Kumar, G.B. Mohanty, U. Sarkar

Tata Institute of Fundamental Research-B, Mumbai, India
S. Banerjee, S. Bhattacharya, R. Chudasama, M. Guchait, S. Karmakar, S. Kumar, G. Majumder, K. Mazumdar, S. Mukherjee, D. Roy

Indian Institute of Science Education and Research (IISER), Pune, India
S. Dube, B. Kansal, S. Pandey, A. Rane, A. Rastogi, S. Sharma

Department of Physics, Isfahan University of Technology, Isfahan, Iran
H. Bakhshiansohi[39], M. Zeinali[40]

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
S. Chenarani[41], S.M. Etesami, M. Khakzad, M. Mohammadi Najafabadi

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], R. Aly[a,b,42], C. Aruta[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c], M. De Palma[a,b], A. Di Florio[a,b], A. Di Pilato[a,b], W. Elmetenawee[a,b], L. Fiore[a], A. Gelmi[a,b], M. Gul[a], G. Iaselli[a,c], M. Ince[a,b], S. Lezki[a,b], G. Maggi[a,c], M. Maggi[a], I. Margjeka[a,b], V. Mastrapasqua[a,b], J.A. Merlin[a], S. My[a,b], S. Nuzzo[a,b], A. Pellecchia[a,b], A. Pompili[a,b], G. Pugliese[a,c], A. Ranieri[a], G. Selvaggi[a,b], L. Silvestris[a], F.M. Simone[a,b], R. Venditti[a], P. Verwilligen[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], S. Braibant-Giacomelli[a,b], L. Brigliadori[a], R. Campanini[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], C. Ciocca[a], M. Cuffiani[a,b], G.M. Dallavalle[a], T. Diotalevi[a,b], F. Fabbri[a], A. Fanfani[a,b], P. Giacomelli[a], L. Giommi[a,b], C. Grandi[a], L. Guiducci[a,b], S. Lo Meo[a,43], L. Lunerti[a,b], S. Marcellini[a], G. Masetti[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]

INFN Sezione di Catania [a], Università di Catania [b], Catania, Italy
S. Albergo[a,b,44], S. Costa[a,b,44], A. Di Mattia[a], R. Potenza[a,b], A. Tricomi[a,b,44], C. Tuve[a,b]

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], A. Cassese[a], R. Ceccarelli[a,b], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], F. Fiori[a,b], E. Focardi[a,b], G. Latino[a,b], P. Lenzi[a,b], M. Lizzo[a,b], M. Meschini[a], S. Paoletti[a], R. Seidita[a,b], G. Sguazzoni[a], L. Viliani[a]

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

INFN Sezione di Genova [a], Università di Genova [b], Genova, Italy
M. Bozzo[a,b], F. Ferro[a], R. Mulargia[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], F. Brivio[a,b], F. Cetorelli[a,b], V. Ciriolo[a,b,20], F. De Guio[a,b], M.E. Dinardo[a,b], P. Dini[a], S. Gennai[a], A. Ghezzi[a,b], P. Govoni[a,b], L. Guzzi[a,b], M. Malberti[a], S. Malvezzi[a], A. Massironi[a], D. Menasce[a], F. Monti[a,b], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], T. Tabarelli de Fatis[a,b], D. Valsecchi[a,b,20], D. Zuolo[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], F. Carnevali[a,b], N. Cavallo[a,c], A. De Iorio[a,b], F. Fabozzi[a,c], A.O.M. Iorio[a,b], L. Lista[a,b], S. Meola[a,d,20], P. Paolucci[a,20], B. Rossi[a], C. Sciacca[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], P. Bortignon[a], A. Bragagnolo[a,b], R. Carlin[a,b], P. Checchia[a], P. De Castro Manzano[a], T. Dorigo[a], F. Gasparini[a,b], U. Gasparini[a,b], S.Y. Hoh[a,b], L. Layer[a,45], M. Margoni[a,b], A.T. Meneguzzo[a,b], M. Presilla[a,b], P. Ronchese[a,b], R. Rossin[a,b], F. Simonetto[a,b], G. Strong[a], M. Tosi[a,b], H. YARAR[a,b], M. Zanetti[a,b], P. Zotto[a,b], A. Zucchetta[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
C. Aime'[a,b], A. Braghieri[a], S. Calzaferri[a,b], D. Fiorina[a,b], 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], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
G.M. Bilei[a], D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], M. Magherini[b], G. Mantovani[a,b],

