

# Search for Soft Unclustered Energy Patterns in Proton-Proton Collisions at 13 TeV

A. Hayrapetyan *et al.*\*  
(CMS Collaboration)

 (Received 8 March 2024; accepted 6 September 2024; published 5 November 2024)

The first search for soft unclustered energy patterns (SUEPs) is performed using an integrated luminosity of  $138 \text{ fb}^{-1}$  of proton-proton collision data at  $\sqrt{s} = 13 \text{ TeV}$ , collected in 2016–2018 by the CMS detector at the LHC. Such SUEPs are predicted by hidden valley models with a new, confining force with a large 't Hooft coupling. In events with boosted topologies, selected by high-threshold hadronic triggers, the multiplicity and sphericity of clustered tracks are used to reject the background from standard model quantum chromodynamics. With no observed excess of events over the standard model expectation, limits are set on the cross section for production via gluon fusion of a scalar mediator with SUEP-like decays.

DOI: [10.1103/PhysRevLett.133.191902](https://doi.org/10.1103/PhysRevLett.133.191902)

Recent experimental searches have not found evidence for beyond the standard model (BSM) physics. Therefore, new models with unconventional experimental signatures that may have evaded previous constraints are being examined more closely. In particular, hidden valley (HV) models [1–6] predict a wide array of possible signals and have the potential to address unanswered questions in the standard model (SM), including the nature of dark matter [6] and the difference between the vacuum expectation value of the Higgs field and the Planck scale, known as the hierarchy problem [2]. The HV models considered here include a dark sector that extends the SM with a non-Abelian gauge group, similar to quantum chromodynamics (QCD), with new matter and gauge fields analogous to the SM quark and gluon fields. The SM particles are neutral under the new, dark interaction—“dark QCD”—and communicate with this sector only through a mediator particle that couples to both sectors.

In this Letter, we present the first dedicated search for a characteristic final state consisting of many low-momentum, isotropically distributed particles, which can be described as a soft unclustered energy pattern (SUEP). This search uses data corresponding to a total integrated luminosity of  $138 \text{ fb}^{-1}$  from proton-proton collisions at a center-of-mass energy of 13 TeV, collected with the CMS detector at the CERN LHC in 2016–2018. The concept of SUEPs was first introduced in Ref. [7] and later expanded in Ref. [8] as a signature of HV models. They had been expected to evade conventional collider data collection

strategies and to be difficult to distinguish from energy deposits from multiple proton-proton interactions (pileup). Similar signatures can arise in other models, such as many-step decays in a hidden sector [9], theories with extra spatial dimensions [10–12], and instantons [13].

The model that motivates this search includes a quasi-conformal dark sector where the dark QCD force has a large 't Hooft coupling  $\lambda \gg 1$  above its confinement scale. When dark partons are produced, they shower and form dark mesons, whose mass scale is much smaller than the mediator mass scale. The showering process includes efficient branching over a larger energy range than SM QCD, and all information about the momenta of the initial partons is lost. The result is a high multiplicity of light HV bound states emitted with a spherical, rather than conical, distribution in the center-of-mass frame of the shower.

This search focuses on a benchmark scenario in which a dark QCD sector is accessed by a heavy scalar mediator  $S$ , which is produced via gluon fusion and couples directly to a dark quark-antiquark pair. If the dark quark masses  $m_{q_D}$  are below the confinement scale  $\Lambda_D$ , and  $\Lambda_D \ll \sqrt{s}$ , the dark quarks undergo a quasiconformal showering and form an isotropic spray of dark pseudoscalar mesons  $\phi$ . In this strongly coupled model, the  $\phi$   $p_T$  spectrum can be described by a Boltzmann distribution determined by the mass of the dark meson,  $m_\phi$ , and a temperature  $T_D$  at the scale of the cutoff,  $\Lambda_D$ . Each  $\phi$  subsequently decays to a pair of dark photons  $A'$ . The dark photon kinetically mixes with the SM hypercharge gauge field and decays promptly to SM particles. A prompt decay is chosen rather than a displaced decay, which would result in an emerging jet signature [14,15], or extremely long lifetimes, which would result in missing transverse momentum or semivisible jets [16,17]. To enforce promptness, defined as a decay length less than 1 mm, and to avoid dark photon mass ( $m_{A'}$ ) ranges that would already be excluded by collider searches [8], we choose  $m_{A'}$  values at the GeV scale. The decay branching

\*Full author list given at the end of the Letter.

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International license](https://creativecommons.org/licenses/by/4.0/). Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI. Funded by SCOAP<sup>3</sup>.

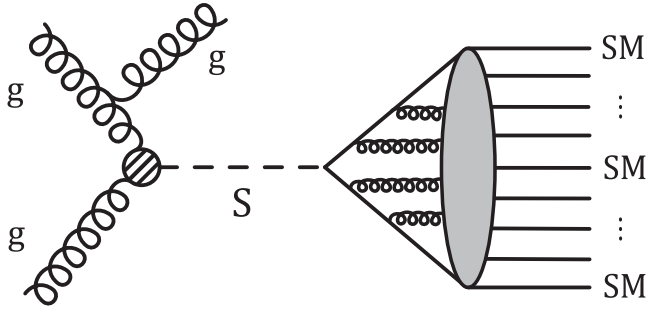


FIG. 1. A schematic Feynman diagram of the benchmark signal model resulting in a SUEP signature.

fraction ( $\mathcal{B}$ ) is dictated by the  $m_{A'}$  value [18]. We consider three cases with different branching fractions:  $m_{A'} = 0.5$  GeV ( $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$  with  $\mathcal{B} = 40\%, 40\%, 20\%$ ),  $m_{A'} = 0.7$  GeV ( $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$  with  $\mathcal{B} = 15\%, 15\%, 70\%$ ), and  $m_{A'} = 1.0$  GeV ( $A' \rightarrow \pi^+\pi^-$  with  $\mathcal{B} = 100\%$ ). The parameters that describe this dark sector model— $m_S$ ,  $m_\phi$ ,  $T_D$ , and  $m_{A'}$ —can be varied to access a wide spectrum of novel topologies that are characterized by the number, momenta, and particle type of the final-state charged tracks. A schematic diagram for this signal model is shown in Fig. 1.

Signal samples are generated using a PYTHIA plugin based on Refs. [8,19]. Multijet QCD samples used for closure tests are produced with MadGraph5\_aMC@NLO 2.6.5 [20]. The PYTHIA 8.240 [21] package is used for parton showering, hadronization, and the underlying event simulation, with the event tune CP5 [22]. The NNPDF 3.1 [23] set of parton distribution functions is used. The Geant4 package [24] is employed to perform a detailed simulation of the CMS detector response. Signal samples are generated with various model parameter values:  $m_\phi$ ,  $T_D$ ,  $m_{A'}$ , and the mediator mass  $m_S$ , limited by what is feasibly produced at the LHC;  $m_{A'}$  is varied as described above. Low values of  $T_D/m_\phi (\leq 0.25)$  are not expected to be realized by any pseudoconformal hidden sector, while high values constitute the “dark pion regime,” where an approximate symmetry generates pseudo-Goldstone bosons [25].

The CMS apparatus [26] is a multipurpose, nearly hermetic detector, designed to trigger on [27,28] and identify electrons, muons, photons, and hadrons [29–31]. A global “particle-flow” algorithm [32] aims to reconstruct all individual particles in an event, combining information provided by the all-silicon inner tracker and by the crystal electromagnetic and brass-scintillator hadron calorimeters, operating inside a 3.8 T superconducting solenoid, with data from the gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. The primary vertex (PV) is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone, as described in Sec. 9.4.1 of Ref. [33]. The reconstructed particles (particle-flow candidates) are

clustered into jets using the anti- $k_T$  algorithm [34,35] with a distance parameter of  $R = 0.4$ , after rejecting charged hadrons that do not originate from the PV but rather from pileup interactions; subsequently, neutral pileup contributions are subtracted [36].

This search uses events that pass a hadronic trigger with a threshold of  $H_T > 900(1050)$  GeV for 2016 (2017 and 2018), where  $H_T$  is defined as the scalar  $p_T$  sum of jets with  $p_T > 30$  GeV and  $|\eta| < 2.5$ . In addition, an offline selection of  $H_T > 1200$  GeV is applied to all data to ensure the trigger is efficient. This implies that all potential SUEP events will have large amounts of hadronic activity. As a consequence, the SUEP system will recoil against an initial state radiation (ISR) jet with large  $p_T$  and therefore will be highly boosted and central in the detector. In addition to this selection, events are rejected if they contain an electron or muon satisfying  $p_T > 25$  GeV,  $|\eta| < 2.4$ , and isolation requirements [29,30], in order to avoid any overlap with associated production channels where a  $W$  or  $Z$  boson is produced and decays leptonically.

For events passing the trigger, reconstructed charged-particle tracks fitting to the PV (and are therefore not associated with pileup vertices) with  $p_T > 0.7$  GeV and  $|\eta| < 2.5$  are clustered into wide jets using the anti- $k_T$  algorithm with a distance parameter of  $R = 1.5$ . These wide jets have no additional requirements except to have  $p_T > 150$  GeV, which removes some events associated with soft QCD while retaining a signal efficiency of  $\approx 100\%$ . The two wide jets with the highest  $p_T$  are defined as the SUEP-ISR system, where the jet with the larger number of tracks is defined as the SUEP candidate, while the other is defined as the ISR candidate. The number of constituent tracks in the SUEP candidate jet is defined as  $n_{\text{constituent}}^{\text{SUEP}}$ . These tracks are then boosted into the rest frame of the SUEP candidate, where the scalar mediator decay pattern is expected to be spherically symmetric. The sphericity of the boosted SUEP candidate is defined using the second and third largest eigenvalues ( $\lambda_2, \lambda_3$ ) of the infrared and collinearly safe generalized sphericity tensor:  $S_{\text{boosted}}^{\text{SUEP}} \equiv \frac{3}{2}(\lambda_2 + \lambda_3)$  [37]. The  $S_{\text{boosted}}^{\text{SUEP}}$  can range from 0, maximally nonspherical, to 1, perfectly spherical. Events where the SUEP candidates have  $n_{\text{constituent}}^{\text{SUEP}} < 30$  or  $S_{\text{boosted}}^{\text{SUEP}} < 0.3$  are rejected, while the signal region (SR) is defined to include events with  $n_{\text{constituent}}^{\text{SUEP}} > 70$  and  $S_{\text{boosted}}^{\text{SUEP}} > 0.5$ .

The primary background consists of events from the QCD multijet process with a large number of tracks. The background in this search is estimated from data, using the extended “ABCD” method proposed in Ref. [38]. The ABCD method makes use of two variables, chosen here to be  $S_{\text{boosted}}^{\text{SUEP}}$  and  $n_{\text{constituent}}^{\text{SUEP}}$ . The classical ABCD method defines one signal region (SR) that includes events passing selection requirements on the two variables and three control regions (CRs) that include events failing one or both selection requirements (“pass-fail,” “fail-pass,” and

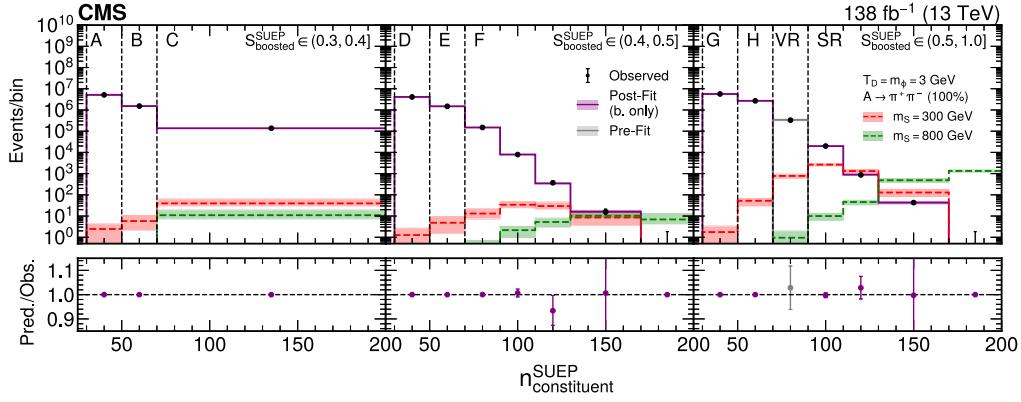


FIG. 2. The number of observed events as a function of the number of tracks in the SUEP candidate, for all CRs A–H and the SR, as well as two signal samples. The three figures correspond to contiguous  $S_{\text{boosted}}^{\text{SUEP}} \in (0.3, 0.4]$ ,  $S_{\text{boosted}}^{\text{SUEP}} \in (0.4, 0.5]$ , and  $S_{\text{boosted}}^{\text{SUEP}} \in (0.5, 1.0]$  ranges. The prefit predicted background distribution is shown in the VR, the first bin of the SR. For all other regions and bins, the postfit values for a background-only fit are shown.

“fail-fail”). In contrast, to correct for linear correlations between the discriminating variables, the extended ABCD method splits each of the pass-fail and fail-pass CRs into two regions and the fail-fail CR into four regions, resulting in a total of eight CRs, as shown in Fig. 2. In this analysis, the SR is further split into bins of  $n_{\text{constituent}}^{\text{SUEP}}$  with edges: 70, 90, 100, 130, 170,  $\infty$ . This binning is optimized for sensitivity across the full range of  $m_S$  values. The prediction for each bin  $i$  in the SR is computed from the yield  $N$  in each of the CRs,

$$N_{\text{SR}}^i = N_{\text{F}}^i \frac{N_{\text{F}} N_{\text{H}}^2 N_{\text{D}}^2 N_{\text{B}}^2}{N_{\text{G}} N_{\text{C}} N_{\text{A}} N_{\text{E}}^4}. \quad (1)$$

Because of the large number of QCD background events, the statistical uncertainty is small,  $< 0.3\%$  in all CRs. The contamination of SUEP signal events in the CRs is negligible for the same reason. The accuracy of the background estimation method is verified with simulated QCD multijet samples by testing the agreement between the prediction from simulated CRs and the simulated yield in the SR. Further, we define the first bin of the SR, which has negligible contribution from signal, as a validation region (VR) in which we perform a closure test.

Systematic uncertainties in the SUEP signal simulation originate from possible mismodeling in the event generation or detector response, and from correction factors that are included when determining the SR selection efficiency. These include uncertainties in the integrated luminosity measurement for each year of data taking [39–41] and the reweighting to match the observed pileup distribution. The variables used in the ABCD method are found not to have substantial dependence on the number of pileup vertices, so an additional uncertainty is not assigned. There is an uncertainty in the trigger efficiency as a function of  $H_{\text{T}}$ ; additionally, the uncertainties in the jet energy corrections and jet energy resolution affect the total  $H_{\text{T}}$  used to select

events. Uncertainties in the parton showering simulation and the track reconstruction algorithms are applied. The effect of the track reconstruction efficiency is estimated by comparing yields after artificially removing tracks based on measured reconstruction inefficiencies [42]. For the model in which the mediator has the same mass as the Higgs boson, additional  $p_{\text{T}}$  reweighting corrections are included [43]. Finally, corrections for a radiation-induced timing shift in the electromagnetic calorimeter readout, resulting in “prefiring” of the trigger system, are applied to 2016 and 2017 simulations [27]. The uncertainties in the parton shower modeling and the  $p_{\text{T}}$  reweighting corrections for the  $m_S = 125$  GeV case are the largest, corresponding to  $\sim 10\%$  of the signal yield. The other aforementioned systematic uncertainties correspond to 0%–4% of the signal yield.

Further systematic uncertainties in the prediction of the extended ABCD method are estimated from data. A first systematic uncertainty covers higher-order correlations between the sphericity and number of constituent tracks in the SUEP candidate that are not taken into account by the extended ABCD method. This is estimated using the ISR candidate, which is a set of tracks distinct from the SUEP candidate in each event. The ISR candidate is obtained by the same wide-jet clustering as the SUEP candidate in order to test the background estimation method by applying the same selections and ABCD method. The discrepancy between the total predicted yield and the measured yield in the SR of 8% is taken as a systematic uncertainty in the normalization value of the predicted background yield. As shown in Eq. (1), the computed prediction in each SR bin  $i$  is proportional to  $N_{\text{F}}^i N_{\text{F}} / N_{\text{C}}$ ; region  $F$  is subdivided, but region  $C$  is not, to reduce the statistical uncertainty. The difference in the  $n_{\text{constituent}}^{\text{SUEP}}$  distribution between CRs  $F$  and  $C$  is used as a proxy for the difference between CR  $F$  and the SR, which impacts the final prediction. The uncertainty is assessed as the ratio  $(N_{\text{F}}^i / N_{\text{F}}) / (N_{\text{C}}^i / N_{\text{C}})$ , measured by

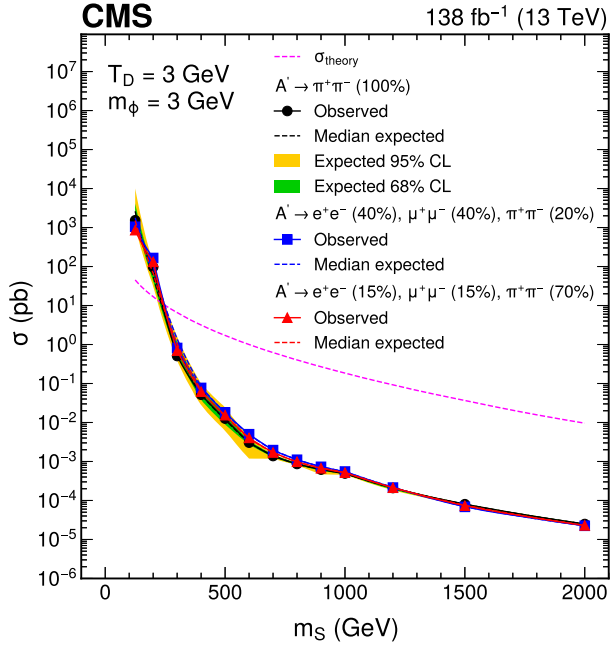


FIG. 3. The 95% CL exclusion limits on the production cross section  $\sigma$  are shown as a function of  $m_S$  for  $m_\phi = T_D = 3$  GeV, for all decay modes.

binning the  $C$  region and using the first two bins, which are the most populated. The ratio is linearly extrapolated to the less-populated bins as a function of the  $n_{\text{constituent}}^{\text{SUEP}}$  centroid for each SR bin and validated in simulation. This ratio approximates  $N_{\text{SR}}^i/N_{\text{F}}^i$ ; it is treated as correlated among all bins because of the extrapolation procedure and set to 100% for the last bin, which has no centroid.

We perform a binned maximum likelihood fit to the  $n_{\text{constituent}}^{\text{SUEP}}$  distribution in the SR, excluding the VR. For each individual SR bin, a Poisson likelihood term is used to describe the statistical fluctuations of the data around the expected central value. The expected values are calculated by the prediction from the extended ABCD method where the yields in all CRs are allowed to float. The signal-to-background ratios are different among the three data-taking periods, so they are kept separate in the fit. The observed and postfit yields are shown as a function of  $n_{\text{constituent}}^{\text{SUEP}}$  in Fig. 2.

