Measurement of D^0 Meson Photoproduction in Ultraperipheral Heavy Ion Collisions

V. Chekhovsky *et al.*[*]
(CMS Collaboration)

(Received 10 September 2025; revised 17 December 2025; accepted 7 January 2026; published 26 March 2026)

This Letter reports the first measurement of photonuclear D^0 meson production in ultraperipheral heavy ion collisions. The study is performed using lead-lead collision data, with an integrated luminosity of 1.34 nb^{-1}, collected by the CMS experiment at a nucleon-nucleon center-of-mass energy of 5.36 TeV. Photonuclear events, where one of the colliding nuclei breaks up and the other remains intact, are selected based on breakup neutron emissions and by requiring no particle activity in a large rapidity interval in the direction of the photon-emitting nucleus. The D^0 mesons are reconstructed via the $D^0 \to K^-\pi^+$ decay channel, with the cross section measured as a function of D^0 meson transverse momentum and rapidity. The results are compared with next-to-leading-order perturbative QCD calculations that employ recent parametrizations of the lead nuclear parton distribution functions, as well as with predictions based on the color glass condensate framework. This measurement is the first photonuclear collision study characterizing parton distribution functions of lead nuclei for parton fractional momenta x (relative to the nucleon) ranging approximately from a few 10^{-4} to 10^{-2} for different hard energy scale Q^2 selections.

DOI: 10.1103/lckg-sdh9

Ultraperipheral collisions (UPCs) of heavy ions serve as a powerful experimental tool for studying the gluonic structure of nuclei and for probing the evolution equations of quantum chromodynamics (QCD) for partons carrying a small fraction of the nucleon momentum, x [1,2]. The UPCs occur when the impact parameter of the collision exceeds the sum of the radii of the two nuclei. At ultrarelativistic energies, the Lorentz-contracted electromagnetic fields surrounding the heavy ions act as sources of high-energy quasireal photons, leading to abundant photonuclear interactions. An overview of recent UPC results from CMS can be found in Ref. [3].

For LHC energies in particular, the large flux of high-energy photons results in sizeable cross sections for the production of heavy quarks [4,5]. Charm photoproduction in UPCs occurs when a quasireal photon emitted from one nucleus interacts with a gluon from the other nucleus, forming a charm quark-antiquark pair ($c\bar{c}$). Measurements of the production yields of charmed hadrons, which result from the hadronization of c quarks, are sensitive to the gluon distribution in the target nucleus [6]. Because of their large masses relative to Λ_{QCD}, the energy scale below which strong coupling becomes large, the production of heavy quarks can be described by perturbative QCD (pQCD) calculations down to zero transverse momentum p_{T}. In photonuclear events, the energy scale of the interaction (Q^2) and the x value of the scattered partons in the nucleus can be inferred from the transverse momenta and rapidities of the final-state c quarks. Consequently, by measuring charmed meson yields as functions of p_{T} and rapidity (y) the properties of gluons in the nucleus can be constrained across different x and Q^2 regions. Similarly, jets produced in UPCs have been used to probe the properties of partons in the nucleus [7]. The low particle multiplicities and negligible backgrounds from strong interactions that characterize such events ensure that the fragmentation and hadronization of c quarks in UPCs occur in a vacuumlike environment, without significant modifications caused by the presence of a large number of color-carrying partons [8–12]. Calculations of heavy-quark production in UPCs have so far been performed at leading order in perturbation theory either within the collinear factorization approach [4,13–15] or using the color glass condensate (CGC) framework [14,16]. More recently, GγA-FONLL [5] has extended these studies to next-to-leading-order accuracy within collinear factorization.

In this Letter, we present the first measurement of the photonuclear production cross section of inclusive D^0 mesons (including beauty-hadron decays) in UPCs. The data presented here probe, for the first time in photonuclear collisions, the parton distribution functions of lead nuclei for x ranging from about 3×10^{-4} to 3×10^{-2} and Q^2 from about 18 to 600 GeV^2. Tabulated results are provided in the HEPData record for this analysis [17].

[*]Full author list given at the end of the Letter.

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Forward calorimeters (HF) extend the pseudorapidity (η) coverage provided by the barrel and endcap detectors. The zero degree calorimeters (ZDCs) are used to measure the energy of very forward neutrons produced from nuclear breakup [18,19]. The ZDCs are located in front of the neutral particle absorber, roughly ± 140 m away from the CMS interaction point, between the two beampipes. They measure neutral particles at $|\eta| > 8.5$. Particles are reconstructed using the CMS particle-flow algorithm [20], which combines the information of the different subdetectors to determine the kinematics of each event. The CMS experiment uses a two-tiered trigger system [21]. The first level (Level-1 or L1) comprises custom hardware processors and uses fast information from the calorimeters and the muon system to achieve the first significant data rate reduction. The second level, i.e., the high-level trigger, implements a simplified version of the CMS offline reconstruction software running on a computer farm and can perform more refined selections. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [22]. Details of the CMS detector configuration at the time of this measurement can be found in Ref. [23].

The analysis uses the lead-lead (PbPb) dataset, corresponding to a recorded integrated luminosity of about 1.34 nb^{-1}, collected in 2023 at a nucleon-nucleon center-of-mass energy of 5.36 TeV. The photonuclear production of D^0 mesons in the p_T range 2–5 GeV is measured using a sample of events triggered by a signal in at least one of the ZDCs that is greater than or equal to the one-neutron ($1n$) threshold (inclusively referred to as Xn). A dedicated L1 trigger algorithm requiring an Xn signal in one ZDC and the absence of signal in the other ($0n$), in coincidence with an L1 jet with energy above 8 GeV, was used to enrich the sample of D^0 mesons with $p_T > 5$ GeV. In this Letter, the notation $Xn0n$ ($0nXn$) indicates that the outgoing lead-ion at negative (positive) rapidities breaks up. Offline, events are required to have one primary vertex, formed by at least two tracks and located within 15 cm of the nominal interaction region along the beamline. Events must additionally fulfill selection criteria intended to reject beam-gas interactions and accelerator-induced backgrounds [24]. To suppress residual contamination from hadronic events, a large rapidity gap is required on the side of the outgoing intact nucleus that emitted the photon, following previous analyses [7,25,26]. This condition is satisfied if no particle-flow candidate with energy above the noise threshold is detected in the η range of the HF calorimeter ($3.0 < |\eta| < 5.2$). An energy threshold of 9.2 (8.6) GeV is applied to the HF detector at positive (negative) η, with values optimized according to each detector's performance. Monte Carlo (MC) simulations are used to estimate signal efficiency, detector acceptance, and some background sources. Photonuclear events are generated with PYTHIA version 8.309 [27], with default photon flux settings for Pb ions acting as a source of quasireal photons in the equivalent photon approximation [28]. The events include direct and resolved photoproduction processes, with the photon PDF modeled using the Cornet-Jankowski-Krawczyk-Lorca, or CJKL, parametrization [29], and the lead nuclear PDF (nPDF) parametrized by EPPS21 [30]. Both promptly ($c \to D^0$) and nonpromptly ($b \to D^0$) produced D^0 mesons are included in the simulation. The events are propagated through the CMS detector with Geant4 [31], with D^0 meson decays simulated using EvtGen 2.0.0 [32], and final-state photon radiation modeled by PHOTOS 2.0 [33].

The D^0 mesons and their charge conjugates ($\bar{D}^0$ mesons) are reconstructed via the hadronic decay channel $D^0 \to K^- \pi^+$, following a strategy similar to that discussed in Ref. [34]. Only D^0 candidates with daughter tracks satisfying high-purity selection criteria [35], along with the conditions $p_T > 1$ GeV and $|\eta| < 2.4$ are considered. The D^0 candidates are then reconstructed by combining pairs of oppositely charged tracks with an invariant mass within 185 MeV of the world-average D^0 meson mass of 1868.48 MeV [36]. This range provides a handle to constrain the modeling of the backgrounds described later in this Letter. For each track pair, two D^0 candidates are created by assigning pion and kaon masses to the tracks in both possible combinations. To reduce the combinatorial background, the D^0 meson candidates are selected based on the value of four topological variables (where the selection value used depends on the p_T and y of the candidate): the three-dimensional decay length normalized to its uncertainty (required to be larger than 2.5–3.5), the pointing angle defined as the angle between the total momentum vector of the tracks and the vector connecting the primary and the secondary vertices (required to be smaller than 0.25–0.50 rad), the opening angle between the two daughter tracks (required to be smaller than 0.3–0.5 rad), and the χ^2 probability of the D^0 vertex fit [37] (p value required to be larger than 0.1). The selection is optimized in each p_T bin to maximize the expected statistical significance of the D^0 meson signal. The D^0 meson yields are extracted in three different p_T intervals (2–5, 5–8, and 8–12 GeV). Four rapidity intervals ($-2 < y < -1$, $-1 < y < 0$, $0 < y < 1$, and $1 < y < 2$) are used for D^0 mesons in bins with $p_T > 5$ GeV, whereas a single rapidity interval ($-1 < y < 1$) is used for p_T interval 2–5 GeV. The D^0 yields are extracted using an unbinned maximum likelihood fit to the invariant mass distributions in the range $1.68 < m_{K\pi} < 2.05$ GeV. The yields are determined separately for the $Xn0n$ and $0nXn$

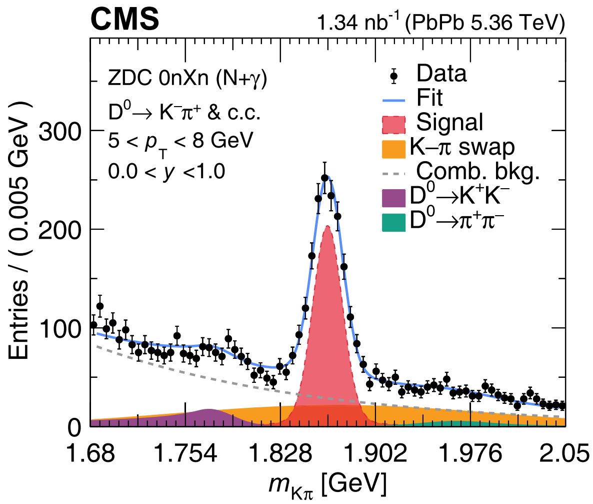

FIG. 1. Invariant mass distribution of D^0 mesons with $5 < p_T < 8$ GeV and $0.0 < y < 1.0$. The description of the fit template is provided in the text.

event categories. In $Xn0n$ events, the incoming photon-emitting nucleus originates from negative rapidities (γN), whereas in $0nXn$ events it comes from positive rapidities ($N\gamma$). An example of the D^0 invariant mass distribution is shown in Fig. 1.