V. Mariani[a,b], M. Menichelli[a], F. Moscatelli[a], A. Piccinelli[a,b], A. Rossi[a,b], A. Santocchia[a,b], D. Spiga[a], T. Tedeschi[a,b]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa Italy, Università di Siena [d], Siena, Italy
P. Azzurri[a], G. Bagliesi[a], V. Bertacchi[a,c], L. Bianchini[a], T. Boccali[a], E. Bossini[a,b], R. Castaldi[a], M.A. Ciocci[a,b], R. Dell'Orso[a], M.R. Di Domenico[a,d], S. Donato[a], 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], S. Parolia[a,b], G. Ramirez-Sanchez[a,c], A. Rizzi[a,b], G. Rolandi[a,c], S. Roy Chowdhury[a,c], A. Scribano[a], N. Shafiei[a,b], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], N. Turini[a,d], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Sapienza Università di Roma [b], Rome, Italy
M. Campana[a,b], F. Cavallari[a], M. Cipriani[a,b], D. Del Re[a,b], E. Di Marco[a], M. Diemoz[a], E. Longo[a,b], P. Meridiani[a], G. Organtini[a,b], F. Pandolfi[a], R. Paramatti[a,b], C. Quaranta[a,b], S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b], L. Soffi[a], R. Tramontano[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], A. Bellora[a,b], J. Berenguer Antequera[a,b], C. Biino[a], N. Cartiglia[a], S. Cometti[a], M. Costa[a,b], R. Covarelli[a,b], N. Demaria[a], B. Kiani[a,b], F. Legger[a], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], E. Monteil[a,b], M. Monteno[a], M.M. Obertino[a,b], G. Ortona[a], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], M. Ruspa[a,c], R. Salvatico[a,b], K. Shchelina[a,b], F. Siviero[a,b], V. Sola[a], A. Solano[a,b], D. Soldi[a,b], A. Staiano[a], M. Tornago[a,b], D. Trocino[a,b]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a], A. Da Rold[a,b], G. Della Ricca[a,b], G. Sorrentino[a,b], F. Vazzoler[a,b]

Kyungpook National University, Daegu, Korea
S. Dogra, C. Huh, B. Kim, D.H. Kim, G.N. Kim, J. Kim, J. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, S.I. Pak, B.C. Radburn-Smith, S. Sekmen, Y.C. Yang

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

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

Korea University, Seoul, Korea
S. Cho, S. Choi, Y. Go, B. Hong, K. Lee, K.S. Lee, J. Lim, J. Park, S.K. Park, J. Yoo

Kyung Hee University, Department of Physics, Seoul, Republic of Korea
J. Goh, A. Gurtu

Sejong University, Seoul, Korea
H.S. Kim, Y. Kim

Seoul National University, Seoul, Korea
J. Almond, J.H. Bhyun, J. Choi, S. Jeon, J. Kim, J.S. Kim, S. Ko, H. Kwon, H. Lee, S. Lee, B.H. Oh, M. Oh, S.B. Oh, H. Seo, U.K. Yang, I. Yoon

University of Seoul, Seoul, Korea
D. Jeon, J.H. Kim, B. Ko, J.S.H. Lee, I.C. Park, Y. Roh, D. Song, I.J. Watson

Yonsei University, Department of Physics, Seoul, Korea
S. Ha, H.D. Yoo

Sungkyunkwan University, Suwon, Korea
Y. Choi, Y. Jeong, H. Lee, Y. Lee, I. Yu

College of Engineering and Technology, American University of the Middle East (AUM), Egaila, Kuwait
T. Beyrouthy, Y. Maghrbi

Riga Technical University, Riga, Latvia
V. Veckalns[46]

Vilnius University, Vilnius, Lithuania
M. Ambrozas, A. Juodagalvis, A. Rinkevicius, G. Tamulaitis, A. Vaitkevicius

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
N. Bin Norjoharuddeen, W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

Universidad de Sonora (UNISON), Hermosillo, Mexico
J.F. Benitez, A. Castaneda Hernandez, J.A. Murillo Quijada, L. Valencia Palomo

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
G. Ayala, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz[47], R. Lopez-Fernandez, C.A. Mondragon Herrera, D.A. Perez Navarro, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico
S. Carrillo Moreno, C. Oropeza Barrera, M. Ramirez-Garcia, F. Vazquez Valencia

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

University of Montenegro, Podgorica, Montenegro
J. Mijuskovic[48], N. Raicevic

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.I. Asghar, A. Awais, M.I.M. Awan, H.R. Hoorani, W.A. Khan, M.A. Shah, M. Shoaib, M. Waqas

AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
V. Avati, L. Grzanka, M. Malawski

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

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
K. Bunkowski, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Walczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
M. Araujo, P. Bargassa, D. Bastos, A. Boletti, P. Faccioli, M. Gallinaro, J. Hollar, N. Leonardo, T. Niknejad, M. Pisano, J. Seixas, O. Toldaiev, J. Varela