We observe no significant excess of events over the SM prediction. The postfit predictions for the  $F$  and SR bins with the highest  $n_{\text{constituent}}^{\text{SUEP}}$  range are  $3.5 \times 10^{-6} \pm 8.4 \times 10^{-4}$  and  $1.2 \times 10^{-5} \pm 2.9 \times 10^{-3}$ , respectively. The modified frequentist construction  $\text{CL}_s$  [44,45] is used to compute 95% confidence level (CL) upper limits on the signal cross section. By comparing these limits to the theoretical cross section for the production of a BSM Higgs boson via gluon fusion through a pointlike effective interaction [46], ranges of the  $m_S - m_\phi - m_{A'} - T_D$  parameter space can be excluded. Figure 3 shows the 95% CL exclusion limits as a function of  $m_S$  for benchmark values of  $T_D$  and  $m_\phi$ . There is similar sensitivity to all  $A'$  decay cases considered. Figure 4 shows the exclusion limits for various scalar masses in the plane of  $m_\phi$  versus  $T_D$ , for the case  $A' \rightarrow \pi^+ \pi^-$ . We set stringent limits on the production cross section for the most SUEP-like region of the parameter space with  $m_S/T_D \sim 100$  and a final state characterized by a large multiplicity of tracks, which tends to populate the two rightmost bins of the SR, shown in Fig. 2.

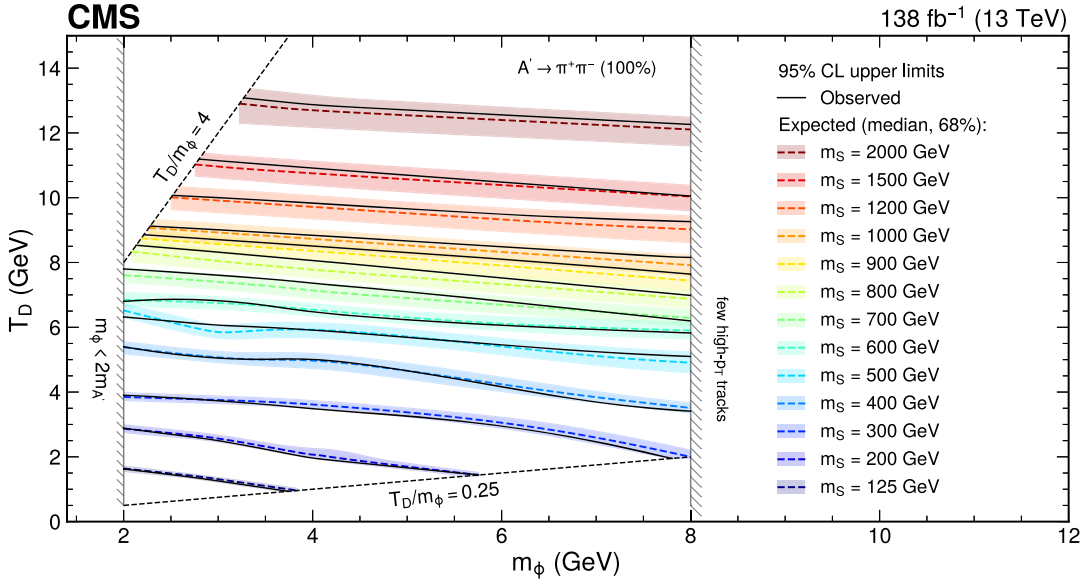


FIG. 4. The observed and expected exclusions for the nominal S cross section in the plane of  $m_\phi$  and  $T_D$ , for various  $m_S$  values, for the case  $m_{A'} = 1.0$  GeV ( $A' \rightarrow \pi^+ \pi^-$  with  $\mathcal{B} = 100\%$ ). The regions below the observed limits are excluded.

In summary, this Letter presents the first search for SUEPs. Data corresponding to an integrated luminosity of  $138 \text{ fb}^{-1}$  are used, collected with a trigger requiring a high scalar sum of jet transverse momenta and reconstructed with the full offline processing. This strategy preferentially selects events with initial-state radiation; the characteristic isotropic event shape of the SUEPs is recovered by boosting into the scalar mediator rest frame and removing the initial-state radiation particles. The number of tracks and the associated sphericity in the SUEP candidate are used to discriminate between the signal and the background from standard model quantum chromodynamics, which is estimated from data in suitable control regions. Stringent limits are placed on the most SUEP-like hidden valley scenarios with highly isotropic dark showers producing a large multiplicity of tracks.

*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: SC (Armenia), BMBWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, FAPERGS, and FAPESP (Brazil); MES and BNSF (Bulgaria); CERN; CAS, MoST, and NSFC (China); Minciencias (Colombia); MSES and CSF (Croatia); RIF (Cyprus); SENESCYT (Ecuador); ERC PRG, RVTT3, and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMBF, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); MES (Latvia); LMTLT (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MOS (Montenegro); MBIE (New Zealand); PAEC (Pakistan); MES and NSC (Poland); FCT (Portugal); MESTD (Serbia); MCIN/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

*Data availability*—Release and preservation of data used by the CMS Collaboration as the basis for publications is guided by the CMS data preservation, re-use, and open access policy [47].

- [1] M. Cvetič, P. Langacker, and G. Shiu, Phenomenology of a three family standard like string model, *Phys. Rev. D* **66**, 066004 (2002).
- [2] Z. Chacko, H.-S. Goh, and R. Harnik, The twin Higgs: Natural electroweak breaking from mirror symmetry, *Phys. Rev. Lett.* **96**, 231802 (2006).
- [3] M. J. Strassler and K. M. Zurek, Echoes of a hidden valley at hadron colliders, *Phys. Lett. B* **651**, 374 (2007).
- [4] T. Hur, D.-W. Jung, P. Ko, and J. Y. Lee, Electroweak symmetry breaking and cold dark matter from strongly interacting hidden sector, *Phys. Lett. B* **696**, 262 (2011).
- [5] S. A. Abel, M. D. Goodsell, J. Jaeckel, V. V. Khoze, and A. Ringwald, Kinetic mixing of the photon with hidden U(1)s in string phenomenology, *J. High Energy Phys.* **07** (2008) 124.
- [6] Y. Bai and P. Schwaller, Scale of dark QCD, *Phys. Rev. D* **89**, 063522 (2014).
- [7] M. J. Strassler, Why unparticle models with mass gaps are examples of hidden valleys, [arXiv:0801.0629](https://arxiv.org/abs/0801.0629).
- [8] S. Knapen, S. Pagan Griso, M. Papucci, and D. J. Robinson, Triggering soft bombs at the LHC, *J. High Energy Phys.* **08** (2017) 076.
- [9] G. Elor, N. L. Rodd, and T. R. Slatyer, Multistep cascade annihilations of dark matter and the galactic center excess, *Phys. Rev. D* **91**, 103531 (2015).
- [10] CMS Collaboration, Search for microscopic black hole signatures at the Large Hadron Collider, *Phys. Lett. B* **697**, 434 (2011).
- [11] S. C. Park, Black holes and the LHC: A review, *Prog. Part. Nucl. Phys.* **67**, 617 (2012).
- [12] A. Costantino, S. Fichet, and P. Tanedo, Effective field theory in AdS: Continuum regime, soft bombs, and IR emergence, *Phys. Rev. D* **102**, 115038 (2020).
- [13] S. Amoroso, D. Kar, and M. Schott, How to discover QCD instantons at the LHC, *Eur. Phys. J. C* **81**, 624 (2021).
- [14] P. Schwaller, D. Stolarski, and A. Weiler, Emerging jets, *J. High Energy Phys.* **05** (2015) 059.
- [15] CMS Collaboration, Search for dark QCD with emerging jets in proton-proton collisions at  $\sqrt{s} = 13 \text{ TeV}$ , *J. High Energy Phys.* **07** (2024) 142.
- [16] T. Cohen, M. Lisanti, and H. K. Lou, Semivisible jets: Dark matter undercover at the LHC, *Phys. Rev. Lett.* **115**, 171804 (2015).
- [17] CMS Collaboration, Search for resonant production of strongly coupled dark matter in proton-proton collisions at 13 TeV, *J. High Energy Phys.* **06** (2022) 156.
- [18] M. Graham, C. Hearty, and M. Williams, Searches for dark photons at accelerators, *Annu. Rev. Nucl. Part. Sci.* **71**, 37 (2021).
- [19] S. Knapen, J. Shelton, and D. Xu, Perturbative benchmark models for a dark shower search program, *Phys. Rev. D* **103**, 115013 (2021).
- [20] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* **07** (2014) 079.
- [21] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and

- P. Z. Skands, An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* **191**, 159 (2015).
- [22] CMS Collaboration, Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements, *Eur. Phys. J. C* **80**, 4 (2020).
- [23] R. D. Ball *et al.* (NNPDF Collaboration), Parton distributions from high-precision collider data, *Eur. Phys. J. C* **77**, 663 (2017).
- [24] S. Agostinelli *et al.* (GEANT4 Collaboration), Geant4—a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 250 (2003).
- [25] J. Barron, D. Curtin, G. Kasieczka, T. Plehn, and A. Spourdalakis, Unsupervised hadronic SUEP at the LHC, *J. High Energy Phys.* **12** (2021) 129.
- [26] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* **3**, S08004 (2008).
- [27] CMS Collaboration, Performance of the CMS Level-1 trigger in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **15**, P10017 (2020).
- [28] CMS Collaboration, The CMS trigger system, *J. Instrum.* **12**, P01020 (2017).
- [29] CMS Collaboration, Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC, *J. Instrum.* **16**, P05014 (2021).
- [30] CMS Collaboration, Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. Instrum.* **13**, P06015 (2018).
- [31] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, *J. Instrum.* **9**, P10009 (2014).
- [32] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, *J. Instrum.* **12**, P10003 (2017).
- [33] CMS Collaboration, Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid, CMS Technical Proposal, Reports No. CERN-LHCC-2015-010, No. CMS-TDR-15-02, 2015.
- [34] M. Cacciari, G. P. Salam, and G. Soyez, The anti- $k_T$  jet clustering algorithm, *J. High Energy Phys.* **04** (2008) 063.
- [35] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, *Eur. Phys. J. C* **72**, 1896 (2012).
- [36] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, *J. Instrum.* **12**, P02014 (2017).
- [37] C. Cesarotti, M. Reece, and M. J. Strassler, The efficacy of event isotropy as an event shape observable, *J. High Energy Phys.* **07** (2021) 215.
- [38] S. Choi and H. Oh, Improved extrapolation methods of data-driven background estimations in high energy physics, *Eur. Phys. J. C* **81**, 643 (2021).
- [39] CMS Collaboration, Precision luminosity measurement in proton-proton collisions at  $\sqrt{s} = 13$  TeV in 2015 and 2016 at CMS, *Eur. Phys. J. C* **81**, 800 (2021).
- [40] CMS Collaboration, CMS luminosity measurement for the 2017 data-taking period at  $\sqrt{s} = 13$  TeV, CMS Physics Analysis Summary, Report No. CMS-PAS-LUM-17-004, 2018, <https://cds.cern.ch/record/2621960>.
- [41] CMS Collaboration, CMS luminosity measurement for the 2018 data-taking period at  $\sqrt{s} = 13$  TeV, CMS Physics Analysis Summary, Report No. CMS-PAS-LUM-18-002, 2019, <https://cds.cern.ch/record/2676164>.
- [42] CMS Collaboration, Measurement of the primary Lund jet plane density in proton-proton collisions at  $\sqrt{s} = 13$  TeV, *J. High Energy Phys.* **05** (2024) 116.
- [43] K. Becker *et al.*, Precise predictions for boosted Higgs production, *SciPost Phys. Core* **7**, 001 (2024).
- [44] T. Junk, Confidence level computation for combining searches with small statistics, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434**, 435 (1999).
- [45] A. L. Read, Presentation of search results: The CL<sub>s</sub> technique, *J. Phys. G* **28**, 2693 (2002).
- [46] LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: 4. Deciphering the nature of the Higgs sector, CERN Report No. CERN-2017-002-M, 2016, 10.23731/CYRM-2017-002.
- [47] <https://cms-docdb.cern.ch/cgi-bin/PublicDocDB/RetrieveFile?docid=6032&filename=CMSDataPolicyV1.2.pdf&version=2>.

A. Hayrapetyan,<sup>1</sup> A. Tumasyan<sup>1,b</sup> W. Adam<sup>2</sup> J. W. Andrejkovic,<sup>2</sup> T. Bergauer<sup>2</sup> S. Chatterjee<sup>2</sup> K. Damanakis<sup>2</sup>,  
M. Dragicevic<sup>2</sup> P. S. Hussain<sup>2</sup> M. Jeitler<sup>2,c</sup> N. Krammer<sup>2</sup> A. Li<sup>2</sup> D. Liko<sup>2</sup> I. Mikulec<sup>2</sup> J. Schieck<sup>2,c</sup>  
R. Schöfbeck<sup>2</sup> D. Schwarz<sup>2</sup> M. Sonawane<sup>2</sup> S. Templ<sup>2</sup> W. Waltenberger<sup>2</sup> C.-E. Wulz<sup>2,c</sup> M. R. Darwish<sup>3,d</sup>  
T. Janssen<sup>3</sup> P. Van Mechelen<sup>3</sup> N. Breugelmans,<sup>4</sup> J. D’Hondt<sup>4</sup> S. Dansana<sup>4</sup> A. De Moor<sup>4</sup> M. Delcourt<sup>4</sup>,  
F. Heyen,<sup>4</sup> S. Lowette<sup>4</sup> I. Makarenko<sup>4</sup> D. Müller<sup>4</sup> S. Tavernier<sup>4</sup> M. Tytgat<sup>4,e</sup> G. P. Van Onsem<sup>4</sup>,  
S. Van Putte<sup>4</sup> D. Vannerom<sup>4</sup> B. Clerbaux<sup>5</sup> A. K. Das,<sup>5</sup> G. De Lentdecker<sup>5</sup> H. Evard<sup>5</sup> L. Favart<sup>5</sup>,  
P. Gianneios<sup>5</sup> D. Hohov<sup>5</sup> J. Jaramillo<sup>5</sup> A. Khalilzadeh,<sup>5</sup> F. A. Khan<sup>5</sup> K. Lee<sup>5</sup> M. Mahdavihorrani<sup>5</sup>,  
A. Malara<sup>5</sup> S. Paredes<sup>5</sup> M. A. Shahzad,<sup>5</sup> L. Thomas<sup>5</sup> M. Vanden Bemden<sup>5</sup> C. Vander Velde<sup>5</sup> P. Vanlaer<sup>5</sup>,  
M. De Coen<sup>6</sup> D. Dobur<sup>6</sup> G. Gokbulut<sup>6</sup> Y. Hong<sup>6</sup> J. Knolle<sup>6</sup> L. Lambrecht<sup>6</sup> D. Marckx<sup>6</sup> G. Mestdach,<sup>6</sup>  
K. Mota Amarilo<sup>6</sup> A. Samalan,<sup>6</sup> K. Skovpen<sup>6</sup> N. Van Den Bossche<sup>6</sup> J. van der Linden<sup>6</sup> L. Wezenbeek<sup>6</sup>,  
A. Benecke<sup>7</sup> A. Bethani<sup>7</sup> G. Bruno<sup>7</sup> C. Caputo<sup>7</sup> J. De Favereau De Jeneret<sup>7</sup> C. Delaere<sup>7</sup> I. S. Donertas<sup>7</sup>,  
A. Giammanco<sup>7</sup> A. O. Guzel<sup>7</sup> Sa. Jain<sup>7</sup> V. Lemaitre,<sup>7</sup> J. Lidrych<sup>7</sup> P. Mastrapasqua<sup>7</sup> T. T. Tran<sup>7</sup> S. Wertz<sup>7</sup>,  
G. A. Alves<sup>8</sup> M. Alves Gallo Pereira<sup>8</sup> E. Coelho<sup>8</sup> G. Correia Silva<sup>8</sup> C. Hensel<sup>8</sup> T. Menezes De Oliveira<sup>8</sup>,  
A. Moraes<sup>8</sup> P. Rebello Teles<sup>8</sup> M. Soeiro,<sup>8</sup> A. Vilela Pereira<sup>8,f</sup> W. L. Aldá Júnior<sup>9</sup> M. Barroso Ferreira Filho<sup>9</sup>