The combinatorial background, arising from track pairs unrelated to genuine D^0 meson decays, is modeled with an exponential function whose slope and normalization are determined from the fit. The signal shape consists of a superposition of two Gaussian functions sharing the same mean but differing in width, a choice made in earlier CMS publications that models the mass peak well [34]. An additional Gaussian function models the invariant mass of D^0 candidates with incorrect mass assignment, for which the mass hypothesis for the pion and kaon are interchanged. The widths of the Gaussian functions for both the D^0 signal and the swapped mass candidates are constrained using MC simulation. A floating multiplicative scaling factor for the width of the distribution is included in the fit to account for potential discrepancies in the signal resolution between data and MC. The ratio of the signal yield to the yield of D^0 candidates with swapped mass assignments is fixed based on MC simulation. A Crystal Ball function is used to describe the peaking backgrounds from the decays $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ [36], with its parameters and the ratio of its integral to the $D^0 \to K^-\pi^+$ yield also fixed according to MC simulations. Of the 18 fits for each D^0 p_T and y bin in $Xn0n$ and $0nXn$ events, 17 result in p values greater than 0.05, and one has a p value of ∼0.01. This distribution of p values is consistent with statistical expectations.

The yields extracted from the fit are corrected for the average trigger prescale factor (applied to reduce the data rate resulting from the high instantaneous luminosity of the LHC), the trigger efficiency, and the efficiency of the offline event selection. The jet trigger efficiency correction is evaluated in intervals of D^0 p_T and rapidity with a two-step procedure. First, the efficiency of the L1 jet selection is evaluated as a function of the leading-track p_T and η with a sample of inclusive photonuclear events. The efficiency map is then used to reweight, on an event-by-event basis, the uncorrected distributions of D^0 meson candidates obtained via the triggered sample in intervals of D^0 p_T and y. The resulting jet trigger efficiency ranges from 21% to 28%, depending on the rapidity, for D^0 mesons in the transverse momentum range $5 < p_T < 8$ GeV, to 46%–54% in the $8 < p_T < 12$ GeV range (no jet trigger is used for $2 < p_T < 5$ GeV). The event selection efficiency, which includes the effect of losses from the rapidity gap and primary vertex requirements, exceeds 98% across all rapidity and p_T intervals, with comparable values for direct and resolved photoproduction. An additional correction accounts for soft electromagnetic interactions from independent PbPb collisions within the same bunch crossing (electromagnetic pileup), which may cause neutron emission from the photon-emitting nucleus, thereby reducing the ZDC $Xn0n$ (or $0nXn$) selection efficiency. The correction factor (about 0.96) is estimated from the average amount of pileup interactions in PbPb collisions and the cross section for single and double electromagnetic dissociation (EMD) [7,38]. The acceptance and reconstruction efficiency of D^0 candidates is evaluated as a function of the D^0 p_T and y, and ranges from 5% for $2 < p_T < 5$ GeV to 25% for $8 < p_T < 12$ GeV.

The measured cross section is subject to several systematic uncertainties arising from the signal extraction, acceptance and reconstruction efficiency, offline selection, trigger selection, branching fraction of the $D^0 \to K^-\pi^+$ decay channel, and integrated luminosity determination. The uncertainty in the rapidity-gap selection efficiency is evaluated by varying the energy threshold for the particle-flow candidates used to determine the presence of a gap between 5 and 15 GeV, resulting in an uncertainty of 7%–23%. The correction for the inefficiency induced by electromagnetic pileup is found to have an uncertainty of 4%. The uncertainty due to the background modeling in the fit is estimated by repeating the fit with different functions for the background. The signal shape is also varied by forcing the means and widths (each separately) of the Gaussian functions that describe the signal to be equal to the values extracted in simulations; these three fit variations result in an uncertainty of 3%–20% depending on the D^0 p_T and y. In the background variation study, a second-order Chebyshev polynomial function is used. The uncertainty in the signal yield coming from the modeling of the $D^0 \to K^+K^-$ and $\pi^+\pi^-$ peaks is estimated from MC to be about 13%. The final uncertainty in the extracted yield is evaluated as the quadratic sum of all the individual uncertainties.

Dedicated studies are conducted to estimate the effects of the differences in the properties of signal events in data and simulation. Specifically, to evaluate the impact of the discrepancies in the distributions of the D^0 meson selection variables, the corrected yields obtained by varying each topological selection are studied. Topological selections are relaxed in a range such that signal events can still be extracted with good statistical significance. The final uncertainty is evaluated as the quadratic sum of the differences between the cross sections obtained when varying each selection and the nominal one (2%–15%). The difference between the D^0 meson reconstruction and selection efficiencies evaluated in direct- and resolved-photon events is taken to account for the differences in the relative abundance of the two classes of signal events in simulation and data; the resulting effect is 1%–5%. An analogous systematic uncertainty is included to account for differences in the fraction of prompt D^0 mesons (f_{prompt}) between data and simulation. This uncertainty is evaluated by reweighting the MC-based efficiency for prompt and nonprompt D^0 mesons according to the f_{prompt} value extracted from the data. The extraction relies on the difference between prompt and nonprompt events in the distribution of the D^0 meson candidate's distance of closest approach, defined as the decay length multiplied by the sine of the pointing angle. The associated uncertainty is approximately 5% across all p_{T} and y intervals.

The D^0 selection and reconstruction efficiency also depends on the distribution of the D^0 mesons in p_{T} and y, as well as on the event multiplicity; this is because the single-track reconstruction efficiency decreases in events with more tracks. The MC samples are reweighted to two alternative distributions, one based on fixed-order-next-to-leading logarithmic (FONLL) calculations and the other on data after accounting for EMD. The charged-hadron multiplicity is also reweighted to match that in data. These variations of the D^0 meson reconstruction and identification efficiency result in a systematic uncertainty of 7% or less. The uncertainty due to the D^0 trigger efficiency is found to be about 20% in the p_{T} bins where the jet trigger is used. The systematic uncertainty in the hadron tracking efficiency (2.3% per track) is taken from the analysis of the proton-proton collision samples collected in 2022–2023 with comparable detector conditions to those of the current data set [39]. The systematic uncertainty associated with the branching fraction is 0.76% [36], and the uncertainty in the integrated luminosity is 6.4% [40].

All systematic uncertainties are treated as symmetric. The total systematic uncertainty in the cross section measurement is computed as the sum in quadrature of the different contributions mentioned above, and is found to range from ∼26%–48%, depending on the D^0 meson y and p_{T}. The dominant source of systematic uncertainties in the 2–5 GeV bin is associated with the modeling of $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays, the change to a Chebyshev polynomial in modeling the background, and the variation of the pointing angle selection. For 5–8 and 8–12 GeV, the systematic uncertainties are dominated by the trigger and rapidity gap thresholds uncertainties, in addition to the modeling of the $D^0 \to K^+K^-$ and $\pi^+\pi^-$ decays. Each source of systematic uncertainty is assumed to be fully correlated across bins, whereas the statistical uncertainties are treated as uncorrelated.

In Fig. 2, the D^0 meson production cross section in $Xn0n$ and rapidity-reflected $0nXn$ events is shown (black markers) as a function of the D^0 rapidity in p_{T} intervals. The cross section is divided by a factor of two to average the contributions of D^0 and $\bar{D}^0$ mesons. Vertical bars indicate the statistical uncertainties, while brackets represent the systematic ones. Forward (positive) rapidities probe smaller values of x, whereas backward (negative) rapidities are sensitive to larger x. Likewise, low-p_{T} D^0 mesons correspond to lower Q^2 values, whereas high-p_{T} hadrons probe the nPDFs at higher Q^2. A qualitative estimate of the kinematic region probed in each D^0 meson p_{T} and y interval can be obtained by approximating Q^2 as $p_{\mathrm{T},c}^2 + m_c^2$, and the parton longitudinal momentum fraction in the nucleus as $x \approx e^{-y}\sqrt{Q^2/s_{\mathrm{NN}}}$, where $\sqrt{s_{\mathrm{NN}}}$ is the nucleon-nucleon center-of-mass energy. Assuming the heavy-flavor hadron carries about half of the parent charm-quark momentum, a D^0 meson produced with $p_{\mathrm{T}} = 2$ GeV at $y = 1$ probes partons with $x \approx 3 \times 10^{-4}$ at a hard scale $Q^2 \approx 18\ \mathrm{GeV}^2$. Conversely, a D^0 meson produced with $p_{\mathrm{T}} = 12$ GeV at $y = -2$ probes partons with $x \approx 0.03$ at $Q^2 \approx 600\ \mathrm{GeV}^2$. Further details on the x and Q^2 coverage of this measurement are given in Ref. [5].