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, D. Budkouski, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavine, A. Lanev, A. Malakhov, V. Matveev[49,50], V. Palichik, V. Perelygin, M. Savina, D. Seitova, V. Shalaev, S. Shmatov, S. Shulha, V. Smirnov, O. Teryaev, N. Voytishin, A. Zarubin, I. Zhizhin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
G. Gavrilov, V. Golovtcov, Y. Ivanov, V. Kim[51], E. Kuznetsova[52], V. Murzin, V. Oreshkin, I. Smirnov, D. Sosnov, V. Sulimov, L. Uvarov, S. Volkov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia
Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, G. Pivovarov, D. Tlisov[†], A. Toropin

Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia
V. Epshteyn, V. Gavrilov, N. Lychkovskaya, A. Nikitenko[53], V. Popov, G. Safronov, A. Spiridonov, A. Stepennov, M. Toms, E. Vlasov, A. Zhokin

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

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
R. Chistov[54], M. Danilov[55], A. Oskin, P. Parygin, S. Polikarpov[55]

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Terkulov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, M. Dubinin[56], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

Novosibirsk State University (NSU), Novosibirsk, Russia
V. Blinov[57], T. Dimova[57], L. Kardapoltsev[57], I. Ovtin[57], Y. Skovpen[57]

Institute for High Energy Physics of National Research Centre 'Kurchatov Institute', Protvino, Russia
I. Azhgirey, I. Bayshev, V. Kachanov, A. Kalinin, D. Konstantinov, V. Petrov, R. Ryutin, A. Sobol, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

National Research Tomsk Polytechnic University, Tomsk, Russia
A. Babaev, V. Okhotnikov, L. Sukhikh

Tomsk State University, Tomsk, Russia
V. Borchsh, V. Ivanchenko, E. Tcherniaev

University of Belgrade: Faculty of Physics and VINCA Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[58], M. Dordevic, P. Milenovic, J. Milosevic, V. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, A. Álvarez Fernández, I. Bachiller, M. Barrio Luna, Cristina F. Bedoya, C.A. Carrillo Montoya, M. Cepeda, M. Cerrada, N. Colino, B. De La Cruz, A. Delgado Peris, J.P. Fernández Ramos, J. Flix, M.C. Fouz, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, J. León Holgado, D. Moran, Á. Navarro Tobar, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, I. Redondo, L. Romero, S. Sánchez Navas, M.S. Soares, L. Urda Gómez, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain
J.F. de Trocóniz, R. Reyes-Almanza

Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
B. Alvarez Gonzalez, J. Cuevas, C. Erice, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, C. Ramón Álvarez, J. Ripoll Sau, V. Rodríguez Bouza, A. Trapote

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, B. Chazin Quero, J. Duarte Campderros, M. Fernandez, C. Fernandez Madrazo, P.J. Fernández Manteca, A. García Alonso, G. Gomez, C. Martinez Rivero, P. Martinez Ruiz del Arbol, F. Matorras, P. Matorras Cuevas, J. Piedra Gomez, C. Prieels, F. Ricci-Tam, T. Rodrigo, A. Ruiz-Jimeno, L. Scodellaro, N. Trevisani, I. Vila, J.M. Vizan Garcia

University of Colombo, Colombo, Sri Lanka
MK Jayananda, B. Kailasapathy[59], D.U.J. Sonnadara, DDC Wickramarathna

University of Ruhuna, Department of Physics, Matara, Sri Lanka
W.G.D. Dharmaratna, K. Liyanage, N. Perera, N. Wickramage

CERN, European Organization for Nuclear Research, Geneva, Switzerland
T.K. Aarrestad, D. Abbaneo, J. Alimena, E. Auffray, G. Auzinger, J. Baechler, P. Baillon[†], A.H. Ball, D. Barney, J. Bendavid, N. Beni, M. Bianco, A. Bocci, E. Brondolin, T. Camporesi, M. Capeans Garrido, G. Cerminara, S.S. Chhibra, L. Cristella, D. d'Enterria, A. Dabrowski, N. Daci, A. David, A. De Roeck, M. Deile, R. Di Maria, M. Dobson, M. Dünser, N. Dupont, A. Elliott-Peisert, N. Emriskova, F. Fallavollita[60], D. Fasanella, S. Fiorendi, A. Florent, G. Franzoni, J. Fulcher, W. Funk, S. Giani, D. Gigi, K. Gill, F. Glege, L. Gouskos, M. Haranko, J. Hegeman, Y. Iiyama, V. Innocente, T. James, P. Janot, J. Kaspar, J. Kieseler, M. Komm, N. Kratochwil, C. Lange, S. Laurila, P. Lecoq, K. Long, C. Lourenço, L. Malgeri, S. Mallios, M. Mannelli, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, M. Mulders, S. Orfanelli, L. Orsini, F. Pantaleo, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, M. Pitt, H. Qu, T. Quast, D. Rabady, A. Racz, M. Rieger, M. Rovere, H. Sakulin, J. Salfeld-Nebgen, S. Scarfi, C. Schäfer, C. Schwick, M. Selvaggi, A. Sharma, P. Silva, W. Snoeys, P. Sphicas[61], S. Summers, V.R. Tavolaro, D. Treille, A. Tsirou, G.P. Van Onsem, M. Verzetti, J. Wanczyk[62], K.A. Wozniak, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
L. Caminada[63], A. Ebrahimi, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, M. Missiroli, T. Rohe