H. Brandao Malbouisson<sup>9</sup>, W. Carvalho<sup>9</sup>, J. Chinellato,<sup>9,g</sup> E. M. Da Costa<sup>9</sup>, G. G. Da Silveira<sup>9,h</sup>  
D. De Jesus Damiao<sup>9</sup>, S. Fonseca De Souza<sup>9</sup>, R. Gomes De Souza<sup>9</sup>, M. Macedo<sup>9</sup>, J. Martins<sup>9,i</sup>, C. Mora Herrera<sup>9</sup>,  
L. Mundim<sup>9</sup>, H. Nogima<sup>9</sup>, J. P. Pinheiro<sup>9</sup>, A. Santoro<sup>9</sup>, A. Sznajder<sup>9</sup>, M. Thiel<sup>9</sup>, C. A. Bernardes<sup>10,h</sup>,  
L. Calligaris<sup>10</sup>, T. R. Fernandez Perez Tomei<sup>10</sup>, E. M. Gregores<sup>10</sup>, I. Maitto Silverio<sup>10</sup>, P. G. Mercadante<sup>10</sup>,  
S. F. Novaes<sup>10</sup>, B. Orzari<sup>10</sup>, Sandra S. Padula<sup>10</sup>, A. Aleksandrov<sup>11</sup>, G. Antchev<sup>11</sup>, R. Hadjiiska<sup>11</sup>, P. Iaydjiev<sup>11</sup>,  
M. Misheva<sup>11</sup>, M. Shopova<sup>11</sup>, G. Sultanov<sup>11</sup>, A. Dimitrov<sup>12</sup>, L. Litov<sup>12</sup>, B. Pavlov<sup>12</sup>, P. Petkov<sup>12</sup>, A. Petrov<sup>12</sup>,  
E. Shumka<sup>12</sup>, S. Keshri<sup>13</sup>, S. Thakur<sup>13</sup>, T. Cheng<sup>14</sup>, T. Javaid<sup>14</sup>, L. Yuan<sup>14</sup>, Z. Hu<sup>15</sup>, Z. Liang<sup>15</sup>, J. Liu<sup>15</sup>,  
K. Yi<sup>15,j,k</sup>, G. M. Chen<sup>16,l</sup>, H. S. Chen<sup>16,l</sup>, M. Chen<sup>16,l</sup>, F. Iemmi<sup>16</sup>, C. H. Jiang<sup>16</sup>, A. Kapoor<sup>16,m</sup>, H. Liao<sup>16</sup>,  
Z.-A. Liu<sup>16,n</sup>, R. Sharma<sup>16,o</sup>, J. N. Song<sup>16,n</sup>, J. Tao<sup>16</sup>, C. Wang<sup>16,l</sup>, J. Wang<sup>16</sup>, Z. Wang<sup>16,l</sup>, H. Zhang<sup>16</sup>,  
J. Zhao<sup>16</sup>, A. Agapitos<sup>17</sup>, Y. Ban<sup>17</sup>, S. Deng<sup>17</sup>, B. Guo<sup>17</sup>, C. Jiang<sup>17</sup>, A. Levin<sup>17</sup>, C. Li<sup>17</sup>, Q. Li<sup>17</sup>, Y. Mao<sup>17</sup>,  
S. Qian<sup>17</sup>, S. J. Qian<sup>17</sup>, X. Qin<sup>17</sup>, X. Sun<sup>17</sup>, D. Wang<sup>17</sup>, H. Yang<sup>17</sup>, L. Zhang<sup>17</sup>, Y. Zhao<sup>17</sup>, C. Zhou<sup>17</sup>, S. Yang<sup>18</sup>,  
Z. You<sup>19</sup>, K. Jaffel<sup>20</sup>, N. Lu<sup>20</sup>, G. Bauer<sup>21,p</sup>, B. Li<sup>21</sup>, J. Zhang<sup>21</sup>, X. Gao<sup>22,q</sup>, Z. Lin<sup>23</sup>, C. Lu<sup>23</sup>, M. Xiao<sup>23</sup>,  
C. Avila<sup>24</sup>, D. A. Barbosa Trujillo<sup>24</sup>, A. Cabrera<sup>24</sup>, C. Florez<sup>24</sup>, J. Fraga<sup>24</sup>, J. A. Reyes Vega<sup>24</sup>, F. Ramirez<sup>25</sup>,  
C. Rendón<sup>25</sup>, M. Rodriguez<sup>25</sup>, A. A. Ruales Barbosa<sup>25</sup>, J. D. Ruiz Alvarez<sup>25</sup>, D. Giljanovic<sup>26</sup>, N. Godinovic<sup>26</sup>,  
D. Lelas<sup>26</sup>, A. Sculac<sup>26</sup>, M. Kovac<sup>27</sup>, A. Petkovic<sup>27</sup>, T. Sculac<sup>27</sup>, P. Bargassa<sup>28</sup>, V. Brigljevic<sup>28</sup>, B. K. Chitroda<sup>28</sup>,  
D. Ferencek<sup>28</sup>, K. Jakovcic<sup>28</sup>, S. Mishra<sup>28</sup>, A. Starodumov<sup>28,r</sup>, T. Susa<sup>28</sup>, A. Attikis<sup>29</sup>, K. Christoforou<sup>29</sup>,  
A. Hadjiagapiou<sup>29</sup>, C. Leonidou<sup>29</sup>, J. Mousa<sup>29</sup>, C. Nicolaou<sup>29</sup>, L. Paizanos<sup>29</sup>, F. Ptochos<sup>29</sup>, P. A. Razis<sup>29</sup>,  
H. Rykaczewski<sup>29</sup>, H. Saka<sup>29</sup>, A. Stepennov<sup>29</sup>, M. Finger<sup>30</sup>, M. Finger Jr.<sup>30</sup>, A. Kveton<sup>30</sup>, E. Carrera Jarrin<sup>31</sup>,  
Y. Assran<sup>32,s,t</sup>, B. El-mahdy<sup>32</sup>, S. Elgammal<sup>32,t</sup>, M. A. Mahmoud<sup>33</sup>, Y. Mohammed<sup>33</sup>, K. Ehataht<sup>34</sup>, M. Kadastik<sup>34</sup>,  
T. Lange<sup>34</sup>, S. Nandan<sup>34</sup>, C. Nielsen<sup>34</sup>, J. Pata<sup>34</sup>, M. Raidal<sup>34</sup>, L. Tani<sup>34</sup>, C. Veelken<sup>34</sup>, H. Kirschenmann<sup>35</sup>,  
K. Osterberg<sup>35</sup>, M. Voutilainen<sup>35</sup>, S. Bharthuar<sup>36</sup>, N. Bin Norjoharuddeen<sup>36</sup>, E. Brücken<sup>36</sup>, F. Garcia<sup>36</sup>,  
P. Inkaew<sup>36</sup>, K. T. S. Kallonen<sup>36</sup>, T. Lampén<sup>36</sup>, K. Lassila-Perini<sup>36</sup>, S. Lehti<sup>36</sup>, T. Lindén<sup>36</sup>, L. Martikainen<sup>36</sup>,  
M. Myllymäki<sup>36</sup>, M. m. Rantanen<sup>36</sup>, H. Siikonen<sup>36</sup>, J. Tuominiemi<sup>36</sup>, P. Luukka<sup>37</sup>, H. Petrow<sup>37</sup>, M. Besancon<sup>38</sup>,  
F. Couderc<sup>38</sup>, M. Dejardin<sup>38</sup>, D. Denegri<sup>38</sup>, J. L. Faure<sup>38</sup>, F. Ferri<sup>38</sup>, S. Ganjour<sup>38</sup>, P. Gras<sup>38</sup>,  
G. Hamel de Monchenault<sup>38</sup>, V. Lohezic<sup>38</sup>, J. Malcles<sup>38</sup>, F. Orlandi<sup>38</sup>, L. Portales<sup>38</sup>, A. Rosowsky<sup>38</sup>,  
M. Ö. Sahin<sup>38</sup>, A. Savoy-Navarro<sup>38,u</sup>, P. Simkina<sup>38</sup>, M. Titov<sup>38</sup>, M. Tornago<sup>38</sup>, F. Beaudette<sup>39</sup>, P. Busson<sup>39</sup>,  
A. Cappati<sup>39</sup>, C. Charlot<sup>39</sup>, M. Chiusi<sup>39</sup>, F. Damas<sup>39</sup>, O. Davignon<sup>39</sup>, A. De Wit<sup>39</sup>, I. T. Ehle<sup>39</sup>,  
B. A. Fontana Santos Alves<sup>39</sup>, S. Ghosh<sup>39</sup>, A. Gilbert<sup>39</sup>, R. Granier de Cassagnac<sup>39</sup>, A. Hakimi<sup>39</sup>,  
B. Harikrishnan<sup>39</sup>, L. Kalipoliti<sup>39</sup>, G. Liu<sup>39</sup>, M. Nguyen<sup>39</sup>, C. Ochando<sup>39</sup>, R. Salerno<sup>39</sup>, J. B. Sauvan<sup>39</sup>,  
Y. Sirois<sup>39</sup>, L. Urda Gómez<sup>39</sup>, E. Vernazza<sup>39</sup>, A. Zabi<sup>39</sup>, A. Zghiche<sup>39</sup>, J.-L. Agram<sup>40,v</sup>, J. Andrea<sup>40</sup>,  
D. Apparú<sup>40</sup>, D. Bloch<sup>40</sup>, J.-M. Brom<sup>40</sup>, E. C. Chabert<sup>40</sup>, C. Collard<sup>40</sup>, S. Falke<sup>40</sup>, U. Goerlach<sup>40</sup>,  
R. Haeblerle<sup>40</sup>, A.-C. Le Bihan<sup>40</sup>, M. Meena<sup>40</sup>, O. Poncet<sup>40</sup>, G. Saha<sup>40</sup>, M. A. Sessini<sup>40</sup>, P. Van Hove<sup>40</sup>,  
P. Vaucelle<sup>40</sup>, A. Di Florio<sup>41</sup>, D. Amram<sup>42</sup>, S. Beauceron<sup>42</sup>, B. Blancon<sup>42</sup>, G. Boudoul<sup>42</sup>, N. Chanon<sup>42</sup>,  
D. Contardo<sup>42</sup>, P. Depasse<sup>42</sup>, C. Dozen<sup>42,w</sup>, H. El Mamouni<sup>42</sup>, J. Fay<sup>42</sup>, S. Gascon<sup>42</sup>, M. Gouzevitch<sup>42</sup>,  
C. Greenberg<sup>42</sup>, G. Grenier<sup>42</sup>, B. Ille<sup>42</sup>, E. Jourdain<sup>42</sup>, I. B. Laktineh<sup>42</sup>, M. Lethuillier<sup>42</sup>, L. Mirabito<sup>42</sup>, S. Perries<sup>42</sup>,  
A. Purohit<sup>42</sup>, M. Vander Donckt<sup>42</sup>, P. Verdier<sup>42</sup>, J. Xiao<sup>42</sup>, G. Adamov<sup>43</sup>, I. Lomidze<sup>43</sup>, Z. Tsamalaidze<sup>43,r</sup>,  
V. Botta<sup>44</sup>, L. Feld<sup>44</sup>, K. Klein<sup>44</sup>, M. Lipinski<sup>44</sup>, D. Meuser<sup>44</sup>, A. Pauls<sup>44</sup>, D. Pérez Adán<sup>44</sup>, N. Röwert<sup>44</sup>,  
M. Teroerde<sup>44</sup>, S. Diekmann<sup>45</sup>, A. Dodonova<sup>45</sup>, N. Eich<sup>45</sup>, D. Eliseev<sup>45</sup>, F. Engelke<sup>45</sup>, J. Erdmann<sup>45</sup>,  
M. Erdmann<sup>45</sup>, P. Fackeldey<sup>45</sup>, B. Fischer<sup>45</sup>, T. Hebbeker<sup>45</sup>, K. Hoepfner<sup>45</sup>, F. Ivone<sup>45</sup>, A. Jung<sup>45</sup>, M. y. Lee<sup>45</sup>,  
F. Mausolf<sup>45</sup>, M. Merschmeyer<sup>45</sup>, A. Meyer<sup>45</sup>, S. Mukherjee<sup>45</sup>, D. Noll<sup>45</sup>, F. Nowotny<sup>45</sup>, A. Pozdnyakov<sup>45</sup>,  
Y. Rath<sup>45</sup>, W. Redjeb<sup>45</sup>, F. Rehm<sup>45</sup>, H. Reithler<sup>45</sup>, V. Sarkisovi<sup>45</sup>, A. Schmidt<sup>45</sup>, A. Sharma<sup>45</sup>, J. L. Spahr<sup>45</sup>,  
A. Stein<sup>45</sup>, F. Torres Da Silva De Araujo<sup>45,x</sup>, S. Wiedenbeck<sup>45</sup>, S. Zaleski<sup>45</sup>, C. Dziwok<sup>46</sup>, G. Flügge<sup>46</sup>, T. Kress<sup>46</sup>,  
A. Nowack<sup>46</sup>, O. Pooth<sup>46</sup>, A. Stahl<sup>46</sup>, T. Ziemons<sup>46</sup>, A. Zotz<sup>46</sup>, H. Aarup Petersen<sup>47</sup>, M. Aldaya Martin<sup>47</sup>,  
J. Alimena<sup>47</sup>, S. Amoroso<sup>47</sup>, Y. An<sup>47</sup>, J. Bach<sup>47</sup>, S. Baxter<sup>47</sup>, M. Bayatmakou<sup>47</sup>, H. Becerril Gonzalez<sup>47</sup>,  
O. Behnke<sup>47</sup>, A. Belvedere<sup>47</sup>, S. Bhattacharya<sup>47</sup>, F. Blekman<sup>47,y</sup>, K. Borrás<sup>47,z</sup>, A. Campbell<sup>47</sup>, A. Cardini<sup>47</sup>,  
C. Cheng<sup>47</sup>, F. Colombina<sup>47</sup>, S. Consuegra Rodríguez<sup>47</sup>, M. De Silva<sup>47</sup>, G. Eckerlin<sup>47</sup>, D. Eckstein<sup>47</sup>,  
L. I. Estevez Banos<sup>47</sup>, O. Filatov<sup>47</sup>, E. Gallo<sup>47,y</sup>, A. Geiser<sup>47</sup>, V. Guglielmi<sup>47</sup>, M. Guthoff<sup>47</sup>, A. Hinzmann<sup>47</sup>,  
L. Jeppe<sup>47</sup>, B. Kaeck<sup>47</sup>, M. Kasemann<sup>47</sup>, C. Kleinwort<sup>47</sup>, R. Kogler<sup>47</sup>, M. Komm<sup>47</sup>, D. Krücker<sup>47</sup>, W. Lange<sup>47</sup>,  
D. Leyva Pernia<sup>47</sup>, K. Lipka<sup>47,aa</sup>, W. Lohmann<sup>47,bb</sup>, F. Lorkowski<sup>47</sup>, R. Mankel<sup>47</sup>, I.-A. Melzer-Pellmann<sup>47</sup>

M. Mendizabal Morentin<sup>47</sup>, A. B. Meyer<sup>47</sup>, G. Milella<sup>47</sup>, K. Moral Figueroa<sup>47</sup>, A. Mussgiller<sup>47</sup>, L. P. Nair<sup>47</sup>, J. Niedziela<sup>47</sup>, A. Nürnberg<sup>47</sup>, Y. Otari<sup>47</sup>, J. Park<sup>47</sup>, E. Ranken<sup>47</sup>, A. Raspereza<sup>47</sup>, D. Rastorguev<sup>47</sup>, J. Rübenach<sup>47</sup>, L. Rygaard<sup>47</sup>, A. Saggio<sup>47</sup>, M. Scham<sup>47,cc,z</sup>, S. Schnake<sup>47,z</sup>, P. Schütze<sup>47</sup>, C. Schwanenberger<sup>47,y</sup>, D. Selivanova<sup>47</sup>, K. Sharko<sup>47</sup>, M. Shchedrolosiev<sup>47</sup>, D. Stafford<sup>47</sup>, F. Vazzoler<sup>47</sup>, A. Ventura Barroso<sup>47</sup>, R. Walsh<sup>47</sup>, D. Wang<sup>47</sup>, Q. Wang<sup>47</sup>, Y. Wen<sup>47</sup>, K. Wichmann<sup>47</sup>, L. Wiens<sup>47,z</sup>, C. Wissing<sup>47</sup>, Y. Yang<sup>47</sup>, A. Zimmermann Castro Santos<sup>47</sup>, A. Albrecht<sup>48</sup>, S. Albrecht<sup>48</sup>, M. Antonello<sup>48</sup>, S. Bein<sup>48</sup>, L. Benato<sup>48</sup>, S. Bollweg<sup>48</sup>, M. Bonanomi<sup>48</sup>, P. Connor<sup>48</sup>, K. El Morabit<sup>48</sup>, Y. Fischer<sup>48</sup>, E. Garutti<sup>48</sup>, A. Grohsjean<sup>48</sup>, J. Haller<sup>48</sup>, H. R. Jabusch<sup>48</sup>, G. Kasieczka<sup>48</sup>, P. Keicher<sup>48</sup>, R. Klanner<sup>48</sup>, W. Korcari<sup>48</sup>, T. Kramer<sup>48</sup>, C. c. Kuo<sup>48</sup>, V. Kutzner<sup>48</sup>, F. Labe<sup>48</sup>, J. Lange<sup>48</sup>, A. Lobanov<sup>48</sup>, C. Matthies<sup>48</sup>, L. Moureaux<sup>48</sup>, M. Mrowietz<sup>48</sup>, A. Nigamova<sup>48</sup>, Y. Nissan<sup>48</sup>, A. Paasch<sup>48</sup>, K. J. Pena Rodriguez<sup>48</sup>, T. Quadfasel<sup>48</sup>, B. Raciti<sup>48</sup>, M. Rieger<sup>48</sup>, D. Savoie<sup>48</sup>, J. Schindler<sup>48</sup>, P. Schleper<sup>48</sup>, M. Schröder<sup>48</sup>, J. Schwandt<sup>48</sup>, M. Sommerhalder<sup>48</sup>, H. Stadie<sup>48</sup>, G. Steinbrück<sup>48</sup>, A. Tews<sup>48</sup>, M. Wolf<sup>48</sup>, S. Brommer<sup>49</sup>, M. Burkart<sup>49</sup>, E. Butz<sup>49</sup>, T. Chwalek<sup>49</sup>, A. Dierlamm<sup>49</sup>, A. Droll<sup>49</sup>, N. Faltermann<sup>49</sup>, M. Giffels<sup>49</sup>, A. Gottmann<sup>49</sup>, F. Hartmann<sup>49,dd</sup>, R. Hofsaess<sup>49</sup>, M. Horzela<sup>49</sup>, U. Husemann<sup>49</sup>, J. Kieseler<sup>49</sup>, M. Klute<sup>49</sup>, R. Koppenhöfer<sup>49</sup>, J. M. Lawhorn<sup>49</sup>, M. Link<sup>49</sup>, A. Lintuluoto<sup>49</sup>, B. Maier<sup>49</sup>, S. Maier<sup>49</sup>, S. Mitra<sup>49</sup>, M. Mormile<sup>49</sup>, Th. Müller<sup>49</sup>, M. Neukum<sup>49</sup>, M. Oh<sup>49</sup>, E. Pfeffer<sup>49</sup>, M. Presilla<sup>49</sup>, G. Quast<sup>49</sup>, K. Rabbertz<sup>49</sup>, B. Regnery<sup>49</sup>, N. Shadskiy<sup>49</sup>, I. Shvetsov<sup>49</sup>, H. J. Simonis<sup>49</sup>, L. Sowa<sup>49</sup>, L. Stockmeier<sup>49</sup>, K. Tauqeer<sup>49</sup>, M. Toms<sup>49</sup>, N. Trevisani<sup>49</sup>, R. F. Von Cube<sup>49</sup>, M. Wassmer<sup>49</sup>, S. Wieland<sup>49</sup>, F. Wittig<sup>49</sup>, R. Wolf<sup>49</sup>, X. Zuo<sup>49</sup>, G. Anagnostou<sup>50</sup>, G. Daskalakis<sup>50</sup>, A. Kyriakis<sup>50</sup>, A. Papadopoulos<sup>50,dd</sup>, A. Stakia<sup>50</sup>, P. Kontaxakis<sup>51</sup>, G. Melachroinos<sup>51</sup>, Z. Painesis<sup>51</sup>, I. Papavergou<sup>51</sup>, I. Paraskevas<sup>51</sup>, N. Saoulidou<sup>51</sup>, K. Theofilatos<sup>51</sup>, E. Tziaferi<sup>51</sup>, K. Vellidis<sup>51</sup>, I. Zisopoulos<sup>51</sup>, G. Bakas<sup>52</sup>, T. Chatzistavrou<sup>52</sup>, G. Karapostoli<sup>52</sup>, K. Kousouris<sup>52</sup>, I. Papakrivopoulos<sup>52</sup>, E. Siamarkou<sup>52</sup>, G. Tsipolitis<sup>52</sup>, A. Zacharopoulou<sup>52</sup>, K. Adamidis<sup>53</sup>, I. Bestintzanos<sup>53</sup>, I. Evangelou<sup>53</sup>, C. Foudas<sup>53</sup>, C. Kamtsikis<sup>53</sup>, P. Katsoulis<sup>53</sup>, P. Kokkas<sup>53</sup>, P. G. Kosmoglou Kioseoglou<sup>53</sup>, N. Manthos<sup>53</sup>, I. Papadopoulos<sup>53</sup>, J. Strogos<sup>53</sup>, C. Hajdu<sup>54</sup>, D. Horvath<sup>54,ee,ff</sup>, K. Márton<sup>54</sup>, A. J. Rádl<sup>54,gg</sup>, F. Sikler<sup>54</sup>, V. Veszpremi<sup>54</sup>, M. Csanád<sup>55</sup>, K. Farkas<sup>55</sup>, A. Fehérkuti<sup>55,hh</sup>, M. M. A. Gadallah<sup>55,ii</sup>, Á. Kadlecik<sup>55</sup>, P. Major<sup>55</sup>, G. Pásztor<sup>55</sup>, G. I. Veres<sup>55</sup>, B. Ujvari<sup>56</sup>, G. Zilizi<sup>56</sup>, G. Bencze<sup>57</sup>, S. Czellar<sup>57</sup>, J. Molnar<sup>57</sup>, Z. Szillasi<sup>57</sup>, T. Csorgo<sup>58,hh</sup>, T. Novak<sup>58</sup>, J. Babbar<sup>59</sup>, S. Bansal<sup>59</sup>, S. B. Beri<sup>59</sup>, V. Bhatnagar<sup>59</sup>, G. Chaudhary<sup>59</sup>, S. Chauhan<sup>59</sup>, N. Dhingra<sup>59,ij</sup>, A. Kaur<sup>59</sup>, A. Kaur<sup>59</sup>, H. Kaur<sup>59</sup>, M. Kaur<sup>59</sup>, S. Kumar<sup>59</sup>, K. Sandeep<sup>59</sup>, T. Sheokand<sup>59</sup>, J. B. Singh<sup>59</sup>, A. Singla<sup>59</sup>, A. Ahmed<sup>60</sup>, A. Bhardwaj<sup>60</sup>, A. Chhetri<sup>60</sup>, B. C. Choudhary<sup>60</sup>, A. Kumar<sup>60</sup>, A. Kumar<sup>60</sup>, M. Naimuddin<sup>60</sup>, K. Ranjan<sup>60</sup>, M. K. Saini<sup>60</sup>, S. Saumya<sup>60</sup>, S. Baradia<sup>61</sup>, S. Barman<sup>61,kk</sup>, S. Bhattacharya<sup>61</sup>, S. Das Gupta<sup>61</sup>, S. Dutta<sup>61</sup>, S. Dutta<sup>61</sup>, S. Sarkar<sup>61</sup>, M. M. Ameen<sup>62</sup>, P. K. Behera<sup>62</sup>, S. C. Behera<sup>62</sup>, S. Chatterjee<sup>62</sup>, G. Dash<sup>62</sup>, P. Jana<sup>62</sup>, P. Kalbhor<sup>62</sup>, S. Kamble<sup>62</sup>, J. R. Komaragiri<sup>62,ll</sup>, D. Kumar<sup>62,ll</sup>, P. R. Pujahari<sup>62</sup>, N. R. Saha<sup>62</sup>, A. Sharma<sup>62</sup>, A. K. Sikdar<sup>62</sup>, R. K. Singh<sup>62</sup>, P. Verma<sup>62</sup>, S. Verma<sup>62</sup>, A. Vijay<sup>62</sup>, S. Dugad<sup>63</sup>, M. Kumar<sup>63</sup>, G. B. Mohanty<sup>63</sup>, B. Parida<sup>63</sup>, M. Shelake<sup>63</sup>, P. Suryadevara<sup>63</sup>, A. Bala<sup>64</sup>, S. Banerjee<sup>64</sup>, R. M. Chatterjee<sup>64</sup>, M. Guchait<sup>64</sup>, Sh. Jain<sup>64</sup>, A. Jaiswal<sup>64</sup>, S. Kumar<sup>64</sup>, G. Majumder<sup>64</sup>, K. Mazumdar<sup>64</sup>, S. Parolia<sup>64</sup>, A. Thachayath<sup>64</sup>, S. Bahinipati<sup>65,mm</sup>, C. Kar<sup>65</sup>, D. Maity<sup>65,nn</sup>, P. Mal<sup>65</sup>, T. Mishra<sup>65</sup>, V. K. Muraleedharan Nair Bindhu<sup>65,nn</sup>, K. Naskar<sup>65,nn</sup>, A. Nayak<sup>65,nn</sup>, S. Nayak<sup>65</sup>, K. Pal<sup>65</sup>, P. Sadangi<sup>65</sup>, S. K. Swain<sup>65</sup>, S. Varghese<sup>65,nn</sup>, D. Vats<sup>65,nn</sup>, S. Acharya<sup>66,oo</sup>, A. Alpana<sup>66</sup>, S. Dube<sup>66</sup>, B. Gomber<sup>66,oo</sup>, P. Hazarika<sup>66</sup>, B. Kansal<sup>66</sup>, A. Laha<sup>66</sup>, B. Sahu<sup>66,oo</sup>, S. Sharma<sup>66</sup>, K. Y. Vaish<sup>66</sup>, H. Bakhshiansohi<sup>67,pp</sup>, A. Jafari<sup>67,qq</sup>, M. Zeinali<sup>67,rr</sup>, S. Bashiri<sup>68</sup>, S. Chenarani<sup>68,ss</sup>, S. M. Etesami<sup>68</sup>, Y. Hosseini<sup>68</sup>, M. Khakzad<sup>68</sup>, E. Khazaie<sup>68,tt</sup>, M. Mohammadi Najafabadi<sup>68</sup>, S. Tizchang<sup>68</sup>, M. Felcini<sup>69</sup>, M. Grunewald<sup>69</sup>, M. Abbrescia<sup>70a,70b</sup>, A. Colaleo<sup>70a,70b</sup>, D. Creanza<sup>70a,70c</sup>, B. D'Anzi<sup>70a,70b</sup>, N. De Filippis<sup>70a,70c</sup>, M. De Palma<sup>70a,70b</sup>, W. Elmetenawee<sup>70a,70b,uu</sup>, L. Fiore<sup>70a</sup>, G. Iaselli<sup>70a,70c</sup>, L. Longo<sup>70a</sup>, M. Louka<sup>70a,70b</sup>, G. Maggi<sup>70a,70c</sup>, M. Maggi<sup>70a</sup>, I. Margjeka<sup>70a</sup>, V. Mastrapasqua<sup>70a,70b</sup>, S. My<sup>70a,70b</sup>, S. Nuzzo<sup>70a,70b</sup>, A. Pellecchia<sup>70a,70b</sup>, A. Pompili<sup>70a,70b</sup>, G. Pugliese<sup>70a,70c</sup>, R. Radogna<sup>70a,70b</sup>, D. Ramos<sup>70a</sup>, A. Ranieri<sup>70a</sup>, L. Silvestris<sup>70a</sup>, F. M. Simone<sup>70a,70c</sup>, Ü. Sözbilir<sup>70a</sup>, A. Stamerra<sup>70a,70b</sup>, D. Troiano<sup>70a,70b</sup>, R. Venditti<sup>70a,70b</sup>, P. Verwilligen<sup>70a</sup>, A. Zaza<sup>70a,70b</sup>, G. Abbiendi<sup>71a</sup>, C. Battilana<sup>71a,71b</sup>, D. Bonacorsi<sup>71a,71b</sup>, L. Borgonovi<sup>71a</sup>, P. Capiluppi<sup>71a,71b</sup>, A. Castro<sup>71a,71b,a</sup>, F. R. Cavallo<sup>71a</sup>, M. Cuffiani<sup>71a,71b</sup>, G. M. Dallavalle<sup>71a</sup>, T. Diotallevi<sup>71a,71b</sup>, F. Fabbri<sup>71a</sup>, A. Fanfani<sup>71a,71b</sup>, D. Fasanella<sup>71a</sup>, P. Giacomelli<sup>71a</sup>, L. Giommi<sup>71a,71b</sup>, C. Grandi<sup>71a</sup>, L. Guiducci<sup>71a,71b</sup>, S. Lo Meo<sup>71a,vv</sup>, M. Lorusso<sup>71a,71b</sup>, L. Lunerti<sup>71a</sup>, S. Marcellini<sup>71a</sup>, G. Masetti<sup>71a</sup>