The measurements are compared with recent pQCD calculations from GγA-FONLL [5], a framework that builds on FONLL [41–43] to model heavy-quark production in photonuclear collisions and employs photon-flux reweighting to reproduce the flux properties expected in UPCs. The predictions include corrections for the EMD survival probability of the photon-emitting nucleus [44]. The subpanels of Fig. 2 display the theory-to-data ratios obtained with lead nPDFs from EPPS21 [30] (middle) and proton PDFs from CT18NLO [45] (bottom). The light blue and red bands represent the uncertainties associated with variations of the FONLL factorization and renormalization scales, while the hatched bands represent the nPDF-parametrization uncertainties. For D^0 mesons with $2 < p_{\mathrm{T}} < 5$ GeV, the theory-to-data ratios obtained with EPPS21 lie slightly above unity (about 1.4). Although still compatible within the combined experimental and theoretical uncertainties, this trend may indicate a stronger nuclear suppression for low-x gluons than predicted. In the highest-p_{T} interval, $8 < p_{\mathrm{T}} < 12$ GeV, the theory-to-data ratio obtained with EPPS21 remains consistently below unity, at about 0.8–0.9, across the probed D^0 meson rapidity range, indicating that

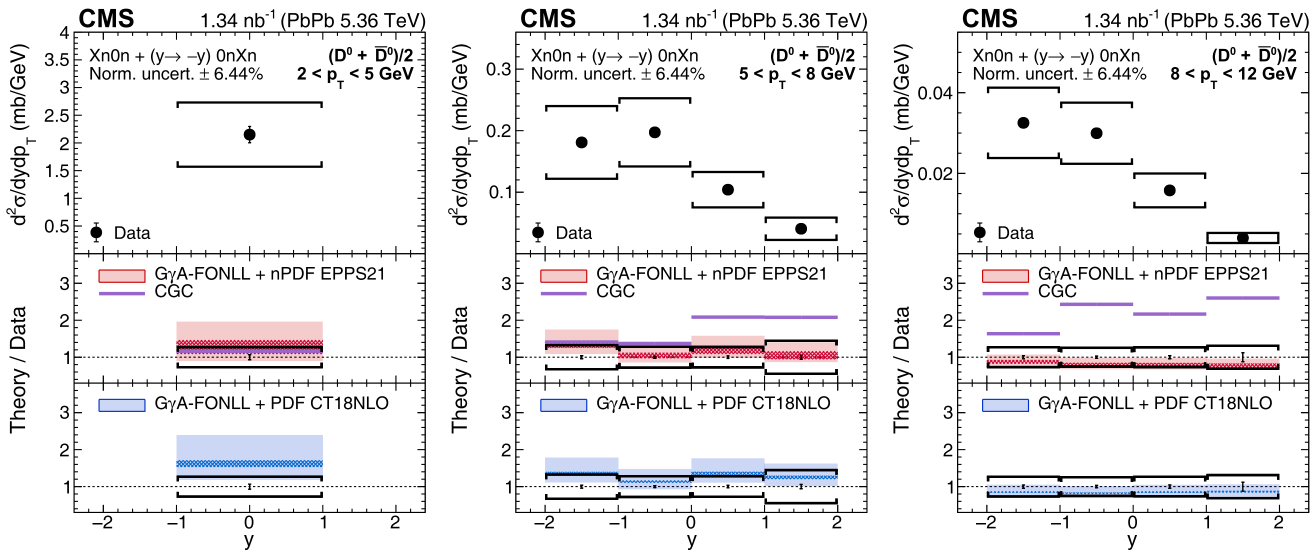

FIG. 2. Cross sections for D^0 production in γN events ($Xn0n + 0nXn$) in three p_T intervals. Vertical bars (brackets) indicate statistical (systematic) uncertainties. Subpanels show theory-over-data ratios: the middle panel compares GγA-FONLL with EPPS21 lead nPDFs and a CGC calculation [16], while the bottom panel shows GγA-FONLL with CT18NLO proton PDFs. Light-shaded bands reflect scale variations, hatched bands represent PDF and nPDF uncertainties. Vertical bars (brackets) represent statistical (systematic) uncertainties on data.

the data slightly exceed the nPDF-based predictions. In the same subpanel, the data are also compared with recent theoretical predictions [16] based on the CGC framework, which relies on nonlinear QCD evolution to model the properties of gluons at low x. The CGC theory-to-data ratio is about 1.2 for D^0 mesons with $2 < p_T < 5$ GeV and $-1 < y < 1$, lying at the upper edge of the measurement. For $p_T > 5$ GeV, the ratio indicates that predictions exceed the data by a factor of 1.5–3. The measurement therefore provides scale-dependent constraints on calculations of charm quark production incorporating nonlinear QCD evolution.

To summarize, this Letter presented the first measurement of the inclusive, prompt and nonprompt, photonuclear D^0 meson cross section as a function of transverse momentum and rapidity in ultraperipheral heavy-ion collisions. Exploiting the clean environment of photonuclear interactions, where final state and hadronization effects are largely reduced compared to hadronic production, this measurement provides novel constraints on nuclear matter over a wide range of parton momentum fraction x and interaction energy scale Q^2. Comparisons with theory provide discrimination among parton distribution function parametrizations and challenge calculations based on nonlinear quantum chromodynamics evolution at high Q^2. By demonstrating both its experimental feasibility and theoretical relevance, this Letter establishes open heavy-flavor production in ultraperipheral LHC collisions as a powerful probe of parton dynamics in nuclei.

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, TARISTU24-TK10 and MoER TK202 (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); SRNSF (Georgia); BMFTR, DFG, and HGF (Germany); GSRI (Greece); NKFIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIT 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, NSC, and NAWA (Poland); FCT (Portugal); MESTD (Serbia); MICIU/AEI and PCTI (Spain); MOSTR (Sri Lanka); Swiss Funding Agencies (Switzerland); MST (Taipei); MHESI and NSTDA (Thailand); TUBITAK and TENMAK (Türkiye); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA). This work is dedicated to the memory of our colleague and friend, Michele Arneodo. Michele was a generous mentor, a passionate physicist, and a kind soul who inspired both students and collaborators with his wisdom, warmth, and dedication to science. His contributions to diffractive physics and his support for young scientists leave a lasting legacy. He will be deeply missed.

Data availability—Release and preservation of data used by the CMS Collaboration as the basis for publications is guided by the CMS data preservation, reuse, and open access policy [46].

[1] M. Strikman, R. Vogt, and S. N. White, Probing small x parton densities in ultraperipheral AA and pA collisions at the LHC, Phys. Rev. Lett. **96**, 082001 (2006).

[2] S. Klein and P. Steinberg, Photonuclear and two-photon interactions at high-energy nuclear colliders, Annu. Rev. Nucl. Part. Sci. **70**, 323 (2020).

[3] CMS Collaboration, Overview of high-density QCD studies with the CMS experiment at the LHC, Phys. Rep. **1115**, 219 (2025).

[4] S. R. Klein, J. Nystrand, and R. Vogt, Heavy quark photoproduction in ultraperipheral heavy ion collisions, Phys. Rev. C **66**, 044906 (2002).

[5] M. Cacciari, G. M. Innocenti, and A. M. Staśto, Inclusive open charm photoproduction in ultraperipheral collisions at the LHC with GγA-FONLL, Phys. Rev. D **112**, 094029 (2025).

[6] O. Behnke, A. Geiser, and M. Lisovyi, Charm, beauty and top at HERA, Prog. Part. Nucl. Phys. **84**, 1 (2015).

[7] ATLAS Collaboration, Measurement of photonuclear jet production in ultraperipheral Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} =$ 5.02 TeV with the ATLAS detector, Phys. Rev. D **111**, 052006 (2025).

[8] ALICE Collaboration, D-meson production in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. C **94**, 054908 (2016).

[9] LHCb Collaboration, Study of prompt D^0 meson production in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5$ TeV, J. High Energy Phys. 10 (2017) 090.

[10] CMS Collaboration, Elliptic flow of charm and strange hadrons in high-multiplicity pPb collisions at $\sqrt{s_{\mathrm{NN}}} =$ 8.16 TeV, Phys. Rev. Lett. **121**, 082301 (2018).

[11] ALICE Collaboration, Λ_c^+ production and baryon-to-meson ratios in pp and p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV at the LHC, Phys. Rev. Lett. **127**, 202301 (2021).

[12] LHCb Collaboration, Observation of strangeness enhancement with charmed mesons in high-multiplicity pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 8.16$ TeV, Phys. Rev. D **110**, L031105 (2023).