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
K. Androsov[62], M. Backhaus, P. Berger, A. Calandri, N. Chernyavskaya, A. De Cosa, G. Dissertori, M. Dittmar, M. Donegà, C. Dorfer, F. Eble, T. Gadek, T.A. Gómez Espinosa,

C. Grab, D. Hits, W. Lustermann, A.-M. Lyon, R.A. Manzoni, C. Martin Perez, M.T. Meinhard, F. Micheli, F. Nessi-Tedaldi, J. Niedziela, F. Pauss, V. Perovic, G. Perrin, S. Pigazzini, M.G. Ratti, M. Reichmann, C. Reissel, T. Reitenspiess, B. Ristic, D. Ruini, D.A. Sanz Becerra, M. Schönenberger, V. Stampf, J. Steggemann[62], R. Wallny, D.H. Zhu

Universität Zürich, Zurich, Switzerland
C. Amsler[64], P. Bärtschi, C. Botta, D. Brzhechko, M.F. Canelli, A. De Wit, R. Del Burgo, J.K. Heikkilä, M. Huwiler, A. Jofrehei, B. Kilminster, S. Leontsinis, A. Macchiolo, P. Meiring, V.M. Mikuni, U. Molinatti, I. Neutelings, G. Rauco, A. Reimers, P. Robmann, S. Sanchez Cruz, K. Schweiger, Y. Takahashi

National Central University, Chung-Li, Taiwan
C. Adloff[65], C.M. Kuo, W. Lin, A. Roy, T. Sarkar[37], S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
L. Ceard, P. Chang, Y. Chao, K.F. Chen, P.H. Chen, W.-S. Hou, Y.y. Li, R.-S. Lu, E. Paganis, A. Psallidas, A. Steen, E. Yazgan, P.r. Yu

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

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
F. Boran, S. Damarseckin[66], Z.S. Demiroglu, F. Dolek, I. Dumanoglu[67], E. Eskut, G. Gokbulut, Y. Guler, E. Gurpinar Guler[68], I. Hos[69], C. Isik, E.E. Kangal[70], O. Kara, A. Kayis Topaksu, U. Kiminsu, G. Onengut, K. Ozdemir[71], A. Polatoz, A.E. Simsek, B. Tali[72], U.G. Tok, S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
B. Isildak[73], G. Karapinar[74], K. Ocalan[75], M. Yalvac[76]

Bogazici University, Istanbul, Turkey
B. Akgun, I.O. Atakisi, E. Gülmez, M. Kaya[77], O. Kaya[78], Ö. Özçelik, S. Tekten[79], E.A. Yetkin[80]

Istanbul Technical University, Istanbul, Turkey
A. Cakir, K. Cankocak[67], Y. Komurcu, S. Sen[81]

Istanbul University, Istanbul, Turkey
F. Aydogmus Sen, S. Cerci[72], B. Kaynak, S. Ozkorucuklu, D. Sunar Cerci[72]

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
D. Anthony, E. Bhal, S. Bologna, J.J. Brooke, A. Bundock, E. Clement, D. Cussans, H. Flacher, J. Goldstein, G.P. Heath, H.F. Heath, L. Kreczko, B. Krikler, S. Paramesvaran, T. Sakuma, S. Seif El Nasr-Storey, V.J. Smith, N. Stylianou[82], J. Taylor, A. Titterton, R. White

Rutherford Appleton Laboratory, Didcot, United Kingdom
K.W. Bell, A. Belyaev[83], C. Brew, R.M. Brown, D.J.A. Cockerill, K.V. Ellis, K. Harder, S. Harper, J. Linacre, K. Manolopoulos, D.M. Newbold, E. Olaiya, D. Petyt, T. Reis, T. Schuh, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams

Imperial College, London, United Kingdom
R. Bainbridge, P. Bloch, S. Bonomally, J. Borg, S. Breeze, O. Buchmuller, V. Cepaitis, G.S. Chahal[84], D. Colling, P. Dauncey, G. Davies, M. Della Negra, S. Fayer, G. Fedi, G. Hall, M.H. Hassanshahi, G. Iles, J. Langford, L. Lyons, A.-M. Magnan, S. Malik, A. Martelli, J. Nash[85], V. Palladino, M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, A. Tapper, K. Uchida, T. Virdee[20], N. Wardle, S.N. Webb, D. Winterbottom, A.G. Zecchinelli