F. L. Navarra<sup>71a,71b</sup> G. Paggi<sup>71a,71b</sup> A. Perrotta<sup>71a</sup> F. Primavera<sup>71a,71b</sup> A. M. Rossi<sup>71a,71b</sup> S. Rossi Tisbeni<sup>71a,71b</sup>  
 T. Rovelli<sup>71a,71b</sup> G. P. Siroli<sup>71a,71b</sup> S. Costa<sup>72a,72b,ww</sup> A. Di Mattia<sup>72a</sup> A. Lapertosa<sup>72a</sup> R. Potenza<sup>72a,72b</sup>  
 A. Tricomi<sup>72a,72b,ww</sup> C. Tuve<sup>72a,72b</sup> P. Assiouras<sup>73a</sup> G. Barbagli<sup>73a</sup> G. Bardelli<sup>73a,73b</sup> B. Camaiani<sup>73a,73b</sup>  
 A. Cassese<sup>73a</sup> R. Ceccarelli<sup>73a</sup> V. Ciulli<sup>73a,73b</sup> C. Civinini<sup>73a</sup> R. D'Alessandro<sup>73a,73b</sup> E. Focardi<sup>73a,73b</sup>  
 T. Kello<sup>73a</sup> G. Latino<sup>73a,73b</sup> P. Lenzi<sup>73a,73b</sup> M. Lizzo<sup>73a</sup> M. Meschini<sup>73a</sup> S. Paoletti<sup>73a</sup> A. Papanastassiou<sup>73a,73b</sup>  
 G. Sguazzoni<sup>73a</sup> L. Viliani<sup>73a</sup> L. Benussi<sup>74</sup> S. Bianco<sup>74</sup> S. Meola<sup>74,xx</sup> D. Piccolo<sup>74</sup> P. Chatagnon<sup>75a</sup>  
 F. Ferro<sup>75a</sup> E. Robutti<sup>75a</sup> S. Tosi<sup>75a,75b</sup> A. Benaglia<sup>76a</sup> G. Boldrini<sup>76a,76b</sup> F. Brivio<sup>76a</sup> F. Cetorelli<sup>76a,76b</sup>  
 F. De Guio<sup>76a,76b</sup> M. E. Dinardo<sup>76a,76b</sup> P. Dini<sup>76a</sup> S. Gennai<sup>76a</sup> R. Gerosa<sup>76a,76b</sup> A. Ghezzi<sup>76a,76b</sup>  
 P. Govoni<sup>76a,76b</sup> L. Guzzi<sup>76a</sup> M. T. Lucchini<sup>76a,76b</sup> M. Malberti<sup>76a</sup> S. Malvezzi<sup>76a</sup> A. Massironi<sup>76a</sup>  
 D. Menasce<sup>76a</sup> L. Moroni<sup>76a</sup> M. Paganoni<sup>76a,76b</sup> S. Palluotto<sup>76a,76b</sup> D. Pedrini<sup>76a</sup> A. Perego<sup>76a,76b</sup>  
 B. S. Pinolini<sup>76a</sup> G. Pizzati<sup>76a,76b</sup> S. Ragazzi<sup>76a,76b</sup> T. Tabarelli de Fatis<sup>76a,76b</sup> S. Buontempo<sup>77a</sup> A. Cagnotta<sup>77a,77b</sup>  
 F. Carnevali<sup>77a,77b</sup> N. Cavallo<sup>77a,77c</sup> F. Fabozzi<sup>77a,77c</sup> A. O. M. Iorio<sup>77a,77b</sup> L. Lista<sup>77a,77b,yy</sup> P. Paolucci<sup>77a,dd</sup>  
 B. Rossi<sup>77a</sup> R. Ardino<sup>78a</sup> P. Azzi<sup>78a</sup> N. Bacchetta<sup>78a,zz</sup> D. Bisello<sup>78a,78b</sup> P. Bortignon<sup>78a</sup> G. Bortolato<sup>78a,78b</sup>  
 A. Bragagnolo<sup>78a,78b</sup> A. C. M. Bulla<sup>78a</sup> R. Carlini<sup>78a,78b</sup> P. Checchia<sup>78a</sup> T. Dorigo<sup>78a</sup> F. Gasparini<sup>78a,78b</sup>  
 U. Gasparini<sup>78a,78b</sup> E. Lusiani<sup>78a</sup> M. Margoni<sup>78a,78b</sup> A. T. Meneguzzo<sup>78a,78b</sup> M. Michelotto<sup>78a</sup>  
 M. Migliorini<sup>78a,78b</sup> J. Pazzini<sup>78a,78b</sup> P. Ronchese<sup>78a,78b</sup> R. Rossin<sup>78a,78b</sup> F. Simonetto<sup>78a,78b</sup> G. Strong<sup>78a</sup>  
 M. Tosi<sup>78a,78b</sup> A. Triossi<sup>78a,78b</sup> S. Ventura<sup>78a</sup> M. Zanetti<sup>78a,78b</sup> P. Zotto<sup>78a,78b</sup> A. Zucchetta<sup>78a,78b</sup> C. Aimè<sup>79a</sup>  
 A. Braghieri<sup>79a</sup> S. Calzaferri<sup>79a</sup> D. Fiorina<sup>79a</sup> P. Montagna<sup>79a,79b</sup> V. Re<sup>79a</sup> C. Riccardi<sup>79a,79b</sup> P. Salvini<sup>79a</sup>  
 I. Vai<sup>79a,79b</sup> P. Vitulo<sup>79a,79b</sup> S. Ajmal<sup>80a,80b</sup> M. E. Ascoti<sup>80a,80b</sup> G. M. Bilei<sup>80a</sup> C. Carrivale<sup>80a,80b</sup>  
 D. Ciangottini<sup>80a,80b</sup> L. Fanò<sup>80a,80b</sup> M. Magherini<sup>80a,80b</sup> V. Mariani<sup>80a,80b</sup> M. Menichelli<sup>80a</sup> F. Moscatelli<sup>80a,aaa</sup>  
 A. Rossi<sup>80a,80b</sup> A. Santocchia<sup>80a,80b</sup> D. Spiga<sup>80a</sup> T. Tedeschi<sup>80a,80b</sup> C. A. Alexe<sup>81a,81c</sup> P. Asenov<sup>81a,81b</sup>  
 P. Azzurri<sup>81a</sup> G. Bagliesi<sup>81a</sup> R. Bhattacharya<sup>81a</sup> L. Bianchini<sup>81a,81b</sup> T. Boccali<sup>81a</sup> E. Bossini<sup>81a</sup>  
 D. Bruschini<sup>81a,81c</sup> R. Castaldi<sup>81a</sup> M. A. Ciocci<sup>81a,81b</sup> M. Cipriani<sup>81a,81b</sup> V. D'Amante<sup>81a,81d</sup> R. Dell'Orso<sup>81a</sup>  
 S. Donato<sup>81a</sup> A. Giassi<sup>81a</sup> F. Ligabue<sup>81a,81c</sup> D. Matos Figueiredo<sup>81a</sup> A. Messineo<sup>81a,81b</sup> M. Musich<sup>81a,81b</sup>  
 F. Palla<sup>81a</sup> A. Rizzi<sup>81a,81b</sup> G. Rolandi<sup>81a,81c</sup> S. Roy Chowdhury<sup>81a</sup> T. Sarkar<sup>81a</sup> A. Scribano<sup>81a</sup> P. Spagnolo<sup>81a</sup>  
 R. Tenchini<sup>81a</sup> G. Tonelli<sup>81a,81b</sup> N. Turini<sup>81a,81d</sup> F. Vaselli<sup>81a,81c</sup> A. Venturi<sup>81a</sup> P. G. Verdini<sup>81a</sup>  
 C. Baldenegro Barrera<sup>82a,82b</sup> P. Barria<sup>82a</sup> C. Basile<sup>82a,82b</sup> M. Campana<sup>82a,82b</sup> F. Cavallari<sup>82a</sup>  
 L. Cunqueiro Mendez<sup>82a,82b</sup> D. Del Re<sup>82a,82b</sup> E. Di Marco<sup>82a,82b</sup> M. Diemoz<sup>82a</sup> F. Errico<sup>82a,82b</sup> E. Longo<sup>82a,82b</sup>  
 J. Mijuskovic<sup>82a,82b</sup> G. Organtini<sup>82a,82b</sup> F. Pandolfi<sup>82a</sup> R. Paramatti<sup>82a,82b</sup> C. Quaranta<sup>82a,82b</sup> S. Rahatlou<sup>82a,82b</sup>  
 C. Rovelli<sup>82a</sup> F. Santanastasio<sup>82a,82b</sup> L. Soffi<sup>82a</sup> N. Amapane<sup>83a,83b</sup> R. Arcidiacono<sup>83a,83c</sup> S. Argiro<sup>83a,83b</sup>  
 M. Arneodo<sup>83a,83c</sup> N. Bartosik<sup>83a</sup> R. Bellan<sup>83a,83b</sup> A. Bellora<sup>83a,83b</sup> C. Biino<sup>83a</sup> C. Borca<sup>83a,83b</sup> N. Cartiglia<sup>83a</sup>  
 M. Costa<sup>83a,83b</sup> R. Covarelli<sup>83a,83b</sup> N. Demaria<sup>83a</sup> L. Finco<sup>83a</sup> M. Grippo<sup>83a,83b</sup> B. Kiani<sup>83a,83b</sup> F. Legger<sup>83a</sup>  
 F. Luongo<sup>83a,83b</sup> C. Mariotti<sup>83a</sup> L. Markovic<sup>83a,83b</sup> S. Maselli<sup>83a</sup> A. Mecca<sup>83a,83b</sup> L. Menzio<sup>83a,83b</sup>  
 P. Meridiani<sup>83a</sup> E. Migliore<sup>83a,83b</sup> M. Monteno<sup>83a</sup> R. Mulargia<sup>83a</sup> M. M. Obertino<sup>83a,83b</sup> G. Ortona<sup>83a</sup>  
 L. Pacher<sup>83a,83b</sup> N. Pastrone<sup>83a</sup> M. Pelliccioni<sup>83a</sup> M. Ruspa<sup>83a,83c</sup> F. Siviero<sup>83a,83b</sup> V. Sola<sup>83a,83b</sup>  
 A. Solano<sup>83a,83b</sup> A. Staiano<sup>83a</sup> C. Tarricone<sup>83a,83b</sup> D. Trocino<sup>83a</sup> G. Umoret<sup>83a,83b</sup> R. White<sup>83a,83b</sup>  
 S. Belforte<sup>84a</sup> V. Candelise<sup>84a,84b</sup> M. Casarsa<sup>84a</sup> F. Cossutti<sup>84a</sup> K. De Leo<sup>84a</sup> G. Della Ricca<sup>84a,84b</sup> S. Dogra<sup>85</sup>  
 J. Hong<sup>85</sup> C. Huh<sup>85</sup> B. Kim<sup>85</sup> J. Kim<sup>85</sup> D. Lee<sup>85</sup> H. Lee<sup>85</sup> S. W. Lee<sup>85</sup> C. S. Moon<sup>85</sup> Y. D. Oh<sup>85</sup>  
 M. S. Ryu<sup>85</sup> S. Sekmen<sup>85</sup> B. Tae<sup>85</sup> Y. C. Yang<sup>85</sup> M. S. Kim<sup>86</sup> G. Bak<sup>87</sup> P. Gwak<sup>87</sup> H. Kim<sup>87</sup> D. H. Moon<sup>87</sup>  
 E. Asilar<sup>88</sup> J. Choi<sup>88</sup> D. Kim<sup>88</sup> T. J. Kim<sup>88</sup> J. A. Merlin<sup>88</sup> Y. Ryou<sup>88</sup> S. Choi<sup>89</sup> S. Han<sup>89</sup> B. Hong<sup>89</sup> K. Lee<sup>89</sup>  
 K. S. Lee<sup>89</sup> S. Lee<sup>89</sup> J. Yoo<sup>89</sup> J. Goh<sup>90</sup> S. Yang<sup>90</sup> H. S. Kim<sup>91</sup> Y. Kim<sup>91</sup> S. Lee<sup>91</sup> J. Almond<sup>92</sup> J. H. Bhyun<sup>92</sup>  
 J. Choi<sup>92</sup> J. Choi<sup>92</sup> W. Jun<sup>92</sup> J. Kim<sup>92</sup> S. Ko<sup>92</sup> H. Kwon<sup>92</sup> H. Lee<sup>92</sup> J. Lee<sup>92</sup> J. Lee<sup>92</sup> B. H. Oh<sup>92</sup>  
 S. B. Oh<sup>92</sup> H. Seo<sup>92</sup> U. K. Yang<sup>92</sup> I. Yoon<sup>92</sup> W. Jang<sup>93</sup> D. Y. Kang<sup>93</sup> Y. Kang<sup>93</sup> S. Kim<sup>93</sup> B. Ko<sup>93</sup>  
 J. S. H. Lee<sup>93</sup> Y. Lee<sup>93</sup> I. C. Park<sup>93</sup> Y. Roh<sup>93</sup> I. J. Watson<sup>93</sup> S. Ha<sup>94</sup> H. D. Yoo<sup>94</sup> M. Choi<sup>95</sup> M. R. Kim<sup>95</sup>  
 H. Lee<sup>95</sup> Y. Lee<sup>95</sup> I. Yu<sup>95</sup> T. Beyrouthy<sup>96</sup> K. Dreimanis<sup>97</sup> A. Gaile<sup>97</sup> G. Pikurs<sup>97</sup> A. Potrebko<sup>97</sup> M. Seidel<sup>97</sup>  
 D. Sidiropoulos Kontos<sup>97</sup> N. R. Strautnieks<sup>98</sup> M. Ambrozas<sup>99</sup> A. Juodagalvis<sup>99</sup> A. Rinkevicius<sup>99</sup>  
 G. Tamulaitis<sup>99</sup> I. Yusuff<sup>100,bbb</sup> Z. Zolkapli<sup>100</sup> J. F. Benitez<sup>101</sup> A. Castaneda Hernandez<sup>101</sup> H. A. Encinas Acosta<sup>101</sup>  
 L. G. Gallegos Maríñez<sup>101</sup> M. León Coello<sup>101</sup> J. A. Murillo Quijada<sup>101</sup> A. Sehwat<sup>101</sup> L. Valencia Palomo<sup>101</sup>  
 G. Ayala<sup>102</sup> H. Castilla-Valdez<sup>102</sup> H. Crotte Ledesma<sup>102</sup> E. De La Cruz-Burelo<sup>102</sup> I. Heredia-De La Cruz<sup>102,ccc</sup>