[13] V. P. Goncalves and C. A. Bertulani, Peripheral heavy ion collisions as a probe of the nuclear gluon distribution, Phys. Rev. C **65**, 054905 (2002).

[14] V. P. Goncalves and M. V. T. Machado, The QCD pomeron in ultraperipheral heavy ion collisions. 3. Photonuclear production of heavy quarks, Eur. Phys. J. C **31**, 371 (2003).

[15] A. Adeluyi, C. A. Bertulani, and M. J. Murray, Nuclear effects in photoproduction of heavy quarks and vector mesons in ultraperipheral PbPb and pPb collisions at the LHC, Phys. Rev. C **86**, 047901 (2012).

[16] P. Gimeno-Estivill, T. Lappi, and H. Mäntysaari, Inclusive D^0 photoproduction in ultraperipheral collisions, Phys. Rev. D **111**, 114036 (2025).

[17] HEPData record for this analysis (2025), 10.17182/hepdata.156822.

[18] O. Surányi *et al.*, Performance of the CMS zero degree calorimeters in pPb collisions at the LHC, J. Instrum. **16**, P05008 (2021).

[19] CMS Collaboration, L1 trigger and ZDC performance during 2023 heavy ion run, CMS Detector Performance Note CMS-DP-2024-002, CERN, Geneva, Switzerland, 2024, https://cds.cern.ch/record/2887066.

[20] CMS Collaboration, Particle-flow reconstruction and global event description with the CMS detector, J. Instrum. **12**, P10003 (2017).

[21] CMS Collaboration, The CMS trigger system, J. Instrum. **12**, P01020 (2016).

[22] CMS Collaboration, The CMS experiment at the CERN LHC, J. Instrum. **3**, S08004 (2008).

[23] CMS Collaboration, Development of the CMS detector for the CERN LHC Run 3, J. Instrum. **19**, P05064 (2023).

[24] CMS Collaboration, Performance of missing transverse momentum reconstruction in proton-proton collisions at $\sqrt{s} = 13$ TeV using the CMS detector, J. Instrum. **14**, P07004 (2019).

[25] ATLAS Collaboration, Two-particle azimuthal correlations in photonuclear ultraperipheral Pb + Pb collisions at 5.02 TeV with ATLAS, Phys. Rev. C **104**, 014903 (2021).

[26] ATLAS Collaboration, Charged-hadron and identified-hadron (K_S^0, Λ, Ξ^-) yield measurements in photonuclear Pb + Pb and p + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with ATLAS, Phys. Rev. C **111**, 064908 (2025).

[27] C. Bierlich *et al.*, A comprehensive guide to the physics and usage of PYTHIA 8.3, SciPost Phys. Codebases **2022**, 8 (2022).

[28] I. Helenius, Simulations of photo-nuclear dijets with PYTHIA 8 and their sensitivity to nuclear PDFs, Proc. Sci. DIS2018 (**2018**) 113.

[29] F. Cornet, P. Jankowski, M. Krawczyk, and A. Lorca, New 5-flavor LO analysis and parametrization of parton distributions in the real photon, Phys. Rev. D **68**, 014010 (2003).

[30] K. J. Eskola, P. Paakkinen, H. Paukkunen, and C. A. Salgado, EPPS21: A global QCD analysis of nuclear PDFs, Eur. Phys. J. C **82**, 413 (2022).

[31] S. Agostinelli *et al.* (GEANT4 Collaboration), Geant4—A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).

[32] D. J. Lange, The EvtGen particle decay simulation package, Nucl. Instrum. Methods Phys. Res., Sect. A **462**, 152 (2001).

[33] E. Barberio, B. van Eijk, and Z. Was, PHOTOS: A universal Monte Carlo for QED radiative corrections in decays, Comput. Phys. Commun. **66**, 115 (1991).

[34] CMS Collaboration, Nuclear modification factor of D^0 mesons in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **782**, 474 (2018).

[35] CMS Collaboration, Description and performance of track and primary-vertex reconstruction with the CMS tracker, J. Instrum. **9**, P10009 (2014).
[36] Particle Data Group, Review of particle physics, Phys. Rev. D **110**, 030001 (2024).
[37] G. E. Forden and D. H. Saxon, Improving vertex position determination by using a kinematic fit, Technical Report, RAL-85-037, RAL, Chilton, 1985, https://cds.cern.ch/record/161017.
[38] ALICE Collaboration, Measurement of the cross section for electromagnetic dissociation with neutron emission in PbPb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. Lett. **109**, 252302 (2012).
[39] CMS Collaboration, Search for the rare decay $D^0 \to \mu^+\mu^-$ in proton-proton collisions at $\sqrt{s} = 13.6$ TeV, Phys. Rev. Lett. **135**, 151803 (2025).
[40] CMS Collaboration, Luminosity measurement for lead-lead collisions at $\sqrt{s_{NN}} = 5.02$ TeV in 2015 and 2018 at CMS, arXiv:2503.03946. Submitted to Eur. J. Phys. C.
[41] M. Cacciari, M. Greco, and P. Nason, The p_T spectrum in heavy-flavor hadroproduction, J. High Energy Phys. 05 (1998) 007.
[42] M. Cacciari, S. Frixione, and P. Nason, The p_T spectrum in heavy-flavor photoproduction, J. High Energy Phys. 03 (2001) 006.
[43] S. Frixione and P. Nason, Phenomenological study of charm photoproduction at HERA, J. High Energy Phys. 03 (2002) 053.
[44] K. J. Eskola, V. Guzey, I. Helenius, P. Paakkinen, and H. Paukkunen, Spatial resolution of dijet photoproduction in near-encounter ultraperipheral nuclear collisions, Phys. Rev. C **110**, 054906 (2024).
[45] T.-J. Hou *et al.*, New CTEQ global analysis of quantum chromodynamics with high-precision data from the LHC, Phys. Rev. D **103**, 014013 (2021).
[46] CMS data availability statement 10.7483/OPENDATA.CMS.1BNU.8V1W.

V. Chekhovsky,[1] A. Hayrapetyan,[1] V. Makarenko,[1] A. Tumasyan,[1,b] W. Adam,[2] J. W. Andrejkovic,[2] L. Benato,[2] T. Bergauer,[2] K. Damanakis,[2] M. Dragicevic,[2] C. Giordano,[2] P. S. Hussain,[2] M. Jeitler,[2,c] N. Krammer,[2] A. Li,[2] D. Liko,[2] I. Mikulec,[2] J. Schieck,[2,c] R. Schöfbeck,[2,c] D. Schwarz,[2] M. Shooshtari,[2] M. Sonawane,[2] W. Waltenberger,[2] C.-E. Wulz,[2,c] T. Janssen,[3] H. Kwon,[3] T. Van Laer,[3] P. Van Mechelen,[3] J. Bierkens,[4] N. Breugelmans,[4] J. D'Hondt,[4] S. Dansana,[4] A. De Moor,[4] M. Delcourt,[4] F. Heyen,[4] Y. Hong,[4] S. Lowette,[4] I. Makarenko,[4] D. Müller,[4] J. Song,[4] S. Tavernier,[4] M. Tytgat,[4,d] G. P. Van Onsem,[4] S. Van Putte,[4] D. Vannerom,[4] B. Bilin,[5] B. Clerbaux,[5] A. K. Das,[5] I. De Bruyn,[5] G. De Lentdecker,[5] H. Evard,[5] L. Favart,[5] P. Gianneios,[5] A. Khalilzadeh,[5] F. A. Khan,[5] A. Malara,[5] M. A. Shahzad,[5] L. Thomas,[5] M. Vanden Bemden,[5] C. Vander Velde,[5] P. Vanlaer,[5] F. Zhang,[5] M. De Coen,[6] D. Dobur,[6] G. Gokbulut,[6] J. Knolle,[6] L. Lambrecht,[6] D. Marckx,[6] K. Skovpen,[6] N. Van Den Bossche,[6] J. van der Linden,[6] J. Vandenbroeck,[6] L. Wezenbeek,[6] S. Bein,[7] A. Benecke,[7] A. Bethani,[7] G. Bruno,[7] A. Cappati,[7] J. De Favereau De Jeneret,[7] C. Delaere,[7] A. Giammanco,[7] A. O. Guzel,[7] Sa. Jain,[7] V. Lemaitre,[7] J. Lidrych,[7] P. Mastrapasqua,[7] S. Turkcapar,[7] G. A. Alves,[8] E. Coelho,[8] G. Correia Silva,[8] C. Hensel,[8] T. Menezes De Oliveira,[8] C. Mora Herrera,[8,e] P. Rebello Teles,[8] M. Soeiro,[8] E. J. Tonelli Manganote,[8,f] A. Vilela Pereira,[8,e] W. L. Aldá Júnior,[9] M. Barroso Ferreira Filho,[9] H. Brandao Malbouisson,[9] W. Carvalho,[9] J. Chinellato,[9,g] M. Costa Reis,[9] E. M. Da Costa,[9] G. G. Da Silveira,[9,h] D. De Jesus Damiao,[9] S. Fonseca De Souza,[9] R. Gomes De Souza,[9] S. S. Jesus,[9] T. Laux Kuhn,[9,h] M. Macedo,[9] K. Mota Amarilo,[9] L. Mundim,[9] H. Nogima,[9] J. P. Pinheiro,[9] A. Santoro,[9] A. Sznajder,[9] M. Thiel,[9] C. A. Bernardes,[10,h] L. Calligaris,[10] T. R. Fernandez Perez Tomei,[10] E. M. Gregores,[10] B. Lopes Da Costa,[10] I. Maietto Silverio,[10] P. G. Mercadante,[10] S. F. Novaes,[10] B. Orzari,[10] Sandra S. Padula,[10] V. Scheurer,[10] A. Aleksandrov,[11] G. Antchev,[11] R. Hadjiiska,[11] P. Iaydjiev,[11] M. Misheva,[11] M. Shopova,[11] G. Sultanov,[11] A. Dimitrov,[12] L. Litov,[12] B. Pavlov,[12] P. Petkov,[12] A. Petrov,[12] E. Shumka,[12] S. Keshri,[13] D. Laroze,[13] S. Thakur,[13] T. Cheng,[14] T. Javaid,[14] L. Yuan,[14] Z. Hu,[15] Z. Liang,[15] J. Liu,[15] G. M. Chen,[16,i] H. S. Chen,[16,i] M. Chen,[16,i] Q. Hou,[16] F. Iemmi,[16] C. H. Jiang,[16] A. Kapoor,[16,j] H. Liao,[16] Z.-A. Liu,[16,k] R. Sharma,[16,l] J. N. Song,[16,k] J. Tao,[16] C. Wang,[16,i] J. Wang,[16] H. Zhang,[16] J. Zhao,[16] A. Agapitos,[17] Y. Ban,[17] A. Carvalho Antunes De Oliveira,[17] S. Deng,[17] B. Guo,[17] Q. Guo,[17] C. Jiang,[17] A. Levin,[17] C. Li,[17] Q. Li,[17] Y. Mao,[17] S. Qian,[17] S. J. Qian,[17] X. Qin,[17] X. Sun,[17] D. Wang,[17] H. Yang,[17] Y. Zhao,[17] C. Zhou,[17] S. Yang,[18] Z. You,[19] K. Jaffel,[20] N. Lu,[20] G. Bauer,[21,m] B. Li,[21,n] H. Wang,[21] K. Yi,[21,o] J. Zhang,[21] Y. Li,[22] Z. Lin,[23] C. Lu,[23] M. Xiao,[23,p] C. Avila,[24] D. A. Barbosa Trujillo,[24] A. Cabrera,[24] C. Florez,[24] J. Fraga,[24] J. A. Reyes Vega,[24] J. Jaramillo,[25] C. Rendón,[25] M. Rodriguez,[25] A. A. Ruales Barbosa,[25] J. D. Ruiz Alvarez,[25] N. Godinovic,[26] D. Lelas,[26] A. Sculac,[26] M. Kovac,[27] A. Petkovic,[27] T. Sculac,[27]