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

Baylor University, Waco, USA
S. Abdullin, A. Brinkerhoff, B. Caraway, J. Dittmann, K. Hatakeyama, A.R. Kanuganti, B. McMaster, N. Pastika, S. Sawant, C. Smith, C. Sutantawibul, J. Wilson

Catholic University of America, Washington, DC, USA
R. Bartek, A. Dominguez, R. Uniyal, A.M. Vargas Hernandez

The University of Alabama, Tuscaloosa, USA
A. Buccilli, O. Charaf, S.I. Cooper, D. Di Croce, S.V. Gleyzer, C. Henderson, C.U. Perez, P. Rumerio[86], C. West

Boston University, Boston, USA
A. Akpinar, A. Albert, D. Arcaro, C. Cosby, Z. Demiragli, E. Fontanesi, D. Gastler, J. Rohlf, K. Salyer, D. Sperka, D. Spitzbart, I. Suarez, A. Tsatsos, S. Yuan, D. Zou

Brown University, Providence, USA
G. Benelli, B. Burkle, X. Coubez[21], D. Cutts, Y.t. Duh, M. Hadley, U. Heintz, J.M. Hogan[87], E. Laird, G. Landsberg, K.T. Lau, J. Lee, J. Luo, M. Narain, S. Sagir[88], E. Usai, W.Y. Wong, X. Yan, D. Yu, W. Zhang

University of California, Davis, Davis, USA
C. Brainerd, R. Breedon, M. Calderon De La Barca Sanchez, M. Chertok, J. Conway, P.T. Cox, R. Erbacher, G. Haza, F. Jensen, O. Kukral, R. Lander, M. Mulhearn, D. Pellett, B. Regnery, D. Taylor, M. Tripathi, Y. Yao, F. Zhang

University of California, Los Angeles, USA
M. Bachtis, R. Cousins, A. Dasgupta, A. Datta, D. Hamilton, J. Hauser, M. Ignatenko, M.A. Iqbal, T. Lam, N. Mccoll, W.A. Nash, S. Regnard, D. Saltzberg, C. Schnaible, B. Stone, V. Valuev

University of California, Riverside, Riverside, USA
K. Burt, Y. Chen, R. Clare, J.W. Gary, M. Gordon, G. Hanson, G. Karapostoli, O.R. Long, N. Manganelli, M. Olmedo Negrete, W. Si, S. Wimpenny, Y. Zhang

University of California, San Diego, La Jolla, USA
J.G. Branson, P. Chang, S. Cittolin, S. Cooperstein, N. Deelen, J. Duarte, R. Gerosa, L. Giannini, D. Gilbert, J. Guiang, R. Kansal, V. Krutelyov, R. Lee, J. Letts, M. Masciovecchio, S. May, S. Padhi, M. Pieri, B.V. Sathia Narayanan, V. Sharma, M. Tadel, A. Vartak, F. Würthwein, Y. Xiang, A. Yagil

University of California, Santa Barbara - Department of Physics, Santa Barbara, USA
N. Amin, C. Campagnari, M. Citron, A. Dorsett, V. Dutta, J. Incandela, M. Kilpatrick, J. Kim, B. Marsh, H. Mei, M. Oshiro, A. Ovcharova, M. Quinnan, J. Richman, U. Sarica, D. Stuart, S. Wang

California Institute of Technology, Pasadena, USA
A. Bornheim, O. Cerri, I. Dutta, J.M. Lawhorn, N. Lu, J. Mao, H.B. Newman, J. Ngadiuba, T.Q. Nguyen, M. Spiropulu, J.R. Vlimant, C. Wang, S. Xie, Z. Zhang, R.Y. Zhu

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

University of Colorado Boulder, Boulder, USA
J.P. Cumalat, W.T. Ford, E. MacDonald, R. Patel, A. Perloff, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, Y. Cheng, J. Chu, D.J. Cranshaw, K. Mcdermott, J. Monroy, J.R. Patterson, D. Quach, J. Reichert, A. Ryd, W. Sun, S.M. Tan, Z. Tao, J. Thom, P. Wittich, M. Zientek

Fermi National Accelerator Laboratory, Batavia, USA
M. Albrow, M. Alyari, G. Apollinari, A. Apresyan, A. Apyan, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, D. Berry, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, A. Canepa, G.B. Cerati, H.W.K. Cheung, F. Chlebana, M. Cremonesi, K.F. Di Petrillo, V.D. Elvira, J. Freeman, Z. Gecse, L. Gray, D. Green, S. Grünendahl, O. Gutsche, R.M. Harris, R. Heller, T.C. Herwig, J. Hirschauer, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, P. Klabbers, T. Klijnsma, B. Klima, M.J. Kortelainen, K.H.M. Kwok, S. Lammel, D. Lincoln, R. Lipton, T. Liu, J. Lykken, C. Madrid, K. Maeshima, C. Mantilla, D. Mason, P. McBride, P. Merkel, S. Mrenna, S. Nahn, V. O'Dell, V. Papadimitriou, K. Pedro, C. Pena[56], O. Prokofyev, F. Ravera, A. Reinsvold Hall, L. Ristori, B. Schneider, E. Sexton-Kennedy, N. Smith, A. Soha, L. Spiegel, S. Stoynev, J. Strait, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, H.A. Weber, A. Woodard