R. Lopez-Fernandez<sup>102</sup>, J. Mejia Guisao<sup>102</sup>, C. A. Mondragon Herrera<sup>102</sup>, A. Sánchez Hernández<sup>102</sup>,  
 C. Oropeza Barrera<sup>103</sup>, D. L. Ramirez Guadarrama<sup>103</sup>, M. Ramírez García<sup>103</sup>, I. Bautista<sup>104</sup>, I. Pedraza<sup>104</sup>,  
 H. A. Salazar Ibarguen<sup>104</sup>, C. Uribe Estrada<sup>104</sup>, I. Bujanja<sup>105</sup>, N. Raicevic<sup>105</sup>, P. H. Butler<sup>106</sup>, A. Ahmad<sup>107</sup>,  
 M. I. Asghar<sup>107</sup>, A. Awais<sup>107</sup>, M. I. M. Awan<sup>107</sup>, H. R. Hoorani<sup>107</sup>, W. A. Khan<sup>107</sup>, V. Avati<sup>108</sup>, L. Grzanka<sup>108</sup>,  
 M. Malawski<sup>108</sup>, H. Bialkowska<sup>109</sup>, M. Bluj<sup>109</sup>, M. Górski<sup>109</sup>, M. Kazana<sup>109</sup>, M. Szeleper<sup>109</sup>, P. Zalewski<sup>109</sup>,  
 K. Bunkowski<sup>110</sup>, K. Doroba<sup>110</sup>, A. Kalinowski<sup>110</sup>, M. Konecki<sup>110</sup>, J. Krolikowski<sup>110</sup>, A. Muhammad<sup>110</sup>,  
 K. Pozniak<sup>111</sup>, W. Zabolotny<sup>111</sup>, M. Araujo<sup>112</sup>, D. Bastos<sup>112</sup>, C. Beirão Da Cruz E Silva<sup>112</sup>, A. Boletti<sup>112</sup>,  
 M. Bozzo<sup>112</sup>, T. Camporesi<sup>112</sup>, G. Da Molin<sup>112</sup>, P. Faccioli<sup>112</sup>, M. Gallinaro<sup>112</sup>, J. Hollar<sup>112</sup>, N. Leonardo<sup>112</sup>,  
 G. B. Marozzo<sup>112</sup>, T. Niknejad<sup>112</sup>, A. Petrilli<sup>112</sup>, M. Pisano<sup>112</sup>, J. Seixas<sup>112</sup>, J. Varela<sup>112</sup>, J. W. Wulff<sup>112</sup>,  
 P. Adzic<sup>113</sup>, P. Milenovic<sup>113</sup>, M. Dordevic<sup>114</sup>, J. Milosevic<sup>114</sup>, L. Nadder<sup>114</sup>, V. Rekovic<sup>114</sup>, J. Alcaraz Maestre<sup>115</sup>,  
 Cristina F. Bedoya<sup>115</sup>, Oliver M. Carretero<sup>115</sup>, M. Cepeda<sup>115</sup>, M. Cerrada<sup>115</sup>, N. Colino<sup>115</sup>, B. De La Cruz<sup>115</sup>,  
 A. Delgado Peris<sup>115</sup>, A. Escalante Del Valle<sup>115</sup>, D. Fernández Del Val<sup>115</sup>, J. P. Fernández Ramos<sup>115</sup>, J. Flix<sup>115</sup>,  
 M. C. Fouz<sup>115</sup>, O. Gonzalez Lopez<sup>115</sup>, S. Goy Lopez<sup>115</sup>, J. M. Hernandez<sup>115</sup>, M. I. Josa<sup>115</sup>,  
 E. Martin Viscasillas<sup>115</sup>, D. Moran<sup>115</sup>, C. M. Morcillo Perez<sup>115</sup>, Á. Navarro Tobar<sup>115</sup>, C. Perez Dengra<sup>115</sup>,  
 A. Pérez-Calero Yzquierdo<sup>115</sup>, J. Puerta Pelayo<sup>115</sup>, I. Redondo<sup>115</sup>, S. Sánchez Navas<sup>115</sup>, J. Sastre<sup>115</sup>,  
 J. Vazquez Escobar<sup>115</sup>, J. F. de Trocóniz<sup>116</sup>, B. Alvarez Gonzalez<sup>117</sup>, J. Cuevas<sup>117</sup>, J. Fernandez Menendez<sup>117</sup>,  
 S. Folgueras<sup>117</sup>, I. Gonzalez Caballero<sup>117</sup>, J. R. González Fernández<sup>117</sup>, P. Leguina<sup>117</sup>, E. Palencia Cortezon<sup>117</sup>,  
 C. Ramón Álvarez<sup>117</sup>, V. Rodríguez Bouza<sup>117</sup>, A. Soto Rodríguez<sup>117</sup>, A. Trapote<sup>117</sup>, C. Vico Villalba<sup>117</sup>,  
 P. Vischia<sup>117</sup>, S. Bhowmik<sup>118</sup>, S. Blanco Fernández<sup>118</sup>, J. A. Brochero Cifuentes<sup>118</sup>, I. J. Cabrillo<sup>118</sup>,  
 A. Calderon<sup>118</sup>, J. Duarte Campderros<sup>118</sup>, M. Fernandez<sup>118</sup>, G. Gomez<sup>118</sup>, C. Lasasoa García<sup>118</sup>,  
 R. Lopez Ruiz<sup>118</sup>, C. Martinez Rivero<sup>118</sup>, P. Martinez Ruiz del Arbol<sup>118</sup>, F. Matorras<sup>118</sup>, P. Matorras Cuevas<sup>118</sup>,  
 E. Navarrete Ramos<sup>118</sup>, J. Piedra Gomez<sup>118</sup>, L. Scodellaro<sup>118</sup>, I. Vila<sup>118</sup>, J. M. Vizan Garcia<sup>118</sup>,  
 B. Kailasapathy<sup>119,ddd</sup>, D. D. C. Wickramarathna<sup>119</sup>, W. G. D. Dharmaratna<sup>120,eee</sup>, K. Liyanage<sup>120</sup>, N. Perera<sup>120</sup>,  
 D. Abbaneo<sup>121</sup>, C. Amendola<sup>121</sup>, E. Auffray<sup>121</sup>, G. Auzinger<sup>121</sup>, J. Baechler<sup>121</sup>, D. Barney<sup>121</sup>,  
 A. Bermúdez Martínez<sup>121</sup>, M. Bianco<sup>121</sup>, B. Bilin<sup>121</sup>, A. A. Bin Anuar<sup>121</sup>, A. Bocci<sup>121</sup>, C. Botta<sup>121</sup>,  
 E. Brondolin<sup>121</sup>, C. Caillol<sup>121</sup>, G. Cerminara<sup>121</sup>, N. Chernyavskaya<sup>121</sup>, D. d’Enterria<sup>121</sup>, A. Dabrowski<sup>121</sup>,  
 A. David<sup>121</sup>, A. De Roeck<sup>121</sup>, M. M. Defranchis<sup>121</sup>, M. Deile<sup>121</sup>, M. Dobson<sup>121</sup>, G. Franzoni<sup>121</sup>, W. Funk<sup>121</sup>,  
 S. Giani<sup>121</sup>, D. Gigi<sup>121</sup>, K. Gill<sup>121</sup>, F. Glege<sup>121</sup>, J. Hegeman<sup>121</sup>, J. K. Heikkilä<sup>121</sup>, B. Huber<sup>121</sup>, V. Innocente<sup>121</sup>,  
 T. James<sup>121</sup>, P. Janot<sup>121</sup>, O. Kaluzinska<sup>121</sup>, S. Laurila<sup>121</sup>, P. Lecoq<sup>121</sup>, E. Leutgeb<sup>121</sup>, C. Lourenço<sup>121</sup>,  
 L. Malgeri<sup>121</sup>, M. Mannelli<sup>121</sup>, A. C. Marini<sup>121</sup>, M. Matthewman<sup>121</sup>, A. Mehta<sup>121</sup>, F. Meijers<sup>121</sup>, S. Mersi<sup>121</sup>,  
 E. Meschi<sup>121</sup>, V. Milosevic<sup>121</sup>, F. Monti<sup>121</sup>, F. Moortgat<sup>121</sup>, M. Mulders<sup>121</sup>, I. Neutelings<sup>121</sup>, S. Orfanelli<sup>121</sup>,  
 F. Pantaleo<sup>121</sup>, G. Petrucciani<sup>121</sup>, A. Pfeiffer<sup>121</sup>, M. Pierini<sup>121</sup>, H. Qu<sup>121</sup>, D. Rabady<sup>121</sup>, B. Ribeiro Lopes<sup>121</sup>,  
 M. Rovere<sup>121</sup>, H. Sakulin<sup>121</sup>, S. Sanchez Cruz<sup>121</sup>, S. Scarfi<sup>121</sup>, C. Schwick<sup>121</sup>, M. Selvaggi<sup>121</sup>, A. Sharma<sup>121</sup>,  
 K. Shchelina<sup>121</sup>, P. Silva<sup>121</sup>, P. Sphicas<sup>121,fff</sup>, A. G. Stahl Leiton<sup>121</sup>, A. Steen<sup>121</sup>, S. Summers<sup>121</sup>, D. Treille<sup>121</sup>,  
 P. Tropea<sup>121</sup>, D. Walter<sup>121</sup>, J. Wanczyk<sup>121,ggg</sup>, J. Wang<sup>121</sup>, S. Wuchterl<sup>121</sup>, P. Zehetner<sup>121</sup>, P. Zejdl<sup>121</sup>,  
 W. D. Zeuner<sup>121</sup>, T. Bevilacqua<sup>122,hhh</sup>, L. Caminada<sup>122,hhh</sup>, A. Ebrahimi<sup>122</sup>, W. Erdmann<sup>122</sup>, R. Horisberger<sup>122</sup>,  
 Q. Ingram<sup>122</sup>, H. C. Kaestli<sup>122</sup>, D. Kotlinski<sup>122</sup>, C. Lange<sup>122</sup>, M. Missiroli<sup>122,hhh</sup>, L. Noehte<sup>122,hhh</sup>, T. Rohe<sup>122</sup>,  
 T. K. Aarrestad<sup>123</sup>, K. Androsov<sup>123,ggg</sup>, M. Backhaus<sup>123</sup>, G. Bonomelli<sup>123</sup>, A. Calandri<sup>123</sup>, C. Cazzaniga<sup>123</sup>,  
 K. Datta<sup>123</sup>, P. De Bryas Dexmiers D’archiac<sup>123,ggg</sup>, A. De Cosa<sup>123</sup>, G. Dissertori<sup>123</sup>, M. Dittmar<sup>123</sup>, M. Donegà<sup>123</sup>,  
 F. Eble<sup>123</sup>, M. Galli<sup>123</sup>, K. Gedia<sup>123</sup>, F. Glessgen<sup>123</sup>, C. Grab<sup>123</sup>, N. Härringer<sup>123</sup>, T. G. Harte<sup>123</sup>, D. Hits<sup>123</sup>,  
 W. Lustermann<sup>123</sup>, A.-M. Lyon<sup>123</sup>, R. A. Manzoni<sup>123</sup>, M. Marchegiani<sup>123</sup>, L. Marchese<sup>123</sup>, C. Martin Perez<sup>123</sup>,  
 A. Mascellani<sup>123,ggg</sup>, F. Nessi-Tedaldi<sup>123</sup>, F. Pauss<sup>123</sup>, V. Perovic<sup>123</sup>, S. Pigazzini<sup>123</sup>, C. Reissel<sup>123</sup>,  
 T. Reitenspiess<sup>123</sup>, B. Ristic<sup>123</sup>, F. Riti<sup>123</sup>, R. Seidita<sup>123</sup>, J. Steggemann<sup>123,ggg</sup>, A. Tarabini<sup>123</sup>, D. Valsecchi<sup>123</sup>,  
 R. Wallny<sup>123</sup>, C. Amsler<sup>124,iii</sup>, P. Bärtschi<sup>124</sup>, M. F. Canelli<sup>124</sup>, K. Cormier<sup>124</sup>, M. Huwiler<sup>124</sup>, W. Jin<sup>124</sup>,  
 A. Jofrehei<sup>124</sup>, B. Kilminster<sup>124</sup>, S. Leontsinis<sup>124</sup>, S. P. Liechti<sup>124</sup>, A. Macchiolo<sup>124</sup>, P. Meiring<sup>124</sup>, F. Meng<sup>124</sup>,  
 U. Molinatti<sup>124</sup>, J. Motta<sup>124</sup>, A. Reimers<sup>124</sup>, P. Robmann<sup>124</sup>, M. Senger<sup>124</sup>, E. Shokr<sup>124</sup>, F. Stäger<sup>124</sup>,  
 R. Tramontano<sup>124</sup>, C. Adloff<sup>125,jjj</sup>, D. Bhowmik<sup>125</sup>, C. M. Kuo<sup>125</sup>, W. Lin<sup>125</sup>, P. K. Rout<sup>125</sup>, P. C. Tiwari<sup>125,ll</sup>,  
 S. S. Yu<sup>125</sup>, L. Ceard<sup>126</sup>, K. F. Chen<sup>126</sup>, P. s. Chen<sup>126</sup>, Z. g. Chen<sup>126</sup>, A. De Iorio<sup>126</sup>, W.-S. Hou<sup>126</sup>, T. h. Hsu<sup>126</sup>,  
 Y. w. Kao<sup>126</sup>, S. Karmakar<sup>126</sup>, G. Kole<sup>126</sup>, Y. y. Li<sup>126</sup>, R.-S. Lu<sup>126</sup>, E. Paganis<sup>126</sup>, X. f. Su<sup>126</sup>