P. Bargassa,[28] V. Brigljevic,[28] B. K. Chitroda,[28] D. Ferencek,[28] K. Jakovcic,[28] A. Starodumov,[28] T. Susa,[28] A. Attikis,[29] K. Christoforou,[29] A. Hadjiagapiou,[29] C. Leonidou,[29] J. Mousa,[29] C. Nicolaou,[29] L. Paizanos,[29] F. Ptochos,[29] P. A. Razis,[29] H. Rykaczewski,[29] H. Saka,[29] A. Stepennov,[29] M. Finger,[30] M. Finger Jr.,[30] A. Kveton,[30] E. Ayala,[31] E. Carrera Jarrin,[32] A. A. Abdelalim,[33,q,r] S. Elgammal,[33,s] A. Ellithi Kamel,[33,t] M. Abdullah Al-Mashad,[34] A. Hussein,[34] M. A. Mahmoud,[34] K. Ehataht,[35] M. Kadastik,[35] T. Lange,[35] C. Nielsen,[35] J. Pata,[35] M. Raidal,[35] L. Tani,[35] C. Veelken,[35] K. Osterberg,[36] M. Voutilainen,[36] N. Bin Norjoharuddeen,[37] E. Brücken,[37] F. Garcia,[37] P. Inkaew,[37] K. T. S. Kallonen,[37] T. Lampén,[37] K. Lassila-Perini,[37] S. Lehti,[37] T. Lindén,[37] N. R. Mancilla Xinto,[37] M. Myllymäki,[37] M. m. Rantanen,[37] S. Saariokari,[37] J. Tuominiemi,[37] H. Kirschenmann,[38] P. Luukka,[38] H. Petrow,[38] M. Besancon,[39] F. Couderc,[39] M. Dejardin,[39] D. Denegri,[39] J. L. Faure,[39] F. Ferri,[39] S. Ganjour,[39] P. Gras,[39] G. Hamel de Monchenault,[39] M. Kumar,[39] V. Lohezic,[39] J. Malcles,[39] F. Orlandi,[39] L. Portales,[39] S. Ronchi,[39] A. Rosowsky,[39] M. Ö. Sahin,[39] A. Savoy-Navarro,[39,u] P. Simkina,[39] M. Titov,[39] M. Tornago,[39] F. Beaudette,[40] G. Boldrini,[40] P. Busson,[40] C. Charlot,[40] M. Chiusi,[40] T. D. Cuisset,[40] F. Damas,[40] O. Davignon,[40] A. De Wit,[40] I. T. Ehle,[40] B. A. Fontana Santos Alves,[40] S. Ghosh,[40] A. Gilbert,[40] R. Granier de Cassagnac,[40] L. Kalipoliti,[40] G. Liu,[40] M. Manoni,[40] M. Nguyen,[40] S. Obraztsov,[40] C. Ochando,[40] R. Salerno,[40] J. B. Sauvan,[40] Y. Sirois,[40] G. Sokmen,[40] L. Urda Gómez,[40] A. Zabi,[40] A. Zghiche,[40] J.-L. Agram,[41,v] J. Andrea,[41] D. Bloch,[41] J.-M. Brom,[41] E. C. Chabert,[41] C. Collard,[41] S. Falke,[41] U. Goerlach,[41] R. Haeberle,[41] A.-C. Le Bihan,[41] M. Meena,[41] O. Poncet,[41] G. Saha,[41] M. A. Sessini,[41] P. Vaucelle,[41] A. Di Florio,[42] D. Amram,[43] S. Beauceron,[43] B. Blancon,[43] G. Boudoul,[43] N. Chanon,[43] D. Contardo,[43] P. Depasse,[43] C. Dozen,[43,w] H. El Mamouni,[43] J. Fay,[43] S. Gascon,[43] M. Gouzevitch,[43] C. Greenberg,[43] G. Grenier,[43] B. Ille,[43] E. Jourd'huy,[43] I. B. Laktineh,[43] M. Lethuillier,[43] L. Mirabito,[43] S. Perries,[43] A. Purohit,[43] M. Vander Donckt,[43] J. Xiao,[43] D. Chokheli,[44] I. Lomidze,[44] Z. Tsamalaidze,[44,x] V. Botta,[45] S. Consuegra Rodríguez,[45] L. Feld,[45] K. Klein,[45] M. Lipinski,[45] D. Meuser,[45] V. Oppenländer,[45] A. Pauls,[45] D. Pérez Adán,[45] N. Röwert,[45] M. Teroerde,[45] C. Daumann,[46] S. Diekmann,[46] A. Dodonova,[46] N. Eich,[46] D. Eliseev,[46] F. Engelke,[46] J. Erdmann,[46] M. Erdmann,[46] B. Fischer,[46] T. Hebbeker,[46] K. Hoepfner,[46] F. Ivone,[46] A. Jung,[46] N. Kumar,[46] M. y. Lee,[46] F. Mausolf,[46] M. Merschmeyer,[46] A. Meyer,[46] F. Nowotny,[46] A. Pozdnyakov,[46] Y. Rath,[46] W. Redjeb,[46] F. Rehm,[46] H. Reithler,[46] V. Sarkisovi,[46] A. Schmidt,[46] C. Seth,[46] A. Sharma,[46] J. L. Spah,[46] F. Torres Da Silva De Araujo,[46,y] S. Wiedenbeck,[46] S. Zaleski,[46] C. Dziwok,[47] G. Flügge,[47] T. Kress,[47] A. Nowack,[47] O. Pooth,[47] A. Stahl,[47] T. Ziemons,[47] A. Zotz,[47] H. Aarup Petersen,[48] M. Aldaya Martin,[48] J. Alimena,[48] S. Amoroso,[48] Y. An,[48] J. Bach,[48] S. Baxter,[48] M. Bayatmakou,[48] H. Becerril Gonzalez,[48] O. Behnke,[48] A. Belvedere,[48] F. Blekman,[48,z] K. Borras,[48,aa] A. Campbell,[48] S. Chatterjee,[48] F. Colombina,[48] M. De Silva,[48] G. Eckerlin,[48] D. Eckstein,[48] E. Gallo,[48,z] A. Geiser,[48] V. Guglielmi,[48] M. Guthoff,[48] A. Hinzmann,[48] L. Jeppe,[48] B. Kaech,[48] M. Kasemann,[48] C. Kleinwort,[48] R. Kogler,[48] M. Komm,[48] D. Krücker,[48] W. Lange,[48] D. Leyva Pernia,[48] K. Lipka,[48,bb] W. Lohmann,[48,cc] F. Lorkowski,[48] R. Mankel,[48] I.-A. Melzer-Pellmann,[48] M. Mendizabal Morentin,[48] A. B. Meyer,[48] G. Milella,[48] K. Moral Figueroa,[48] A. Mussgiller,[48] L. P. Nair,[48] J. Niedziela,[48] A. Nürnberg,[48] J. Park,[48] E. Ranken,[48] A. Raspereza,[48] D. Rastorguev,[48] L. Rygaard,[48] M. Scham,[48,dd,aa] S. Schnake,[48,aa] P. Schütze,[48] C. Schwanenberger,[48,z] D. Selivanova,[48] K. Sharko,[48] M. Shchedrolosiev,[48] D. Stafford,[48] F. Vazzoler,[48] A. Ventura Barroso,[48] R. Walsh,[48] D. Wang,[48] Q. Wang,[48] K. Wichmann,[48] L. Wiens,[48,aa] C. Wissing,[48] Y. Yang,[48] S. Zakharov,[48] A. Zimermmane Castro Santos,[48] A. Albrecht,[49] M. Antonello,[49] S. Bollweg,[49] M. Bonanomi,[49] K. El Morabit,[49] Y. Fischer,[49] M. Frahm,[49] E. Garutti,[49] A. Grohsjean,[49] J. Haller,[49] D. Hundhausen,[49] H. R. Jabusch,[49] G. Kasieczka,[49] P. Keicher,[49] R. Klanner,[49] W. Korcari,[49] T. Kramer,[49] C. c. Kuo,[49] V. Kutzner,[49] F. Labe,[49] J. Lange,[49] A. Lobanov,[49] C. Matthies,[49] L. Moureaux,[49] M. Mrowietz,[49] A. Nigamova,[49] K. Nikolopoulos,[49] Y. Nissan,[49] A. Paasch,[49] K. J. Pena Rodriguez,[49] T. Quadfasel,[49] B. Raciti,[49] M. Rieger,[49] D. Savoiu,[49] J. Schindler,[49] P. Schleper,[49] M. Schröder,[49] J. Schwandt,[49] M. Sommerhalder,[49] H. Stadie,[49] G. Steinbrück,[49] A. Tews,[49] R. Ward,[49] B. Wiederspan,[49] M. Wolf,[49] S. Brommer,[50] E. Butz,[50] Y. M. Chen,[50] T. Chwalek,[50] A. Dierlamm,[50] G. G. Dincer,[50] U. Elicabuk,[50] N. Faltermann,[50] M. Giffels,[50] A. Gottmann,[50] F. Hartmann,[50,ee] R. Hofsaess,[50] M. Horzela,[50] U. Husemann,[50] J. Kieseler,[50] M. Klute,[50] O. Lavoryk,[50] J. M. Lawhorn,[50] M. Link,[50] A. Lintuluoto,[50] S. Maier,[50] M. Mormile,[50] Th. Müller,[50] M. Neukum,[50] M. Oh,[50] E. Pfeffer,[50] M. Presilla,[50]