University of Florida, Gainesville, USA
D. Acosta, P. Avery, D. Bourilkov, L. Cadamuro, V. Cherepanov, F. Errico, R.D. Field, D. Guerrero, B.M. Joshi, M. Kim, J. Konigsberg, A. Korytov, K.H. Lo, K. Matchev, N. Menendez, G. Mitselmakher, D. Rosenzweig, S. Rosenzweig, K. Shi, J. Sturdy, J. Wang, E. Yigitbasi, X. Zuo

Florida State University, Tallahassee, USA
T. Adams, A. Askew, D. Diaz, R. Habibullah, S. Hagopian, V. Hagopian, K.F. Johnson, R. Khurana, T. Kolberg, G. Martinez, H. Prosper, C. Schiber, R. Yohay, J. Zhang

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, S. Butalla, T. Elkafrawy[13], M. Hohlmann, R. Kumar Verma, D. Noonan, M. Rahmani, M. Saunders, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, L. Apanasevich, H. Becerril Gonzalez, R. Cavanaugh, X. Chen, S. Dittmer, O. Evdokimov, C.E. Gerber, D.A. Hangal, D.J. Hofman, C. Mills, G. Oh, T. Roy, M.B. Tonjes, N. Varelas, J. Viinikainen, X. Wang, Z. Wu, Z. Ye

The University of Iowa, Iowa City, USA
M. Alhusseini, K. Dilsiz[89], S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, O.K. Köseyan, J.-P. Merlo, A. Mestvirishvili[90], A. Moeller, J. Nachtman, H. Ogul[91], Y. Onel, F. Ozok[92], A. Penzo, C. Snyder, E. Tiras[93], J. Wetzel

Johns Hopkins University, Baltimore, USA
O. Amram, B. Blumenfeld, L. Corcodilos, J. Davis, M. Eminizer, A.V. Gritsan, S. Kyriacou, P. Maksimovic, J. Roskes, M. Swartz, T.Á. Vámi

The University of Kansas, Lawrence, USA
C. Baldenegro Barrera, P. Baringer, A. Bean, A. Bylinkin, T. Isidori, S. Khalil, J. King,

G. Krintiras, A. Kropivnitskaya, C. Lindsey, N. Minafra, M. Murray, C. Rogan, C. Royon, S. Sanders, E. Schmitz, J.D. Tapia Takaki, Q. Wang, J. Williams, G. Wilson

Kansas State University, Manhattan, USA
S. Duric, A. Ivanov, K. Kaadze, D. Kim, Y. Maravin, T. Mitchell, A. Modak, K. Nam

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

University of Maryland, College Park, USA
E. Adams, A. Baden, O. Baron, A. Belloni, S.C. Eno, Y. Feng, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Koeth, A.C. Mignerey, S. Nabili, M. Seidel, A. Skuja, S.C. Tonwar, L. Wang, K. Wong

Massachusetts Institute of Technology, Cambridge, USA
D. Abercrombie, G. Andreassi, R. Bi, S. Brandt, W. Busza, I.A. Cali, Y. Chen, M. D'Alfonso, G. Gomez Ceballos, M. Goncharov, P. Harris, M. Hu, M. Klute, D. Kovalskyi, J. Krupa, Y.-J. Lee, B. Maier, A.C. Marini, C. Mironov, C. Paus, D. Rankin, C. Roland, G. Roland, Z. Shi, G.S.F. Stephans, K. Tatar, J. Wang, Z. Wang, B. Wyslouch

University of Minnesota, Minneapolis, USA
R.M. Chatterjee, A. Evans, P. Hansen, J. Hiltbrand, Sh. Jain, M. Krohn, Y. Kubota, Z. Lesko, J. Mans, M. Revering, R. Rusack, R. Saradhy, N. Schroeder, N. Strobbe, M.A. Wadud

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

University of Nebraska-Lincoln, Lincoln, USA
K. Bloom, M. Bryson, S. Chauhan, D.R. Claes, C. Fangmeier, L. Finco, F. Golf, J.R. González Fernández, C. Joo, I. Kravchenko, M. Musich, J.E. Siado, G.R. Snow[†], W. Tabb, F. Yan

State University of New York at Buffalo, Buffalo, USA
G. Agarwal, H. Bandyopadhyay, L. Hay, I. Iashvili, A. Kharchilava, C. McLean, D. Nguyen, J. Pekkanen, S. Rappoccio, A. Williams