J. Thomas-Wilsker<sup>126</sup>, L. s. Tsai<sup>126</sup>, H. y. Wu<sup>126</sup>, E. Yazgan<sup>126</sup>, C. Asawatangtrakuldee<sup>127</sup>, N. Srimanobhas<sup>127</sup>, V. Wachirapusanand<sup>127</sup>, D. Agyel<sup>128</sup>, F. Boran<sup>128</sup>, F. Dolek<sup>128</sup>, I. Dumanoglu<sup>128,kkk</sup>, E. Eskut<sup>128</sup>, Y. Guler<sup>128,III</sup>, E. Gurpinar Guler<sup>128,III</sup>, C. Isik<sup>128</sup>, O. Kara<sup>128</sup>, A. Kayis Topaksu<sup>128</sup>, U. Kiminsu<sup>128</sup>, G. Onengut<sup>128</sup>, K. Ozdemir<sup>128,mmm</sup>, A. Polatoz<sup>128</sup>, B. Tali<sup>128,nnn</sup>, U. G. Tok<sup>128</sup>, S. Turkcapar<sup>128</sup>, E. Uslan<sup>128</sup>, I. S. Zorbakir<sup>128</sup>, G. Sokmen<sup>129</sup>, M. Yalvac<sup>129,ooo</sup>, B. Akgun<sup>130</sup>, I. O. Atakisi<sup>130</sup>, E. Gülmez<sup>130</sup>, M. Kaya<sup>130,ppp</sup>, O. Kaya<sup>130,qqq</sup>, S. Tekten<sup>130,rrr</sup>, A. Cakir<sup>131</sup>, K. Cankocak<sup>131,kkk,sss</sup>, G. G. Dincer<sup>131,kkk</sup>, Y. Komurcu<sup>131</sup>, S. Sen<sup>131,ttt</sup>, O. Aydilek<sup>132,uuu</sup>, B. Hacisahinoglu<sup>132</sup>, I. Hos<sup>132,vvv</sup>, B. Kaynak<sup>132</sup>, S. Ozkorucuklu<sup>132</sup>, O. Potok<sup>132</sup>, H. Sert<sup>132</sup>, C. Simsek<sup>132</sup>, C. Zorbilmez<sup>132</sup>, S. Cerci<sup>133,nnn</sup>, B. Isildak<sup>133,www</sup>, D. Sunar Cerci<sup>133</sup>, T. Yetkin<sup>133</sup>, A. Boyaryntsev<sup>134</sup>, B. Grynyov<sup>134</sup>, L. Levchuk<sup>135</sup>, D. Anthony<sup>136</sup>, J. J. Brooke<sup>136</sup>, A. Bundock<sup>136</sup>, F. Bury<sup>136</sup>, E. Clement<sup>136</sup>, D. Cussans<sup>136</sup>, H. Flacher<sup>136</sup>, M. Glowacki<sup>136</sup>, J. Goldstein<sup>136</sup>, H. F. Heath<sup>136</sup>, M.-L. Holmberg<sup>136</sup>, L. Kreczko<sup>136</sup>, S. Paramesvaran<sup>136</sup>, L. Robertshaw<sup>136</sup>, S. Seif El Nasr-Storey<sup>136</sup>, V. J. Smith<sup>136</sup>, N. Stylianou<sup>136,xxx</sup>, K. Walkingshaw Pass<sup>136</sup>, A. H. Ball<sup>137</sup>, K. W. Bell<sup>137</sup>, A. Belyaev<sup>137,yyy</sup>, C. Brew<sup>137</sup>, R. M. Brown<sup>137</sup>, D. J. A. Cockerill<sup>137</sup>, C. Cooke<sup>137</sup>, A. Elliot<sup>137</sup>, K. V. Ellis<sup>137</sup>, K. Harder<sup>137</sup>, S. Harper<sup>137</sup>, J. Linacre<sup>137</sup>, K. Manolopoulos<sup>137</sup>, D. M. Newbold<sup>137</sup>, E. Olaiya<sup>137</sup>, D. Petyt<sup>137</sup>, T. Reis<sup>137</sup>, A. R. Sahasransu<sup>137</sup>, G. Salvi<sup>137</sup>, T. Schuh<sup>137</sup>, C. H. Shepherd-Themistocleous<sup>137</sup>, I. R. Tomalin<sup>137</sup>, K. C. Whalen<sup>137</sup>, T. Williams<sup>137</sup>, I. Andreou<sup>138</sup>, R. Bainbridge<sup>138</sup>, P. Bloch<sup>138</sup>, C. E. Brown<sup>138</sup>, O. Buchmuller<sup>138</sup>, V. Cacchio<sup>138</sup>, C. A. Carrillo Montoya<sup>138</sup>, G. S. Chahal<sup>138,zzz</sup>, D. Colling<sup>138</sup>, J. S. Dancu<sup>138</sup>, I. Das<sup>138</sup>, P. Dauncey<sup>138</sup>, G. Davies<sup>138</sup>, J. Davies<sup>138</sup>, M. Della Negra<sup>138</sup>, S. Fayer<sup>138</sup>, G. Fedi<sup>138</sup>, G. Hall<sup>138</sup>, M. H. Hassanshahi<sup>138</sup>, A. Howard<sup>138</sup>, G. Iles<sup>138</sup>, M. Knight<sup>138</sup>, J. Langford<sup>138</sup>, J. León Holgado<sup>138</sup>, L. Lyons<sup>138</sup>, A.-M. Magnan<sup>138</sup>, S. Mallios<sup>138</sup>, M. Mieskolainen<sup>138</sup>, J. Nash<sup>138,aaaa</sup>, M. Pesaresi<sup>138</sup>, P. B. Pradeep<sup>138</sup>, B. C. Radburn-Smith<sup>138</sup>, A. Richards<sup>138</sup>, A. Rose<sup>138</sup>, K. Savva<sup>138</sup>, C. Seez<sup>138</sup>, R. Shukla<sup>138</sup>, A. Tapper<sup>138</sup>, K. Uchida<sup>138</sup>, G. P. Uttley<sup>138</sup>, L. H. Vage<sup>138</sup>, T. Virdee<sup>138,dd</sup>, M. Vojinovic<sup>138</sup>, N. Wardle<sup>138</sup>, D. Winterbottom<sup>138</sup>, K. Coldham<sup>139</sup>, J. E. Cole<sup>139</sup>, A. Khan<sup>139</sup>, P. Kyberd<sup>139</sup>, I. D. Reid<sup>139</sup>, S. Abdullin<sup>140</sup>, A. Brinkerhoff<sup>140</sup>, B. Caraway<sup>140</sup>, E. Collins<sup>140</sup>, J. Dittmann<sup>140</sup>, K. Hatakeyama<sup>140</sup>, J. Hiltbrand<sup>140</sup>, B. McMaster<sup>140</sup>, J. Samudio<sup>140</sup>, S. Sawant<sup>140</sup>, C. Sutantawibul<sup>140</sup>, J. Wilson<sup>140</sup>, R. Bartek<sup>141</sup>, A. Dominguez<sup>141</sup>, C. Huerta Escamilla<sup>141</sup>, A. E. Simsek<sup>141</sup>, R. Uniyal<sup>141</sup>, A. M. Vargas Hernandez<sup>141</sup>, B. Bam<sup>142</sup>, A. Buchot Perraguin<sup>142</sup>, R. Chudasama<sup>142</sup>, S. I. Cooper<sup>142</sup>, C. Crovella<sup>142</sup>, S. V. Gleyzer<sup>142</sup>, E. Pearson<sup>142</sup>, C. U. Perez<sup>142</sup>, P. Rumerio<sup>142,bbbb</sup>, E. Usai<sup>142</sup>, R. Yi<sup>142</sup>, A. Akpinar<sup>143</sup>, C. Cosby<sup>143</sup>, G. De Castro<sup>143</sup>, Z. Demiragli<sup>143</sup>, C. Erice<sup>143</sup>, C. Fangmeier<sup>143</sup>, C. Fernandez Madrazo<sup>143</sup>, E. Fontanesi<sup>143</sup>, D. Gastler<sup>143</sup>, F. Golf<sup>143</sup>, S. Jeon<sup>143</sup>, J. O'cain<sup>143</sup>, I. Reed<sup>143</sup>, J. Rohlf<sup>143</sup>, K. Salyer<sup>143</sup>, D. Sperka<sup>143</sup>, D. Spitzbart<sup>143</sup>, I. Suarez<sup>143</sup>, A. Tsatsos<sup>143</sup>, A. G. Zecchinelli<sup>143</sup>, G. Benelli<sup>144</sup>, X. Coubez<sup>144,z</sup>, D. Cutts<sup>144</sup>, L. Gouskos<sup>144</sup>, M. Hadley<sup>144</sup>, U. Heintz<sup>144</sup>, J. M. Hogan<sup>144,cccc</sup>, T. Kwon<sup>144</sup>, G. Landsberg<sup>144</sup>, K. T. Lau<sup>144</sup>, D. Li<sup>144</sup>, J. Luo<sup>144</sup>, S. Mondal<sup>144</sup>, M. Narain<sup>144,a</sup>, N. Pervan<sup>144</sup>, T. Russell<sup>144</sup>, S. Sagir<sup>144,dddd</sup>, F. Simpson<sup>144</sup>, M. Stamenkovic<sup>144</sup>, N. Venkatasubramanian<sup>144</sup>, X. Yan<sup>144</sup>, W. Zhang<sup>144</sup>, S. Abbott<sup>145</sup>, C. Brainerd<sup>145</sup>, R. Breedon<sup>145</sup>, H. Cai<sup>145</sup>, M. Calderon De La Barca Sanchez<sup>145</sup>, M. Chertok<sup>145</sup>, M. Citron<sup>145</sup>, J. Conway<sup>145</sup>, P. T. Cox<sup>145</sup>, R. Erbacher<sup>145</sup>, F. Jensen<sup>145</sup>, O. Kukral<sup>145</sup>, G. Mocellin<sup>145</sup>, M. Mulhearn<sup>145</sup>, S. Ostrom<sup>145</sup>, W. Wei<sup>145</sup>, Y. Yao<sup>145</sup>, S. Yoo<sup>145</sup>, F. Zhang<sup>145</sup>, M. Bachtis<sup>146</sup>, R. Cousins<sup>146</sup>, A. Datta<sup>146</sup>, G. Flores Avila<sup>146</sup>, J. Hauser<sup>146</sup>, M. Ignatenko<sup>146</sup>, M. A. Iqbal<sup>146</sup>, T. Lam<sup>146</sup>, E. Manca<sup>146</sup>, A. Nunez Del Prado<sup>146</sup>, D. Saltzberg<sup>146</sup>, V. Valuev<sup>146</sup>, R. Clare<sup>147</sup>, J. W. Gary<sup>147</sup>, M. Gordon<sup>147</sup>, G. Hanson<sup>147</sup>, W. Si<sup>147</sup>, S. Wimpenny<sup>147,a</sup>, A. Aportela<sup>148</sup>, A. Arora<sup>148</sup>, J. G. Branson<sup>148</sup>, S. Cittolin<sup>148</sup>, S. Cooperstein<sup>148</sup>, D. Diaz<sup>148</sup>, J. Duarte<sup>148</sup>, L. Giannini<sup>148</sup>, Y. Gu<sup>148</sup>, J. Guiang<sup>148</sup>, R. Kansal<sup>148</sup>, V. Krutelyov<sup>148</sup>, R. Lee<sup>148</sup>, J. Letts<sup>148</sup>, M. Masciovecchio<sup>148</sup>, F. Mokhtar<sup>148</sup>, S. Mukherjee<sup>148</sup>, M. Pieri<sup>148</sup>, M. Quinnan<sup>148</sup>, B. V. Sathia Narayanan<sup>148</sup>, V. Sharma<sup>148</sup>, M. Tadel<sup>148</sup>, E. Vourliotis<sup>148</sup>, F. Würthwein<sup>148</sup>, Y. Xiang<sup>148</sup>, A. Yagil<sup>148</sup>, A. Barzdukas<sup>149</sup>, L. Brennan<sup>149</sup>, C. Campagnari<sup>149</sup>, K. Downham<sup>149</sup>, C. Grieco<sup>149</sup>, J. Incandela<sup>149</sup>, J. Kim<sup>149</sup>, A. J. Li<sup>149</sup>, P. Masterson<sup>149</sup>, H. Mei<sup>149</sup>, J. Richman<sup>149</sup>, S. N. Santpur<sup>149</sup>, U. Sarica<sup>149</sup>, R. Schmitz<sup>149</sup>, F. Setti<sup>149</sup>, J. Sheplock<sup>149</sup>, D. Stuart<sup>149</sup>, T. Á. Vámi<sup>149</sup>, S. Wang<sup>149</sup>, D. Zhang<sup>149</sup>, A. Bornheim<sup>150</sup>, O. Cerri<sup>150</sup>, A. Latorre<sup>150</sup>, J. Mao<sup>150</sup>, H. B. Newman<sup>150</sup>, G. Reales Gutiérrez<sup>150</sup>, M. Spiropulu<sup>150</sup>, J. R. Vlimant<sup>150</sup>, C. Wang<sup>150</sup>, S. Xie<sup>150</sup>, R. Y. Zhu<sup>150</sup>, J. Alison<sup>151</sup>, S. An<sup>151</sup>, M. B. Andrews<sup>151</sup>, P. Bryant<sup>151</sup>, M. Cremonesi<sup>151</sup>, V. Dutta<sup>151</sup>, T. Ferguson<sup>151</sup>, T. A. Gómez Espinosa<sup>151</sup>, A. Harilal<sup>151</sup>, A. Kallil Tharayil<sup>151</sup>, C. Liu<sup>151</sup>, T. Mudholkar<sup>151</sup>, S. Murthy<sup>151</sup>, P. Palit<sup>151</sup>, K. Park<sup>151</sup>, M. Paulini<sup>151</sup>, A. Roberts<sup>151</sup>, A. Sanchez<sup>151</sup>, W. Terrill<sup>151</sup>, J. P. Cumalat<sup>152</sup>

W. T. Ford<sup>152</sup>, A. Hart<sup>152</sup>, A. Hassani<sup>152</sup>, G. Karathanasis<sup>152</sup>, N. Manganelli<sup>152</sup>, A. Perloff<sup>152</sup>, C. Savard<sup>152</sup>,  
 N. Schonbeck<sup>152</sup>, K. Stenson<sup>152</sup>, K. A. Ulmer<sup>152</sup>, S. R. Wagner<sup>152</sup>, N. Zipper<sup>152</sup>, D. Zuolo<sup>152</sup>, J. Alexander<sup>153</sup>,  
 S. Bright-Thonney<sup>153</sup>, X. Chen<sup>153</sup>, D. J. Cranshaw<sup>153</sup>, J. Fan<sup>153</sup>, X. Fan<sup>153</sup>, S. Hogan<sup>153</sup>, P. Kotamnives<sup>153</sup>,  
 J. Monroy<sup>153</sup>, M. Oshiro<sup>153</sup>, J. R. Patterson<sup>153</sup>, M. Reid<sup>153</sup>, A. Ryd<sup>153</sup>, J. Thom<sup>153</sup>, P. Wittich<sup>153</sup>, R. Zou<sup>153</sup>,  
 M. Albrow<sup>154</sup>, M. Alyari<sup>154</sup>, O. Amram<sup>154</sup>, G. Apollinari<sup>154</sup>, A. Apresyan<sup>154</sup>, L. A. T. Bauerdick<sup>154</sup>, D. Berry<sup>154</sup>,  
 J. Berryhill<sup>154</sup>, P. C. Bhat<sup>154</sup>, K. Burkett<sup>154</sup>, J. N. Butler<sup>154</sup>, A. Canepa<sup>154</sup>, G. B. Cerati<sup>154</sup>, H. W. K. Cheung<sup>154</sup>,  
 F. Chlebana<sup>154</sup>, G. Cummings<sup>154</sup>, K. F. Di Petrillo<sup>154</sup>, J. Dickinson<sup>154</sup>, I. Dutta<sup>154</sup>, V. D. Elvira<sup>154</sup>, Y. Feng<sup>154</sup>,  
 J. Freeman<sup>154</sup>, A. Gandrakota<sup>154</sup>, Z. Gecse<sup>154</sup>, L. Gray<sup>154</sup>, D. Green<sup>154</sup>, A. Grummer<sup>154</sup>, S. Grünendahl<sup>154</sup>,  
 D. Guerrero<sup>154</sup>, O. Gutsche<sup>154</sup>, R. M. Harris<sup>154</sup>, R. Heller<sup>154</sup>, T. C. Herwig<sup>154</sup>, J. Hirschauer<sup>154</sup>, B. Jayatilaka<sup>154</sup>,  
 S. Jindariani<sup>154</sup>, M. Johnson<sup>154</sup>, U. Joshi<sup>154</sup>, T. Klijnsma<sup>154</sup>, B. Klima<sup>154</sup>, K. H. M. Kwok<sup>154</sup>, S. Lammel<sup>154</sup>,  
 D. Lincoln<sup>154</sup>, R. Lipton<sup>154</sup>, T. Liu<sup>154</sup>, C. Madrid<sup>154</sup>, K. Maeshima<sup>154</sup>, C. Mantilla<sup>154</sup>, D. Mason<sup>154</sup>,  
 P. McBride<sup>154</sup>, P. Merkel<sup>154</sup>, S. Mrenna<sup>154</sup>, S. Nahn<sup>154</sup>, J. Ngadiuba<sup>154</sup>, D. Noonan<sup>154</sup>, S. Norberg<sup>154</sup>,  
 V. Papadimitriou<sup>154</sup>, N. Pastika<sup>154</sup>, K. Pedro<sup>154</sup>, C. Pena<sup>154,eeee</sup>, F. Ravera<sup>154</sup>, A. Reinsvold Hall<sup>154,ffff</sup>,  
 L. Ristori<sup>154</sup>, M. Safdari<sup>154</sup>, E. Sexton-Kennedy<sup>154</sup>, N. Smith<sup>154</sup>, A. Soha<sup>154</sup>, L. Spiegel<sup>154</sup>, S. Stoynev<sup>154</sup>,  
 J. Strait<sup>154</sup>, L. Taylor<sup>154</sup>, S. Tkaczyk<sup>154</sup>, N. V. Tran<sup>154</sup>, L. Uplegger<sup>154</sup>, E. W. Vaandering<sup>154</sup>, I. Zoi<sup>154</sup>,  
 C. Aruta<sup>155</sup>, P. Avery<sup>155</sup>, D. Bourilkov<sup>155</sup>, P. Chang<sup>155</sup>, V. Cherepanov<sup>155</sup>, R. D. Field<sup>155</sup>, E. Koenig<sup>155</sup>,  
 M. Kolosova<sup>155</sup>, J. Konigsberg<sup>155</sup>, A. Korytov<sup>155</sup>, K. Matchev<sup>155</sup>, N. Menendez<sup>155</sup>, G. Mitselmakher<sup>155</sup>,  
 K. Mohrman<sup>155</sup>, A. Muthirakalayil Madhu<sup>155</sup>, N. Rawal<sup>155</sup>, S. Rosenzweig<sup>155</sup>, Y. Takahashi<sup>155</sup>, J. Wang<sup>155</sup>,  
 T. Adams<sup>156</sup>, A. Al Kadhimi<sup>156</sup>, A. Askew<sup>156</sup>, S. Bower<sup>156</sup>, R. Habibullah<sup>156</sup>, V. Hagopian<sup>156</sup>, R. Hashmi<sup>156</sup>,  
 R. S. Kim<sup>156</sup>, S. Kim<sup>156</sup>, T. Kolberg<sup>156</sup>, G. Martinez<sup>156</sup>, H. Prosper<sup>156</sup>, P. R. Prova<sup>156</sup>, M. Wulansatiti<sup>156</sup>,  
 R. Yohay<sup>156</sup>, J. Zhang<sup>156</sup>, B. Alsufyani<sup>157</sup>, M. M. Baarmand<sup>157</sup>, S. Butalla<sup>157</sup>, S. Das<sup>157</sup>, T. Elkafrawy<sup>157,gggg</sup>,  
 M. Hohlmann<sup>157</sup>, M. Rahmani<sup>157</sup>, E. Yanes<sup>157</sup>, M. R. Adams<sup>158</sup>, A. Baty<sup>158</sup>, C. Bennett<sup>158</sup>, R. Cavanaugh<sup>158</sup>,  
 R. Escobar Franco<sup>158</sup>, O. Evdokimov<sup>158</sup>, C. E. Gerber<sup>158</sup>, M. Hawksworth<sup>158</sup>, A. Hingrajiya<sup>158</sup>, D. J. Hofman<sup>158</sup>,  
 J. h. Lee<sup>158</sup>, D. S. Lemos<sup>158</sup>, A. H. Merrit<sup>158</sup>, C. Mills<sup>158</sup>, S. Nanda<sup>158</sup>, G. Oh<sup>158</sup>, B. Ozek<sup>158</sup>, D. Pilipovic<sup>158</sup>,  
 R. Pradhan<sup>158</sup>, E. Prifti<sup>158</sup>, T. Roy<sup>158</sup>, S. Rudrabhatla<sup>158</sup>, M. B. Tonjes<sup>158</sup>, N. Varelas<sup>158</sup>, M. A. Wadud<sup>158</sup>,  
 Z. Ye<sup>158</sup>, J. Yoo<sup>158</sup>, M. Alhousseini<sup>159</sup>, D. Blend<sup>159</sup>, K. Dilsiz<sup>159,hhhh</sup>, L. Emediato<sup>159</sup>, G. Karaman<sup>159</sup>,  
 O. K. Köseyan<sup>159</sup>, J.-P. Merlo<sup>159</sup>, A. Mestvirishvili<sup>159,iiii</sup>, O. Neogi<sup>159</sup>, H. Ogul<sup>159,jjjj</sup>, Y. Onel<sup>159</sup>, A. Penzo<sup>159</sup>,  
 C. Snyder<sup>159</sup>, E. Tiras<sup>159,kkkk</sup>, B. Blumenfeld<sup>160</sup>, L. Corcodilos<sup>160</sup>, J. Davis<sup>160</sup>, A. V. Gritsan<sup>160</sup>, L. Kang<sup>160</sup>,  
 S. Kyriacou<sup>160</sup>, P. Maksimovic<sup>160</sup>, M. Roguljic<sup>160</sup>, J. Roskes<sup>160</sup>, S. Sekhar<sup>160</sup>, M. Swartz<sup>160</sup>, A. Abreu<sup>161</sup>,  
 L. F. Alcerro Alcerro<sup>161</sup>, J. Anguiano<sup>161</sup>, S. Arteaga Escatel<sup>161</sup>, P. Baringer<sup>161</sup>, A. Bean<sup>161</sup>, Z. Flowers<sup>161</sup>,  
 D. Grove<sup>161</sup>, J. King<sup>161</sup>, G. Krintiras<sup>161</sup>, M. Lazarovits<sup>161</sup>, C. Le Mahieu<sup>161</sup>, J. Marquez<sup>161</sup>, N. Minafra<sup>161</sup>,  
 M. Murray<sup>161</sup>, M. Nickel<sup>161</sup>, M. Pitt<sup>161</sup>, S. Popescu<sup>161,llll</sup>, C. Rogan<sup>161</sup>, C. Royon<sup>161</sup>, R. Salvatico<sup>161</sup>,  
 S. Sanders<sup>161</sup>, C. Smith<sup>161</sup>, G. Wilson<sup>161</sup>, B. Allmond<sup>162</sup>, R. Gujju Gurnadha<sup>162</sup>, A. Ivanov<sup>162</sup>, K. Kaadze<sup>162</sup>,  
 Y. Maravin<sup>162</sup>, J. Natoli<sup>162</sup>, D. Roy<sup>162</sup>, G. Sorrentino<sup>162</sup>, A. Baden<sup>163</sup>, A. Belloni<sup>163</sup>, J. Bistany-riebman<sup>163</sup>,  
 Y. M. Chen<sup>163</sup>, S. C. Eno<sup>163</sup>, N. J. Hadley<sup>163</sup>, S. Jabeen<sup>163</sup>, R. G. Kellogg<sup>163</sup>, T. Koeth<sup>163</sup>, B. Kronheim<sup>163</sup>,  
 Y. Lai<sup>163</sup>, S. Lascio<sup>163</sup>, A. C. Mignerey<sup>163</sup>, S. Nabili<sup>163</sup>, C. Palmer<sup>163</sup>, C. Papageorgakis<sup>163</sup>, M. M. Paranjpe<sup>163</sup>,  
 L. Wang<sup>163</sup>, J. Bendavid<sup>164</sup>, I. A. Cali<sup>164</sup>, P. c. Chou<sup>164</sup>, M. D'Alfonso<sup>164</sup>, J. Eysermans<sup>164</sup>, C. Freer<sup>164</sup>,  
 G. Gomez-Ceballos<sup>164</sup>, M. Goncharov<sup>164</sup>, G. Grosso<sup>164</sup>, P. Harris<sup>164</sup>, D. Hoang<sup>164</sup>, D. Kovalskyi<sup>164</sup>, J. Krupa<sup>164</sup>,  
 L. Lavezzo<sup>164</sup>, Y.-J. Lee<sup>164</sup>, K. Long<sup>164</sup>, C. McGinn<sup>164</sup>, A. Novak<sup>164</sup>, C. Paus<sup>164</sup>, D. Rankin<sup>164</sup>, C. Roland<sup>164</sup>,  
 G. Roland<sup>164</sup>, S. Rothman<sup>164</sup>, G. S. F. Stephans<sup>164</sup>, P. Van Steenweghen<sup>164</sup>, Z. Wang<sup>164</sup>, B. Wyslouch<sup>164</sup>,  
 T. J. Yang<sup>164</sup>, B. Crossman<sup>165</sup>, B. M. Joshi<sup>165</sup>, C. Kapsiak<sup>165</sup>, M. Krohn<sup>165</sup>, D. Mahon<sup>165</sup>, J. Mans<sup>165</sup>,  
 B. Marzocchi<sup>165</sup>, M. Revering<sup>165</sup>, R. Rusack<sup>165</sup>, R. Saradhy<sup>165</sup>, N. Strobbe<sup>165</sup>, K. Bloom<sup>166</sup>, D. R. Claes<sup>166</sup>,  
 G. Haza<sup>166</sup>, J. Hossain<sup>166</sup>, C. Joo<sup>166</sup>, I. Kravchenko<sup>166</sup>, J. E. Siado<sup>166</sup>, W. Tabb<sup>166</sup>, A. Vagnerini<sup>166</sup>,  
 A. Wightman<sup>166</sup>, F. Yan<sup>166</sup>, D. Yu<sup>166</sup>, H. Bandyopadhyay<sup>167</sup>, L. Hay<sup>167</sup>, H. w. Hsia<sup>167</sup>, I. Iashvili<sup>167</sup>,  
 A. Kalogeropoulos<sup>167</sup>, A. Kharchilava<sup>167</sup>, M. Morris<sup>167</sup>, D. Nguyen<sup>167</sup>, S. Rappoccio<sup>167</sup>, H. Rejeb Sfar<sup>167</sup>,  
 A. Williams<sup>167</sup>, P. Young<sup>167</sup>, G. Alverson<sup>168</sup>, E. Barberis<sup>168</sup>, J. Bonilla<sup>168</sup>, J. Dervan<sup>168</sup>, Y. Haddad<sup>168</sup>, Y. Han<sup>168</sup>,  
 A. Krishna<sup>168</sup>, J. Li<sup>168</sup>, M. Lu<sup>168</sup>, G. Madigan<sup>168</sup>, R. McCarthy<sup>168</sup>, D. M. Morse<sup>168</sup>, V. Nguyen<sup>168</sup>,  
 T. Orimoto<sup>168</sup>, A. Parker<sup>168</sup>, L. Skinnari<sup>168</sup>, D. Wood<sup>168</sup>, J. Bueghly<sup>169</sup>, S. Dittmer<sup>169</sup>, K. A. Hahn<sup>169</sup>, Y. Liu<sup>169</sup>,  
 Y. Miao<sup>169</sup>, D. G. Monk<sup>169</sup>, M. H. Schmitt<sup>169</sup>, A. Talierno<sup>169</sup>, M. Velasco<sup>169</sup>, G. Agarwal<sup>170</sup>, R. Band<sup>170</sup>