G. Quast,[50] K. Rabbertz,[50] B. Regnery,[50] R. Schmieder,[50] N. Shadskiy,[50] I. Shvetsov,[50] H. J. Simonis,[50] L. Sowa,[50] L. Stockmeier,[50] K. Tauqeer,[50] M. Toms,[50] B. Topko,[50] N. Trevisani,[50] T. Voigtländer,[50] R. F. Von Cube,[50] J. Von Den Driesch,[50] M. Wassmer,[50] S. Wieland,[50] F. Wittig,[50] R. Wolf,[50] W. D. Zeuner,[50] X. Zuo,[50] G. Anagnostou,[51] G. Daskalakis,[51] A. Kyriakis,[51] A. Papadopoulos,[51,ee] A. Stakia,[51] G. Melachroinos,[52] Z. Painesis,[52] I. Paraskevas,[52] N. Saoulidou,[52] K. Theofilatos,[52] E. Tziaferi,[52] K. Vellidis,[52] I. Zisopoulos,[52] T. Chatzistavrou,[53] G. Karapostoli,[53] K. Kousouris,[53] E. Siamarkou,[53] G. Tsipolitis,[53] I. Bestintzanos,[54] I. Evangelou,[54] C. Foudas,[54] C. Kamtsikis,[54] P. Katsoulis,[54] P. Kokkas,[54] P. G. Kosmoglou Kioseoglou,[54] N. Manthos,[54] I. Papadopoulos,[54] J. Strologas,[54] D. Druzhkin,[55] C. Hajdu,[55] D. Horvath,[55,ff,gg] K. Márton,[55] A. J. Rádl,[55,hh] F. Sikler,[55] V. Veszpremi,[55] M. Csanád,[56] K. Farkas,[56] A. Fehérkuti,[56,ii] M. M. A. Gadallah,[56,jj] Á. Kadlecsik,[56] B. Cs. Kovács,[56] G. Pásztor,[56] G. I. Veres,[56] B. Ujvari,[57] G. Zilizi,[57] G. Bencze,[58] S. Czellar,[58] J. Molnar,[58] Z. Szillasi,[58] T. Csorgo,[59,ii] F. Nemes,[59,ii] T. Novak,[59] S. Bansal,[60] S. B. Beri,[60] V. Bhatnagar,[60] G. Chaudhary,[60] S. Chauhan,[60] N. Dhingra,[60,kk] A. Kaur,[60] A. Kaur,[60] H. Kaur,[60] M. Kaur,[60] S. Kumar,[60] T. Sheokand,[60] J. B. Singh,[60] A. Singla,[60] A. Bhardwaj,[61] A. Chhetri,[61] B. C. Choudhary,[61] A. Kumar,[61] A. Kumar,[61] M. Naimuddin,[61] K. Ranjan,[61] M. K. Saini,[61] S. Saumya,[61] S. Mukherjee,[62] S. Baradia,[63] S. Barman,[63,ll] S. Bhattacharya,[63] S. Das Gupta,[63] S. Dutta,[63] S. Dutta,[63] S. Sarkar,[63] M. M. Ameen,[64] P. K. Behera,[64] S. C. Behera,[64] S. Chatterjee,[64] G. Dash,[64] A. Dattamunsi,[64] P. Jana,[64] P. Kalbhor,[64] S. Kamble,[64] J. R. Komaragiri,[64,mm] D. Kumar,[64,mm] T. Mishra,[64] B. Parida,[64,nn] P. R. Pujahari,[64] N. R. Saha,[64] A. K. Sikdar,[64] R. K. Singh,[64] P. Verma,[64] S. Verma,[64] A. Vijay,[64] L. Bhatt,[65] S. Dugad,[65] G. B. Mohanty,[65] M. Shelake,[65] P. Suryadevara,[65] A. Bala,[66] S. Banerjee,[66] S. Bhowmik,[66,oo] R. M. Chatterjee,[66] M. Guchait,[66] Sh. Jain,[66] A. Jaiswal,[66] B. M. Joshi,[66] S. Kumar,[66] G. Majumder,[66] K. Mazumdar,[66] S. Parolia,[66] A. Thachayath,[66] S. Bahinipati,[67,pp] D. Maity,[67,qq] P. Mal,[67] K. Naskar,[67,qq] A. Nayak,[67,qq] S. Nayak,[67] K. Pal,[67] R. Raturi,[67] P. Sadangi,[67] S. K. Swain,[67] S. Varghese,[67,qq] D. Vats,[67,qq] S. Acharya,[68,rr] A. Alpana,[68] S. Dube,[68] B. Gomber,[68,rr] P. Hazarika,[68] B. Kansal,[68] A. Laha,[68] B. Sahu,[68,rr] R. Sharma,[68] S. Sharma,[68] K. Y. Vaish,[68] H. Bakhshiansohi,[69,ss] A. Jafari,[69,tt] M. Zeinali,[69,uu] S. Bashiri,[70] S. Chenarani,[70,vv] S. M. Etesami,[70] Y. Hosseini,[70] M. Khakzad,[70] E. Khazaie,[70] M. Mohammadi Najafabadi,[70] S. Tizchang,[70,ww] M. Felcini,[71] M. Grunewald,[71] M. Abbrescia,[72a,72b] M. Barbieri,[72a,72b] M. Buonsante,[72a,72b] A. Colaleo,[72a,72b] D. Creanza,[72a,72c] B. D'Anzi,[72a,72b] N. De Filippis,[72a,72c] M. De Palma,[72a,72b] W. Elmetenawee,[72a,72b,q] N. Ferrara,[72a,72b] L. Fiore,[72a] G. Iaselli,[72a,72c] L. Longo,[72a] M. Louka,[72a,72b] G. Maggi,[72a,72c] M. Maggi,[72a] I. Margjeka,[72a] V. Mastrapasqua,[72a,72b] S. My,[72a,72b] S. Nuzzo,[72a,72b] A. Pellecchia,[72a,72b] A. Pompili,[72a,72b] G. Pugliese,[72a,72c] R. Radogna,[72a,72b] D. Ramos,[72a] A. Ranieri,[72a] L. Silvestris,[72a] F. M. Simone,[72a,72c] Ü. Sözbilir,[72a] A. Stamerra,[72a,72b] D. Troiano,[72a,72b] R. Venditti,[72a,72b] P. Verwilligen,[72a] A. Zaza,[72a,72b] G. Abbiendi,[73a] C. Battilana,[73a,73b] D. Bonacorsi,[73a,73b] P. Capiluppi,[73a,73b] A. Castro,[73a,73b,a] F. R. Cavallo,[73a] M. Cuffiani,[73a,73b] G. M. Dallavalle,[73a] T. Diotalevi,[73a,73b] F. Fabbri,[73a] A. Fanfani,[73a,73b] D. Fasanella,[73a] P. Giacomelli,[73a] L. Giommi,[73a,73b] C. Grandi,[73a] L. Guiducci,[73a,73b] S. Lo Meo,[73a,xx] M. Lorusso,[73a,73b] L. Lunerti,[73a] S. Marcellini,[73a] G. Masetti,[73a] F. L. Navarria,[73a,73b] G. Paggi,[73a,73b] A. Perrotta,[73a] F. Primavera,[73a,73b] A. M. Rossi,[73a,73b] S. Rossi Tisbeni,[73a,73b] T. Rovelli,[73a,73b] G. P. Siroli,[73a,73b] S. Costa,[74a,74b,yy] A. Di Mattia,[74a] A. Lapertosa,[74a] R. Potenza,[74a,74b] A. Tricomi,[74a,74b,yy] J. Altork,[75a,75b] P. Assiouras,[75a] G. Barbagli,[75a] G. Bardelli,[75a] M. Bartolini,[75a,75b] A. Calandri,[75a,75b] B. Camaiani,[75a,75b] A. Cassese,[75a] R. Ceccarelli,[75a] V. Ciulli,[75a,75b] C. Civinini,[75a] R. D'Alessandro,[75a,75b] L. Damenti,[75a,75b] E. Focardi,[75a,75b] T. Kello,[75a] G. Latino,[75a,75b] P. Lenzi,[75a,75b] M. Lizzo,[75a] M. Meschini,[75a] S. Paoletti,[75a] A. Papanastassiou,[75a,75b] G. Sguazzoni,[75a] L. Viliani,[75a] L. Benussi,[76] S. Bianco,[76] S. Meola,[76,zz] D. Piccolo,[76] M. Alves Gallo Pereira,[77a] F. Ferro,[77a] E. Robutti,[77a] S. Tosi,[77a,77b] A. Benaglia,[78a] F. Brivio,[78a] F. Cetorelli,[78a,78b] F. De Guio,[78a,78b] M. E. Dinardo,[78a,78b] P. Dini,[78a] S. Gennai,[78a] R. Gerosa,[78a,78b] A. Ghezzi,[78a,78b] P. Govoni,[78a,78b] L. Guzzi,[78a] G. Lavizzari,[78a,78b] M. T. Lucchini,[78a,78b] M. Malberti,[78a] S. Malvezzi,[78a] A. Massironi,[78a] D. Menasce,[78a] L. Moroni,[78a] M. Paganoni,[78a,78b] S. Palluotto,[78a,78b] D. Pedrini,[78a] A. Perego,[78a,78b] B. S. Pinolini,[78a] G. Pizzati,[78a,78b] S. Ragazzi,[78a,78b] T. Tabarelli de Fatis,[78a,78b] S. Buontempo,[79a] A. Cagnotta,[79a,79b] F. Carnevali,[79a,79b] N. Cavallo,[79a,79c] C. Di Fraia,[79a,79b] F. Fabozzi,[79a,79c] L. Favilla,[79a,79d] A. O. M. Iorio,[79a,79b] L. Lista,[79a,79b,aaa] P. Paolucci,[79a,ee] B. Rossi,[79a] R. Ardino,[80a] P. Azzi,[80a] N. Bacchetta,[80a,bbb] A. Bergnoli,[80a] D. Bisello,[80a,80b] P. Bortignon,[80a] G. Bortolato,[80a,80b] A. C. M. Bulla,[80a] R. Carlin,[80a,80b] P. Checchia,[80a]