Northeastern University, Boston, USA
G. Alverson, E. Barberis, C. Freer, Y. Haddad, A. Hortiangtham, J. Li, G. Madigan, B. Marzocchi, D.M. Morse, V. Nguyen, T. Orimoto, A. Parker, L. Skinnari, A. Tishelman-Charny, T. Wamorkar, B. Wang, A. Wisecarver, D. Wood

Northwestern University, Evanston, USA
S. Bhattacharya, J. Bueghly, Z. Chen, A. Gilbert, T. Gunter, K.A. Hahn, N. Odell, M.H. Schmitt, K. Sung, M. Velasco

University of Notre Dame, Notre Dame, USA
R. Band, R. Bucci, N. Dev, R. Goldouzian, M. Hildreth, K. Hurtado Anampa, C. Jessop, K. Lannon, N. Loukas, N. Marinelli, I. Mcalister, F. Meng, K. Mohrman, Y. Musienko[49], R. Ruchti, P. Siddireddy, M. Wayne, A. Wightman, M. Wolf, M. Zarucki, L. Zygala

The Ohio State University, Columbus, USA
B. Bylsma, B. Cardwell, L.S. Durkin, B. Francis, C. Hill, A. Lefeld, M. Nunez Ornelas, K. Wei, B.L. Winer, B.R. Yates

Princeton University, Princeton, USA
F.M. Addesa, B. Bonham, P. Das, G. Dezoort, P. Elmer, A. Frankenthal, B. Greenberg,

N. Haubrich, S. Higginbotham, A. Kalogeropoulos, G. Kopp, S. Kwan, D. Lange, M.T. Lucchini, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, D. Stickland, C. Tully

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

Purdue University, West Lafayette, USA
A.S. Bakshi, V.E. Barnes, R. Chawla, S. Das, L. Gutay, M. Jones, A.W. Jung, S. Karmarkar, M. Liu, G. Negro, N. Neumeister, G. Paspalaki, C.C. Peng, S. Piperov, A. Purohit, J.F. Schulte, M. Stojanovic[16], J. Thieman, F. Wang, R. Xiao, W. Xie

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

Rice University, Houston, USA
A. Baty, S. Dildick, K.M. Ecklund, S. Freed, F.J.M. Geurts, A. Kumar, W. Li, B.P. Padley, R. Redjimi, J. Roberts[†], W. Shi, A.G. Stahl Leiton

University of Rochester, Rochester, USA
A. Bodek, P. de Barbaro, R. Demina, J.L. Dulemba, C. Fallon, T. Ferbel, M. Galanti, A. Garcia-Bellido, O. Hindrichs, A. Khukhunaishvili, E. Ranken, R. Taus

Rutgers, The State University of New Jersey, Piscataway, USA
B. Chiarito, J.P. Chou, A. Gandrakota, Y. Gershtein, E. Halkiadakis, A. Hart, M. Heindl, E. Hughes, S. Kaplan, O. Karacheban[24], I. Laflotte, A. Lath, R. Montalvo, K. Nash, M. Osherson, S. Salur, S. Schnetzer, S. Somalwar, R. Stone, S.A. Thayil, S. Thomas, H. Wang

University of Tennessee, Knoxville, USA
H. Acharya, A.G. Delannoy, S. Spanier

Texas A&M University, College Station, USA
O. Bouhali[94], M. Dalchenko, A. Delgado, R. Eusebi, J. Gilmore, T. Huang, T. Kamon[95], H. Kim, S. Luo, S. Malhotra, R. Mueller, D. Overton, D. Rathjens, A. Safonov

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, V. Hegde, S. Kunori, K. Lamichhane, S.W. Lee, T. Mengke, S. Muthumuni, T. Peltola, S. Undleeb, I. Volobouev, Z. Wang, A. Whitbeck

Vanderbilt University, Nashville, USA
E. Appelt, S. Greene, A. Gurrola, W. Johns, C. Maguire, A. Melo, H. Ni, K. Padeken, F. Romeo, P. Sheldon, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, B. Cox, G. Cummings, J. Hakala, R. Hirosky, M. Joyce, A. Ledovskoy, A. Li, C. Neu, B. Tannenwald, E. Wolfe

Wayne State University, Detroit, USA
P.E. Karchin, N. Poudyal, P. Thapa

University of Wisconsin - Madison, Madison, WI, USA
K. Black, T. Bose, J. Buchanan, C. Caillol, S. Dasu, I. De Bruyn, P. Everaerts, F. Fienga, C. Galloni, H. He, M. Herndon, A. Hervé, U. Hussain, A. Lanaro, A. Loeliger, R. Loveless, J. Madhusudanan Sreekala, A. Mallampalli, A. Mohammadi, D. Pinna, A. Savin, V. Shang, V. Sharma, W.H. Smith, D. Teague, S. Trembath-reichert, W. Vetens