R. Bucci,<sup>170</sup> S. Castells,<sup>170</sup> A. Das,<sup>170</sup> R. Goldouzian,<sup>170</sup> M. Hildreth,<sup>170</sup> K. W. Ho,<sup>170</sup> K. Hurtado Anampa,<sup>170</sup>  
 T. Ivanov,<sup>170</sup> C. Jessop,<sup>170</sup> K. Lannon,<sup>170</sup> J. Lawrence,<sup>170</sup> N. Loukas,<sup>170</sup> L. Lutton,<sup>170</sup> J. Mariano,<sup>170</sup>  
 N. Marinelli,<sup>170</sup> I. Mcalister,<sup>170</sup> T. McCauley,<sup>170</sup> C. Mcgrady,<sup>170</sup> C. Moore,<sup>170</sup> Y. Musienko,<sup>170,r</sup> H. Nelson,<sup>170</sup>  
 M. Osherson,<sup>170</sup> A. Piccinelli,<sup>170</sup> R. Ruchti,<sup>170</sup> A. Townsend,<sup>170</sup> Y. Wan,<sup>170</sup> M. Wayne,<sup>170</sup> H. Yockey,<sup>170</sup>  
 M. Zarucki,<sup>170</sup> L. Zygala,<sup>170</sup> A. Basnet,<sup>171</sup> B. Bylsma,<sup>171</sup> M. Carrigan,<sup>171</sup> L. S. Durkin,<sup>171</sup> C. Hill,<sup>171</sup>  
 M. Joyce,<sup>171</sup> M. Nunez Ornelas,<sup>171</sup> K. Wei,<sup>171</sup> B. L. Winer,<sup>171</sup> B. R. Yates,<sup>171</sup> H. Bouchamaoui,<sup>172</sup> P. Das,<sup>172</sup>  
 G. Dezoort,<sup>172</sup> P. Elmer,<sup>172</sup> A. Frankenthal,<sup>172</sup> B. Greenberg,<sup>172</sup> N. Haubrich,<sup>172</sup> K. Kennedy,<sup>172</sup> G. Kopp,<sup>172</sup>  
 S. Kwan,<sup>172</sup> D. Lange,<sup>172</sup> A. Loeliger,<sup>172</sup> D. Marlow,<sup>172</sup> I. Ojalvo,<sup>172</sup> J. Olsen,<sup>172</sup> A. Shevelev,<sup>172</sup>  
 D. Stickland,<sup>172</sup> C. Tully,<sup>172</sup> S. Malik,<sup>173</sup> A. S. Bakshi,<sup>174</sup> S. Chandra,<sup>174</sup> R. Chawla,<sup>174</sup> A. Gu,<sup>174</sup> L. Gutay,<sup>174</sup>  
 M. Jones,<sup>174</sup> A. W. Jung,<sup>174</sup> A. M. Koshy,<sup>174</sup> M. Liu,<sup>174</sup> G. Negro,<sup>174</sup> N. Neumeister,<sup>174</sup> G. Paspalaki,<sup>174</sup>  
 S. Piperov,<sup>174</sup> V. Scheurer,<sup>174</sup> J. F. Schulte,<sup>174</sup> M. Stojanovic,<sup>174</sup> J. Thieman,<sup>174</sup> A. K. Viridi,<sup>174</sup> F. Wang,<sup>174</sup>  
 W. Xie,<sup>174</sup> J. Dolen,<sup>175</sup> N. Parashar,<sup>175</sup> A. Pathak,<sup>175</sup> D. Acosta,<sup>176</sup> T. Carnahan,<sup>176</sup> K. M. Ecklund,<sup>176</sup>  
 P. J. Fernández Manteca,<sup>176</sup> S. Freed,<sup>176</sup> P. Gardner,<sup>176</sup> F. J. M. Geurts,<sup>176</sup> W. Li,<sup>176</sup> J. Lin,<sup>176</sup> O. Miguel Colin,<sup>176</sup>  
 B. P. Padley,<sup>176</sup> R. Redjimi,<sup>176</sup> J. Rotter,<sup>176</sup> E. Yigitbasi,<sup>176</sup> Y. Zhang,<sup>176</sup> A. Bodek,<sup>177</sup> P. de Barbaro,<sup>177</sup>  
 R. Demina,<sup>177</sup> J. L. Dulemba,<sup>177</sup> A. Garcia-Bellido,<sup>177</sup> O. Hindrichs,<sup>177</sup> A. Khukhunaishvili,<sup>177</sup> N. Parmar,<sup>177</sup>  
 P. Parygin,<sup>177,r</sup> E. Popova,<sup>177,r</sup> R. Taus,<sup>177</sup> B. Chiarito,<sup>178</sup> J. P. Chou,<sup>178</sup> S. V. Clark,<sup>178</sup> D. Gadkari,<sup>178</sup>  
 Y. Gershtein,<sup>178</sup> E. Halkiadakis,<sup>178</sup> M. Heindl,<sup>178</sup> C. Houghton,<sup>178</sup> D. Jaroslawski,<sup>178</sup> O. Karacheban,<sup>178,bb</sup>  
 S. Konstantinou,<sup>178</sup> I. Laflotte,<sup>178</sup> A. Lath,<sup>178</sup> R. Montalvo,<sup>178</sup> K. Nash,<sup>178</sup> J. Reichert,<sup>178</sup> H. Routray,<sup>178</sup>  
 P. Saha,<sup>178</sup> S. Salur,<sup>178</sup> S. Schnetzer,<sup>178</sup> S. Somalwar,<sup>178</sup> R. Stone,<sup>178</sup> S. A. Thayil,<sup>178</sup> S. Thomas,<sup>178</sup> J. Vora,<sup>178</sup>  
 H. Wang,<sup>178</sup> H. Acharya,<sup>179</sup> D. Ally,<sup>179</sup> A. G. Delannoy,<sup>179</sup> S. Fiorendi,<sup>179</sup> S. Higginbotham,<sup>179</sup> T. Holmes,<sup>179</sup>  
 A. R. Kanuganti,<sup>179</sup> N. Karunarathna,<sup>179</sup> L. Lee,<sup>179</sup> E. Nibigira,<sup>179</sup> S. Spanier,<sup>179</sup> D. Aebi,<sup>180</sup> M. Ahmad,<sup>180</sup>  
 T. Akhter,<sup>180</sup> O. Bouhali,<sup>180,mmmm</sup> R. Eusebi,<sup>180</sup> J. Gilmore,<sup>180</sup> T. Huang,<sup>180</sup> T. Kamon,<sup>180,nnnn</sup> H. Kim,<sup>180</sup>  
 S. Luo,<sup>180</sup> R. Mueller,<sup>180</sup> D. Overton,<sup>180</sup> D. Rathjens,<sup>180</sup> A. Safonov,<sup>180</sup> N. Akchurin,<sup>181</sup> J. Damgov,<sup>181</sup>  
 N. Gogate,<sup>181</sup> V. Hegde,<sup>181</sup> A. Hussain,<sup>181</sup> Y. Kazhykarim,<sup>181</sup> K. Lamichhane,<sup>181</sup> S. W. Lee,<sup>181</sup> A. Mankel,<sup>181</sup>  
 T. Peltola,<sup>181</sup> I. Volobouev,<sup>181</sup> E. Appelt,<sup>182</sup> Y. Chen,<sup>182</sup> S. Greene,<sup>182</sup> A. Gurrola,<sup>182</sup> W. Johns,<sup>182</sup>  
 R. Kunnawalkam Elayavalli,<sup>182</sup> A. Melo,<sup>182</sup> F. Romeo,<sup>182</sup> P. Sheldon,<sup>182</sup> S. Tuo,<sup>182</sup> J. Velkovska,<sup>182</sup>  
 J. Viinikainen,<sup>182</sup> B. Cardwell,<sup>183</sup> B. Cox,<sup>183</sup> J. Hakala,<sup>183</sup> R. Hirosky,<sup>183</sup> A. Ledovskoy,<sup>183</sup> C. Neu,<sup>183</sup>  
 S. Bhattacharya,<sup>184</sup> P. E. Karchin,<sup>184</sup> A. Aravind,<sup>185</sup> S. Banerjee,<sup>185</sup> K. Black,<sup>185</sup> T. Bose,<sup>185</sup> S. Dasu,<sup>185</sup>  
 I. De Bruyn,<sup>185</sup> P. Everaerts,<sup>185</sup> C. Galloni,<sup>185</sup> H. He,<sup>185</sup> M. Herndon,<sup>185</sup> A. Herve,<sup>185</sup> C. K. Koraka,<sup>185</sup>  
 A. Lanaro,<sup>185</sup> R. Loveless,<sup>185</sup> J. Madhusudanan Sreekala,<sup>185</sup> A. Mallampalli,<sup>185</sup> A. Mohammadi,<sup>185</sup> S. Mondal,<sup>185</sup>  
 G. Parida,<sup>185</sup> L. Pétré,<sup>185</sup> D. Pinna,<sup>185</sup> A. Savin,<sup>185</sup> V. Shang,<sup>185</sup> V. Sharma,<sup>185</sup> W. H. Smith,<sup>185</sup> D. Teague,<sup>185</sup>  
 H. F. Tsoi,<sup>185</sup> W. Vetens,<sup>185</sup> A. Warden,<sup>185</sup> S. Afanasiev,<sup>186</sup> V. Alexakhin,<sup>186</sup> V. Andreev,<sup>186</sup> Yu. Andreev,<sup>186</sup>  
 T. Aushev,<sup>186</sup> M. Azarkin,<sup>186</sup> A. Babaev,<sup>186</sup> V. Blinov,<sup>186,r</sup> E. Boos,<sup>186</sup> V. Borshch,<sup>186</sup> D. Budkouski,<sup>186</sup>  
 V. Bunichev,<sup>186</sup> V. Chekhovsky,<sup>186</sup> R. Chistov,<sup>186,r</sup> M. Danilov,<sup>186,r</sup> A. Dermenev,<sup>186</sup> T. Dimova,<sup>186,r</sup>  
 D. Druzhkin,<sup>186,oooo</sup> M. Dubinin,<sup>186,eeee</sup> L. Dudko,<sup>186</sup> A. Ershov,<sup>186</sup> G. Gavrilo,<sup>186</sup> V. Gavrilo,<sup>186</sup>  
 S. Gninenko,<sup>186</sup> V. Golovtcov,<sup>186</sup> N. Golubev,<sup>186</sup> I. Golutvin,<sup>186,a</sup> I. Gorbunov,<sup>186</sup> A. Gribushin,<sup>186</sup> Y. Ivanov,<sup>186</sup>  
 V. Kachanov,<sup>186</sup> V. Karjavine,<sup>186</sup> A. Karneyeu,<sup>186</sup> V. Kim,<sup>186,r</sup> M. Kirakosyan,<sup>186</sup> D. Kirpichnikov,<sup>186</sup>  
 M. Kirsanov,<sup>186</sup> V. Klyukhin,<sup>186</sup> O. Kodolova,<sup>186,pppp</sup> D. Konstantinov,<sup>186</sup> V. Korenkov,<sup>186</sup> A. Kozyrev,<sup>186,r</sup>  
 N. Krasnikov,<sup>186</sup> A. Lanev,<sup>186</sup> P. Levchenko,<sup>186,qqqq</sup> N. Lychkovskaya,<sup>186</sup> V. Makarenko,<sup>186</sup> A. Malakhov,<sup>186</sup>  
 V. Matveev,<sup>186,r</sup> V. Murzin,<sup>186</sup> A. Nikitenko,<sup>186,rrrr,pppp</sup> S. Obraztsov,<sup>186</sup> V. Oreshkin,<sup>186</sup> V. Palichik,<sup>186</sup>  
 V. Perelygin,<sup>186</sup> S. Petrushanko,<sup>186</sup> S. Polikarpov,<sup>186,r</sup> V. Popov,<sup>186</sup> O. Radchenko,<sup>186,r</sup> M. Savina,<sup>186</sup>  
 V. Savrin,<sup>186</sup> V. Shalae,<sup>186</sup> S. Shmatov,<sup>186</sup> S. Shulha,<sup>186</sup> Y. Skovpen,<sup>186,r</sup> S. Slabospitskii,<sup>186</sup> V. Smirnov,<sup>186</sup>  
 A. Snigirev,<sup>186</sup> D. Sosnov,<sup>186</sup> V. Sulimov,<sup>186</sup> E. Tcherniaev,<sup>186</sup> A. Terkulov,<sup>186</sup> O. Teryaev,<sup>186</sup> I. Tlisova,<sup>186</sup>  
 A. Toropin,<sup>186</sup> L. Uvarov,<sup>186</sup> A. Uzunian,<sup>186</sup> A. Vorobyev,<sup>186,a</sup> N. Voytishin,<sup>186</sup> B. S. Yuldashev,<sup>186,ssss</sup>  
 A. Zarubin,<sup>186</sup> I. Zhizhin,<sup>186</sup> and A. Zhokin<sup>186</sup>

(CMS Collaboration)