T. Dorigo,[80a,ccc] F. Gasparini,[80a,80b] U. Gasparini,[80a,80b] S. Giorgetti,[80a] E. Lusiani,[80a] M. Margoni,[80a,80b] A. T. Meneguzzo,[80a,80b] J. Pazzini,[80a,80b] P. Ronchese,[80a,80b] R. Rossin,[80a,80b] F. Simonetto,[80a,80b] M. Tosi,[80a,80b] A. Triossi,[80a,80b] S. Ventura,[80a] P. Zotto,[80a,80b] A. Zucchetta,[80a,80b] G. Zumerle,[80a,80b] A. Braghieri,[81a] S. Calzaferri,[81a] D. Fiorina,[81a] P. Montagna,[81a,81b] M. Pelliccioni,[81a] V. Re,[81a] C. Riccardi,[81a,81b] P. Salvini,[81a] I. Vai,[81a,81b] P. Vitulo,[81a,81b] S. Ajmal,[82a,82b] M. E. Ascioti,[82a,82b] G. M. Bilei,[82a] C. Carrivale,[82a,82b] D. Ciangottini,[82a,82b] L. Della Penna,[82a] L. Fanò,[82a,82b] V. Mariani,[82a,82b] M. Menichelli,[82a] F. Moscatelli,[82a,ddd] A. Rossi,[82a,82b] A. Santocchia,[82a,82b] D. Spiga,[82a] T. Tedeschi,[82a,82b] C. Aimè,[83a,83b] C. A. Alexe,[83a,83c] P. Asenov,[83a,83b] P. Azzurri,[83a] G. Bagliesi,[83a] R. Bhattacharya,[83a] L. Bianchini,[83a,83b] T. Boccali,[83a] E. Bossini,[83a] D. Bruschini,[83a,83c] R. Castaldi,[83a] F. Cattafesta,[83a,83c] M. A. Ciocci,[83a,83b] M. Cipriani,[83a,83b] V. D'Amante,[83a,83d] R. Dell'Orso,[83a] S. Donato,[83a,83b] R. Forti,[83a,83b] A. Giassi,[83a] F. Ligabue,[83a,83c] A. C. Marini,[83a,83b] D. Matos Figueiredo,[83a] A. Messineo,[83a,83b] S. Mishra,[83a] V. K. Muraleedharan Nair Bindhu,[83a,83b] M. Musich,[83a,83b] S. Nandan,[83a] F. Palla,[83a] M. Riggirello,[83a,83c] A. Rizzi,[83a,83b] G. Rolandi,[83a,83c] S. Roy Chowdhury,[83a,oo] T. Sarkar,[83a] A. Scribano,[83a] P. Spagnolo,[83a] F. Tenchini,[83a,83b] R. Tenchini,[83a] G. Tonelli,[83a,83b] N. Turini,[83a,83d] F. Vaselli,[83a,83c] A. Venturi,[83a] P. G. Verdini,[83a] P. Akrap,[84a,84b] C. Basile,[84a,84b] F. Cavallari,[84a] L. Cunqueiro Mendez,[84a,84b] F. De Riggi,[84a,84b] D. Del Re,[84a,84b] E. Di Marco,[84a,84b] M. Diemoz,[84a] F. Errico,[84a,84b] L. Frosina,[84a,84b] R. Gargiulo,[84a,84b] B. Harikrishnan,[84a,84b] F. Lombardi,[84a,84b] E. Longo,[84a,84b] L. Martikainen,[84a,84b] J. Mijuskovic,[84a,84b] G. Organtini,[84a,84b] N. Palmeri,[84a,84b] F. Pandolfi,[84a] R. Paramatti,[84a,84b] C. Quaranta,[84a,84b] S. Rahatlou,[84a,84b] C. Rovelli,[84a] F. Santanastasio,[84a,84b] L. Soffi,[84a] V. Vladimirov,[84a,84b] N. Amapane,[85a,85b] R. Arcidiacono,[85a,85c] S. Argiro,[85a,85b] M. Arneodo,[85a,85c] N. Bartosik,[85a,85c] R. Bellan,[85a,85b] C. Biino,[85a] C. Borca,[85a,85b] N. Cartiglia,[85a] M. Costa,[85a,85b] R. Covarelli,[85a,85b] N. Demaria,[85a] L. Finco,[85a] M. Grippo,[85a,85b] B. Kiani,[85a,85b] L. Lanteri,[85a,85b] F. Legger,[85a] F. Luongo,[85a,85b] C. Mariotti,[85a] L. Markovic,[85a,85b] S. Maselli,[85a] A. Mecca,[85a,85b] L. Menzio,[85a,85b] P. Meridiani,[85a] E. Migliore,[85a,85b] M. Monteno,[85a] R. Mulargia,[85a] M. M. Obertino,[85a,85b] G. Ortona,[85a] L. Pacher,[85a,85b] N. Pastrone,[85a] M. Ruspa,[85a,85c] F. Siviero,[85a,85b] V. Sola,[85a,85b] A. Solano,[85a,85b] A. Staiano,[85a] C. Tarricone,[85a,85b] D. Trocino,[85a] G. Umoret,[85a,85b] R. White,[85a,85b] J. Babbar,[86a,86b] S. Belforte,[86a] V. Candelise,[86a,86b] M. Casarsa,[86a] F. Cossutti,[86a] K. De Leo,[86a] G. Della Ricca,[86a,86b] R. Delli Gatti,[86a,86b] S. Dogra,[87] J. Hong,[87] J. Kim,[87] D. Lee,[87] H. Lee,[87] J. Lee,[87] S. W. Lee,[87] C. S. Moon,[87] Y. D. Oh,[87] M. S. Ryu,[87] S. Sekmen,[87] B. Tae,[87] Y. C. Yang,[87] M. S. Kim,[88] G. Bak,[89] P. Gwak,[89] H. Kim,[89] D. H. Moon,[89] E. Asilar,[90] J. Choi,[90,eee] D. Kim,[90] T. J. Kim,[90] J. A. Merlin,[90] Y. Ryou,[90] S. Choi,[91] S. Han,[91] B. Hong,[91] K. Lee,[91] K. S. Lee,[91] S. Lee,[91] J. Yoo,[91] J. Goh,[92] J. Shin,[92] S. Yang,[92] Y. Kang,[93] H. S. Kim,[93] Y. Kim,[93] S. Lee,[93] J. Almond,[94] J. H. Bhyun,[94] J. Choi,[94] J. Choi,[94] W. Jun,[94] J. Kim,[94] Y. Kim,[94] Y. W. Kim,[94] S. Ko,[94] H. Lee,[94] J. Lee,[94] J. Lee,[94] B. H. Oh,[94] S. B. Oh,[94] H. Seo,[94] J. Shin,[94] U. K. Yang,[94] I. Yoon,[94] W. Jang,[95] D. Y. Kang,[95] S. Kim,[95] B. Ko,[95] J. S. H. Lee,[95] Y. Lee,[95] I. C. Park,[95] Y. Roh,[95] I. J. Watson,[95] G. Cho,[96] S. Ha,[96] K. Hwang,[96] B. Kim,[96] S. Kim,[96] K. Lee,[96] H. D. Yoo,[96] M. Choi,[97] M. R. Kim,[97] Y. Lee,[97] I. Yu,[97] T. Beyrouthy,[98] Y. Gharbia,[98] F. Alazemi,[99] K. Dreimanis,[100] O. M. Eberlins,[100] A. Gaile,[100] C. Munoz Diaz,[100] D. Osite,[100] G. Pikurs,[100] A. Potrebko,[100] M. Seidel,[100] D. Sidiropoulos Kontos,[100] N. R. Strautnieks,[101] M. Ambrozas,[102] A. Juodagalvis,[102] A. Rinkevicius,[102] G. Tamulaitis,[102] I. Yusuff,[103,fff] Z. Zolkapli,[103] J. F. Benitez,[104] A. Castaneda Hernandez,[104] L. E. Cuevas Picos,[104] H. A. Encinas Acosta,[104] L. G. Gallegos Maríñez,[104] M. León Coello,[104] J. A. Murillo Quijada,[104] A. Sehrawat,[104] L. Valencia Palomo,[104] G. Ayala,[105] H. Castilla-Valdez,[105] H. Crotte Ledesma,[105] E. De La Cruz-Burelo,[105] I. Heredia-De La Cruz,[105,ggg] R. Lopez-Fernandez,[105] J. Mejia Guisao,[105] A. Sánchez Hernández,[105] C. Oropeza Barrera,[106] D. L. Ramirez Guadarrama,[106] M. Ramírez García,[106] I. Bautista,[107] F. E. Neri Huerta,[107] I. Pedraza,[107] H. A. Salazar Ibarguen,[107] C. Uribe Estrada,[107] I. Bubanja,[108] N. Raicevic,[108] P. H. Butler,[109] A. Ahmad,[110] M. I. Asghar,[110] A. Awais,[110] M. I. M. Awan,[110] W. A. Khan,[110] V. Avati,[111] A. Bellora,[111,hhh] L. Forthomme,[111] L. Grzanka,[111] M. Malawski,[111] K. Piotrzkowski,[111] M. Bluj,[112] M. Górski,[112] M. Kazana,[112] M. Szleper,[112] P. Zalewski,[112] K. Bunkowski,[113] K. Doroba,[113] A. Kalinowski,[113] M. Konecki,[113] J. Krolikowski,[113] A. Muhammad,[113] P. Fokow,[114] K. Pozniak,[114] W. Zabolotny,[114] M. Araujo,[115] D. Bastos,[115] C. Beirão Da Cruz E Silva,[115] A. Boletti,[115] M. Bozzo,[115] T. Camporesi,[115] G. Da Molin,[115] P. Faccioli,[115] M. Gallinaro,[115] J. Hollar,[115] N. Leonardo,[115] G. B. Marozzo,[115] A. Petrilli,[115] M. Pisano,[115] J. Seixas,[115]