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt, Alexandria, Egypt
3: Also at Université Libre de Bruxelles, Bruxelles, Belgium
4: Also at Universidade Estadual de Campinas, Campinas, Brazil
5: Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil
6: Also at University of Chinese Academy of Sciences, Beijing, China
7: Also at Department of Physics, Tsinghua University, Beijing, China, Beijing, China
8: Also at UFMS, Nova Andradina, Brazil
9: Also at Nanjing Normal University Department of Physics, Nanjing, China
10: Now at The University of Iowa, Iowa City, USA
11: Also at Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of NRC 'Kurchatov Institute', Moscow, Russia
12: Also at Joint Institute for Nuclear Research, Dubna, Russia
13: Also at Ain Shams University, Cairo, Egypt
14: Also at Zewail City of Science and Technology, Zewail, Egypt
15: Also at British University in Egypt, Cairo, Egypt
16: Also at Purdue University, West Lafayette, USA
17: Also at Université de Haute Alsace, Mulhouse, France
18: Also at Tbilisi State University, Tbilisi, Georgia
19: Also at Erzincan Binali Yildirim University, Erzincan, Turkey
20: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
21: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
22: Also at University of Hamburg, Hamburg, Germany
23: Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran, Isfahan, Iran
24: Also at Brandenburg University of Technology, Cottbus, Germany
25: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
26: Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt
27: Also at Eszterhazy Karoly University, Karoly Robert Campus, Gyongyos, Hungary
28: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary, Debrecen, Hungary
29: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
30: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary, Budapest, Hungary
31: Also at Wigner Research Centre for Physics, Budapest, Hungary
32: Also at IIT Bhubaneswar, Bhubaneswar, India, Bhubaneswar, India
33: Also at Institute of Physics, Bhubaneswar, India
34: Also at G.H.G. Khalsa College, Punjab, India
35: Also at Shoolini University, Solan, India
36: Also at University of Hyderabad, Hyderabad, India
37: Also at University of Visva-Bharati, Santiniketan, India
38: Also at Indian Institute of Technology (IIT), Mumbai, India
39: Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany
40: Also at Sharif University of Technology, Tehran, Iran
41: Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran

42: Now at INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
43: Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy
44: Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy
45: Also at Università di Napoli 'Federico II', NAPOLI, Italy
46: Also at Riga Technical University, Riga, Latvia, Riga, Latvia
47: Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico
48: Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
49: Also at Institute for Nuclear Research, Moscow, Russia
50: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
51: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
52: Also at University of Florida, Gainesville, USA
53: Also at Imperial College, London, United Kingdom
54: Also at Moscow Institute of Physics and Technology, Moscow, Russia, Moscow, Russia
55: Also at P.N. Lebedev Physical Institute, Moscow, Russia
56: Also at California Institute of Technology, Pasadena, USA
57: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
58: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
59: Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka
60: Also at INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy, Pavia, Italy
61: Also at National and Kapodistrian University of Athens, Athens, Greece
62: Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland
63: Also at Universität Zürich, Zurich, Switzerland
64: Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria, Vienna, Austria
65: Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France
66: Also at Şırnak University, Sirnak, Turkey
67: Also at Near East University, Research Center of Experimental Health Science, Nicosia, Turkey
68: Also at Konya Technical University, Konya, Turkey
69: Also at Istanbul University - Cerraphasa, Faculty of Engineering, Istanbul, Turkey
70: Also at Mersin University, Mersin, Turkey
71: Also at Piri Reis University, Istanbul, Turkey
72: Also at Adiyaman University, Adiyaman, Turkey
73: Also at Ozyegin University, Istanbul, Turkey
74: Also at Izmir Institute of Technology, Izmir, Turkey
75: Also at Necmettin Erbakan University, Konya, Turkey
76: Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey, Yozgat, Turkey
77: Also at Marmara University, Istanbul, Turkey
78: Also at Milli Savunma University, Istanbul, Turkey
79: Also at Kafkas University, Kars, Turkey
80: Also at Istanbul Bilgi University, Istanbul, Turkey
81: Also at Hacettepe University, Ankara, Turkey
82: Also at Vrije Universiteit Brussel, Brussel, Belgium
83: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
84: Also at IPPP Durham University, Durham, United Kingdom
85: Also at Monash University, Faculty of Science, Clayton, Australia

86: Also at Università di Torino, TORINO, Italy
87: Also at Bethel University, St. Paul, Minneapolis, USA, St. Paul, USA
88: Also at Karamanoğlu Mehmetbey University, Karaman, Turkey
89: Also at Bingol University, Bingol, Turkey
90: Also at Georgian Technical University, Tbilisi, Georgia
91: Also at Sinop University, Sinop, Turkey
92: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
93: Also at Erciyes University, KAYSERI, Turkey
94: Also at Texas A&M University at Qatar, Doha, Qatar
95: Also at Kyungpook National University, Daegu, Korea, Daegu, Korea