- <sup>1</sup>*Yerevan Physics Institute, Yerevan, Armenia*  
<sup>2</sup>*Institut für Hochenergiephysik, Vienna, Austria*  
<sup>3</sup>*Universiteit Antwerpen, Antwerpen, Belgium*  
<sup>4</sup>*Vrije Universiteit Brussel, Brussel, Belgium*  
<sup>5</sup>*Université Libre de Bruxelles, Bruxelles, Belgium*  
<sup>6</sup>*Ghent University, Ghent, Belgium*  
<sup>7</sup>*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*  
<sup>8</sup>*Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil*  
<sup>9</sup>*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*  
<sup>10</sup>*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*  
<sup>11</sup>*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*  
<sup>12</sup>*University of Sofia, Sofia, Bulgaria*  
<sup>13</sup>*Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7 D, Arica, Chile*  
<sup>14</sup>*Beihang University, Beijing, China*  
<sup>15</sup>*Department of Physics, Tsinghua University, Beijing, China*  
<sup>16</sup>*Institute of High Energy Physics, Beijing, China*  
<sup>17</sup>*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*  
<sup>18</sup>*Guangdong Provincial Key Laboratory of Nuclear Science and Guangdong-Hong Kong Joint Laboratory of Quantum Matter, South China Normal University, Guangzhou, China*  
<sup>19</sup>*Sun Yat-Sen University, Guangzhou, China*  
<sup>20</sup>*University of Science and Technology of China, Hefei, China*  
<sup>21</sup>*Nanjing Normal University, Nanjing, China*  
<sup>22</sup>*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE) - Fudan University, Shanghai, China*  
<sup>23</sup>*Zhejiang University, Hangzhou, Zhejiang, China*  
<sup>24</sup>*Universidad de Los Andes, Bogota, Colombia*  
<sup>25</sup>*Universidad de Antioquia, Medellin, Colombia*  
<sup>26</sup>*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*  
<sup>27</sup>*University of Split, Faculty of Science, Split, Croatia*  
<sup>28</sup>*Institute Rudjer Boskovic, Zagreb, Croatia*  
<sup>29</sup>*University of Cyprus, Nicosia, Cyprus*  
<sup>30</sup>*Charles University, Prague, Czech Republic*  
<sup>31</sup>*Universidad San Francisco de Quito, Quito, Ecuador*  
<sup>32</sup>*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*  
<sup>33</sup>*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*  
<sup>34</sup>*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*  
<sup>35</sup>*Department of Physics, University of Helsinki, Helsinki, Finland*  
<sup>36</sup>*Helsinki Institute of Physics, Helsinki, Finland*  
<sup>37</sup>*Lappeenranta-Lahti University of Technology, Lappeenranta, Finland*  
<sup>38</sup>*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*  
<sup>39</sup>*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*  
<sup>40</sup>*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*  
<sup>41</sup>*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*  
<sup>42</sup>*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*  
<sup>43</sup>*Georgian Technical University, Tbilisi, Georgia*  
<sup>44</sup>*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*  
<sup>45</sup>*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*  
<sup>46</sup>*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*  
<sup>47</sup>*Deutsches Elektronen-Synchrotron, Hamburg, Germany*  
<sup>48</sup>*University of Hamburg, Hamburg, Germany*  
<sup>49</sup>*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*  
<sup>50</sup>*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*  
<sup>51</sup>*National and Kapodistrian University of Athens, Athens, Greece*  
<sup>52</sup>*National Technical University of Athens, Athens, Greece*  
<sup>53</sup>*University of Ioánnina, Ioánnina, Greece*  
<sup>54</sup>*HUN-REN Wigner Research Centre for Physics, Budapest, Hungary*  
<sup>55</sup>*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*  
<sup>56</sup>*Faculty of Informatics, University of Debrecen, Debrecen, Hungary*

- <sup>57</sup>*Institute of Nuclear Research ATOMKI, Debrecen, Hungary*
- <sup>58</sup>*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
- <sup>59</sup>*Panjab University, Chandigarh, India*
- <sup>60</sup>*University of Delhi, Delhi, India*
- <sup>61</sup>*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
- <sup>62</sup>*Indian Institute of Technology Madras, Madras, India*
- <sup>63</sup>*Tata Institute of Fundamental Research-A, Mumbai, India*
- <sup>64</sup>*Tata Institute of Fundamental Research-B, Mumbai, India*
- <sup>65</sup>*National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India*
- <sup>66</sup>*Indian Institute of Science Education and Research (IISER), Pune, India*
- <sup>67</sup>*Isfahan University of Technology, Isfahan, Iran*
- <sup>68</sup>*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
- <sup>69</sup>*University College Dublin, Dublin, Ireland*
- <sup>70a</sup>*INFN Sezione di Bari, Bari, Italy*
- <sup>70b</sup>*Università di Bari, Bari, Italy*
- <sup>70c</sup>*Politecnico di Bari, Bari, Italy*
- <sup>71a</sup>*INFN Sezione di Bologna, Bologna, Italy*
- <sup>71b</sup>*Università di Bologna, Bologna, Italy*
- <sup>72a</sup>*INFN Sezione di Catania, Catania, Italy*
- <sup>72b</sup>*Università di Catania, Catania, Italy*
- <sup>73a</sup>*INFN Sezione di Firenze, Firenze, Italy*
- <sup>73b</sup>*Università di Firenze, Firenze, Italy*
- <sup>74</sup>*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
- <sup>75a</sup>*INFN Sezione di Genova, Genova, Italy*
- <sup>75b</sup>*Università di Genova, Genova, Italy*
- <sup>76a</sup>*INFN Sezione di Milano-Bicocca, Milano, Italy*
- <sup>76b</sup>*Università di Milano-Bicocca, Milano, Italy*
- <sup>77a</sup>*INFN Sezione di Napoli, Napoli, Italy*
- <sup>77b</sup>*Università di Napoli 'Federico II', Napoli, Italy*
- <sup>77c</sup>*Università della Basilicata, Potenza, Italy*
- <sup>77d</sup>*Scuola Superiore Meridionale (SSM), Napoli, Italy*
- <sup>78a</sup>*INFN Sezione di Padova, Padova, Italy*
- <sup>78b</sup>*Università di Padova, Padova, Italy*
- <sup>78c</sup>*Università di Trento, Trento, Italy*
- <sup>79a</sup>*INFN Sezione di Pavia, Pavia, Italy*
- <sup>79b</sup>*Università di Pavia, Pavia, Italy*
- <sup>80a</sup>*INFN Sezione di Perugia, Perugia, Italy*
- <sup>80b</sup>*Università di Perugia, Perugia, Italy*
- <sup>81a</sup>*INFN Sezione di Pisa, Pisa, Italy*
- <sup>81b</sup>*Università di Pisa, Pisa, Italy*
- <sup>81c</sup>*Scuola Normale Superiore di Pisa, Pisa, Italy*
- <sup>81d</sup>*Università di Siena, Siena, Italy*
- <sup>82a</sup>*INFN Sezione di Roma, Roma, Italy*
- <sup>82b</sup>*Sapienza Università di Roma, Roma, Italy*
- <sup>83a</sup>*INFN Sezione di Torino, Torino, Italy*
- <sup>83b</sup>*Università di Torino, Torino, Italy*
- <sup>83c</sup>*Università del Piemonte Orientale, Novara, Italy*
- <sup>84a</sup>*INFN Sezione di Trieste, Trieste, Italy*
- <sup>84b</sup>*Università di Trieste, Trieste, Italy*
- <sup>85</sup>*Kyungpook National University, Daegu, Korea*
- <sup>86</sup>*Department of Mathematics and Physics - GWNNU, Gangneung, Korea*
- <sup>87</sup>*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
- <sup>88</sup>*Hanyang University, Seoul, Korea*
- <sup>89</sup>*Korea University, Seoul, Korea*
- <sup>90</sup>*Kyung Hee University, Department of Physics, Seoul, Korea*
- <sup>91</sup>*Sejong University, Seoul, Korea*
- <sup>92</sup>*Seoul National University, Seoul, Korea*
- <sup>93</sup>*University of Seoul, Seoul, Korea*
- <sup>94</sup>*Yonsei University, Department of Physics, Seoul, Korea*
- <sup>95</sup>*Sungkyunkwan University, Suwon, Korea*

- <sup>96</sup>*College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait*
- <sup>97</sup>*Riga Technical University, Riga, Latvia*
- <sup>98</sup>*University of Latvia (LU), Riga, Latvia*
- <sup>99</sup>*Vilnius University, Vilnius, Lithuania*
- <sup>100</sup>*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
- <sup>101</sup>*Universidad de Sonora (UNISON), Hermosillo, Mexico*
- <sup>102</sup>*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
- <sup>103</sup>*Universidad Iberoamericana, Mexico City, Mexico*
- <sup>104</sup>*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
- <sup>105</sup>*University of Montenegro, Podgorica, Montenegro*
- <sup>106</sup>*University of Canterbury, Christchurch, New Zealand*
- <sup>107</sup>*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
- <sup>108</sup>*AGH University of Krakow, Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland*
- <sup>109</sup>*National Centre for Nuclear Research, Swierk, Poland*
- <sup>110</sup>*Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland*
- <sup>111</sup>*Warsaw University of Technology, Warsaw, Poland*
- <sup>112</sup>*Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal*
- <sup>113</sup>*Faculty of Physics, University of Belgrade, Belgrade, Serbia*
- <sup>114</sup>*VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia*
- <sup>115</sup>*Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain*
- <sup>116</sup>*Universidad Autónoma de Madrid, Madrid, Spain*
- <sup>117</sup>*Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain*
- <sup>118</sup>*Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain*
- <sup>119</sup>*University of Colombo, Colombo, Sri Lanka*
- <sup>120</sup>*University of Ruhuna, Department of Physics, Matara, Sri Lanka*
- <sup>121</sup>*CERN, European Organization for Nuclear Research, Geneva, Switzerland*
- <sup>122</sup>*Paul Scherrer Institut, Villigen, Switzerland*
- <sup>123</sup>*ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland*
- <sup>124</sup>*Universität Zürich, Zurich, Switzerland*
- <sup>125</sup>*National Central University, Chung-Li, Taiwan*
- <sup>126</sup>*National Taiwan University (NTU), Taipei, Taiwan*
- <sup>127</sup>*High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
- <sup>128</sup>*Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey*
- <sup>129</sup>*Middle East Technical University, Physics Department, Ankara, Turkey*
- <sup>130</sup>*Bogazici University, Istanbul, Turkey*
- <sup>131</sup>*Istanbul Technical University, Istanbul, Turkey*
- <sup>132</sup>*Istanbul University, Istanbul, Turkey*
- <sup>133</sup>*Yildiz Technical University, Istanbul, Turkey*
- <sup>134</sup>*Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine*
- <sup>135</sup>*National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine*
- <sup>136</sup>*University of Bristol, Bristol, United Kingdom*
- <sup>137</sup>*Rutherford Appleton Laboratory, Didcot, United Kingdom*
- <sup>138</sup>*Imperial College, London, United Kingdom*
- <sup>139</sup>*Brunel University, Uxbridge, United Kingdom*
- <sup>140</sup>*Baylor University, Waco, Texas, USA*
- <sup>141</sup>*Catholic University of America, Washington, DC, USA*
- <sup>142</sup>*The University of Alabama, Tuscaloosa, Alabama, USA*
- <sup>143</sup>*Boston University, Boston, Massachusetts, USA*
- <sup>144</sup>*Brown University, Providence, Rhode Island, USA*
- <sup>145</sup>*University of California, Davis, Davis, California, USA*
- <sup>146</sup>*University of California, Los Angeles, California, USA*
- <sup>147</sup>*University of California, Riverside, Riverside, California, USA*
- <sup>148</sup>*University of California, San Diego, La Jolla, California, USA*
- <sup>149</sup>*University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA*
- <sup>150</sup>*California Institute of Technology, Pasadena, California, USA*
- <sup>151</sup>*Carnegie Mellon University, Pittsburgh, Pennsylvania, USA*
- <sup>152</sup>*University of Colorado Boulder, Boulder, Colorado, USA*
- <sup>153</sup>*Cornell University, Ithaca, New York, USA*
- <sup>154</sup>*Fermi National Accelerator Laboratory, Batavia, Illinois, USA*
- <sup>155</sup>*University of Florida, Gainesville, Florida, USA*

- <sup>156</sup>Florida State University, Tallahassee, Florida, USA  
<sup>157</sup>Florida Institute of Technology, Melbourne, Florida, USA  
<sup>158</sup>University of Illinois Chicago, Chicago, USA, Chicago, USA  
<sup>159</sup>The University of Iowa, Iowa City, Iowa, USA  
<sup>160</sup>Johns Hopkins University, Baltimore, Maryland, USA  
<sup>161</sup>The University of Kansas, Lawrence, Kansas, USA  
<sup>162</sup>Kansas State University, Manhattan, Kansas, USA  
<sup>163</sup>University of Maryland, College Park, Maryland, USA  
<sup>164</sup>Massachusetts Institute of Technology, Cambridge, Massachusetts, USA  
<sup>165</sup>University of Minnesota, Minneapolis, Minnesota, USA  
<sup>166</sup>University of Nebraska-Lincoln, Lincoln, Nebraska, USA  
<sup>167</sup>State University of New York at Buffalo, Buffalo, New York, USA  
<sup>168</sup>Northeastern University, Boston, Massachusetts, USA  
<sup>169</sup>Northwestern University, Evanston, Illinois, USA  
<sup>170</sup>University of Notre Dame, Notre Dame, Indiana, USA  
<sup>171</sup>The Ohio State University, Columbus, Ohio, USA  
<sup>172</sup>Princeton University, Princeton, New Jersey, USA  
<sup>173</sup>University of Puerto Rico, Mayaguez, Puerto Rico, USA  
<sup>174</sup>Purdue University, West Lafayette, Indiana, USA  
<sup>175</sup>Purdue University Northwest, Hammond, Indiana, USA  
<sup>176</sup>Rice University, Houston, Texas, USA  
<sup>177</sup>University of Rochester, Rochester, New York, USA  
<sup>178</sup>Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA  
<sup>179</sup>University of Tennessee, Knoxville, Tennessee, USA  
<sup>180</sup>Texas A&M University, College Station, Texas, USA  
<sup>181</sup>Texas Tech University, Lubbock, Texas, USA  
<sup>182</sup>Vanderbilt University, Nashville, Tennessee, USA  
<sup>183</sup>University of Virginia, Charlottesville, Virginia, USA  
<sup>184</sup>Wayne State University, Detroit, Michigan, USA  
<sup>185</sup>University of Wisconsin - Madison, Madison, Wisconsin, USA  
<sup>186</sup>An institute or international laboratory covered by a cooperation agreement with [CERN](#)

<sup>a</sup>Deceased.

<sup>b</sup>Also at Yerevan State University, Yerevan, Armenia.

<sup>c</sup>Also at TU Wien, Vienna, Austria.

<sup>d</sup>Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.

<sup>e</sup>Also at Ghent University, Ghent, Belgium.

<sup>f</sup>Also at Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil.

<sup>g</sup>Also at Universidade Estadual de Campinas, Campinas, Brazil.

<sup>h</sup>Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

<sup>i</sup>Also at UFMS, Nova Andradina, Brazil.

<sup>j</sup>Also at Nanjing Normal University, Nanjing, China.

<sup>k</sup>Also at The University of Iowa, Iowa City, Iowa, USA.

<sup>l</sup>Also at University of Chinese Academy of Sciences, Beijing, China.

<sup>m</sup>Also at China Center of Advanced Science and Technology, Beijing, China.

<sup>n</sup>Also at University of Chinese Academy of Sciences, Beijing, China.

<sup>o</sup>Also at China Spallation Neutron Source, Guangdong, China.

<sup>p</sup>Also at Henan Normal University, Xinxiang, China.

<sup>q</sup>Also at Université Libre de Bruxelles, Bruxelles, Belgium.

<sup>r</sup>Also at Another institute or international laboratory covered by a cooperation agreement with CERN.

<sup>s</sup>Also at Suez University, Suez, Egypt.

<sup>t</sup>Also at British University in Egypt, Cairo, Egypt.

<sup>u</sup>Also at Purdue University, West Lafayette, Indiana, USA.

<sup>v</sup>Also at Université de Haute Alsace, Mulhouse, France.

<sup>w</sup>Also at Department of Physics, Tsinghua University, Beijing, China.

<sup>x</sup>Also at The University of the State of Amazonas, Manaus, Brazil.

<sup>y</sup>Also at University of Hamburg, Hamburg, Germany.

<sup>z</sup>Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.

<sup>aa</sup>Also at Bergische University Wuppertal (BUW), Wuppertal, Germany.

- bb Also at Brandenburg University of Technology, Cottbus, Germany.
- cc Also at Forschungszentrum Jülich, Juelich, Germany.
- dd Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
- ee Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
- ff Also at Universitatea Babeş-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.
- gg Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
- hh Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary.
- ii Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
- jj Also at Punjab Agricultural University, Ludhiana, India.
- kk Also at University of Visva-Bharati, Santiniketan, India.
- ll Also at Indian Institute of Science (IISc), Bangalore, India.
- mm Also at IIT Bhubaneswar, Bhubaneswar, India.
- nn Also at Institute of Physics, Bhubaneswar, India.
- oo Also at University of Hyderabad, Hyderabad, India.
- pp Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
- qq Also at Isfahan University of Technology, Isfahan, Iran.
- rr Also at Sharif University of Technology, Tehran, Iran.
- ss Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
- tt Also at Department of Physics, Isfahan University of Technology, Isfahan, Iran.
- uu Also at Helwan University, Cairo, Egypt.
- vv Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
- ww Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
- xx Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
- yy Also at Scuola Superiore Meridionale, Università di Napoli 'Federico II', Napoli, Italy.
- zz Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
- aaa Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
- bbb Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
- ccc Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
- ddd Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
- eee Also at Saegis Campus, Nugegoda, Sri Lanka.
- fff Also at National and Kapodistrian University of Athens, Athens, Greece.
- ggg Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
- hhh Also at Universität Zürich, Zurich, Switzerland.
- iii Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
- jjj Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
- kkk Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
- lll Also at Konya Technical University, Konya, Turkey.
- mmm Also at Izmir Bakircay University, Izmir, Turkey.
- nnn Also at Adiyaman University, Adiyaman, Turkey.
- ooo Also at Bozok Universitetesi Rektörlüğü, Yozgat, Turkey.
- ppp Also at Marmara University, Istanbul, Turkey.
- qqq Also at Milli Savunma University, Istanbul, Turkey.
- rrr Also at Kafkas University, Kars, Turkey.
- sss Also at Istanbul Okan University, Istanbul, Turkey.
- ttt Also at Hacettepe University, Ankara, Turkey.
- uuu Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
- vvv Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
- www Also at Yildiz Technical University, Istanbul, Turkey.
- xxx Also at Vrije Universiteit Brussel, Brussel, Belgium.
- yyy Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- zzz Also at IPPP Durham University, Durham, United Kingdom.
- aaaa Also at Monash University, Faculty of Science, Clayton, Australia.
- bbbb Also at Università di Torino, Torino, Italy.
- cccc Also at Bethel University, St. Paul, Minnesota, USA.
- dddd Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
- eeee Also at California Institute of Technology, Pasadena, California, USA.
- ffff Also at United States Naval Academy, Annapolis, Maryland, USA.
- gggg Also at Ain Shams University, Cairo, Egypt.
- hhhh Also at Bingol University, Bingol, Turkey.
- iiii Also at Georgian Technical University, Tbilisi, Georgia.

<sup>jjjj</sup> Also at Sinop University, Sinop, Turkey.

<sup>kkkk</sup> Also at Erciyes University, Kayseri, Turkey.

<sup>llll</sup> Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.

<sup>mmmm</sup> Also at Texas A&M University at Qatar, Doha, Qatar.

<sup>nnnn</sup> Also at Kyungpook National University, Daegu, Korea.

<sup>oooo</sup> Also at Universiteit Antwerpen, Antwerpen, Belgium.

<sup>pppp</sup> Also at Yerevan Physics Institute, Yerevan, Armenia.

<sup>qqqq</sup> Also at Northeastern University, Boston, Massachusetts, USA.

<sup>rrrr</sup> Also at Imperial College, London, United Kingdom.

<sup>ssss</sup> Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.