J. Varela,[115] J. W. Wulff,[115] P. Adzic,[116] P. Milenovic,[116] D. Devetak,[117] M. Dordevic,[117] J. Milosevic,[117] L. Nadderd,[117] V. Rekovic,[117] M. Stojanovic,[117] J. Alcaraz Maestre,[118] Cristina F. Bedoya,[118] J. A. Brochero Cifuentes,[118] Oliver M. Carretero,[118] M. Cepeda,[118] M. Cerrada,[118] N. Colino,[118] B. De La Cruz,[118] A. Delgado Peris,[118] A. Escalante Del Valle,[118] D. Fernández Del Val,[118] J. P. Fernández Ramos,[118] J. Flix,[118] M. C. Fouz,[118] O. Gonzalez Lopez,[118] S. Goy Lopez,[118] J. M. Hernandez,[118] M. I. Josa,[118] J. Llorente Merino,[118] C. Martin Perez,[118] E. Martin Viscasillas,[118] D. Moran,[118] C. M. Morcillo Perez,[118] Á. Navarro Tobar,[118] C. Perez Dengra,[118] A. Pérez-Calero Yzquierdo,[118] J. Puerta Pelayo,[118] I. Redondo,[118] J. Sastre,[118] J. Vazquez Escobar,[118] J. F. de Trocóniz,[119] B. Alvarez Gonzalez,[120] A. Cardini,[120] J. Cuevas,[120] J. Del Riego Badas,[120] J. Fernandez Menendez,[120] S. Folgueras,[120] I. Gonzalez Caballero,[120] P. Leguina,[120] M. Obeso Menendez,[120] E. Palencia Cortezon,[120] J. Prado Pico,[120] V. Rodríguez Bouza,[120] A. Soto Rodríguez,[120] A. Trapote,[120] C. Vico Villalba,[120] P. Vischia,[120] S. Blanco Fernández,[121] I. J. Cabrillo,[121] A. Calderon,[121] J. Duarte Campderros,[121] M. Fernandez,[121] G. Gomez,[121] C. Lasaosa García,[121] R. Lopez Ruiz,[121] C. Martinez Rivero,[121] P. Martinez Ruiz del Arbol,[121] F. Matorras,[121] P. Matorras Cuevas,[121] E. Navarrete Ramos,[121] J. Piedra Gomez,[121] L. Scodellaro,[121] I. Vila,[121] J. M. Vizan Garcia,[121] B. Kailasapathy,[122,iii] D. D. C. Wickramarathna,[122] W. G. D. Dharmaratna,[123,jjj] K. Liyanage,[123] N. Perera,[123] D. Abbaneo,[124] C. Amendola,[124] E. Auffray,[124] J. Baechler,[124] D. Barney,[124] A. Bermúdez Martínez,[124] M. Bianco,[124] A. A. Bin Anuar,[124] A. Bocci,[124] L. Borgonovi,[124] C. Botta,[124] A. Bragagnolo,[124] E. Brondolin,[124] C. E. Brown,[124] C. Caillol,[124] G. Cerminara,[124] N. Chernyavskaya,[124] P. Connor,[124] D. d'Enterria,[124] A. Dabrowski,[124] A. David,[124] A. De Roeck,[124] M. M. Defranchis,[124] M. Deile,[124] M. Dobson,[124] W. Funk,[124] S. Giani,[124] D. Gigi,[124] K. Gill,[124] F. Glege,[124] M. Glowacki,[124] A. Gruber,[124] J. Hegeman,[124] J. K. Heikkilä,[124] B. Huber,[124] V. Innocente,[124] T. James,[124] P. Janot,[124] O. Kaluzinska,[124] O. Karacheban,[124,cc] G. Karathanasis,[124] S. Laurila,[124] P. Lecoq,[124] E. Leutgeb,[124] C. Lourenço,[124] M. Magherini,[124] L. Malgeri,[124] M. Mannelli,[124] M. Matthewman,[124] A. Mehta,[124] F. Meijers,[124] S. Mersi,[124] E. Meschi,[124] M. Migliorini,[124] V. Milosevic,[124] F. Monti,[124] F. Moortgat,[124] M. Mulders,[124] I. Neutelings,[124] S. Orfanelli,[124] F. Pantaleo,[124] G. Petrucciani,[124] A. Pfeiffer,[124] M. Pierini,[124] M. Pitt,[124] H. Qu,[124] D. Rabady,[124] B. Ribeiro Lopes,[124] F. Riti,[124] M. Rovere,[124] H. Sakulin,[124] R. Salvatico,[124] S. Sanchez Cruz,[124] S. Scarfi,[124] M. Selvaggi,[124] A. Sharma,[124] K. Shchelina,[124] P. Silva,[124] P. Sphicas,[124,kkk] A. G. Stahl Leiton,[124] A. Steen,[124] S. Summers,[124] D. Treille,[124] P. Tropea,[124] E. Vernazza,[124] J. Wanczyk,[124,lll] J. Wang,[124] S. Wuchterl,[124] P. Zehetner,[124] P. Zejdl,[124] T. Bevilacqua,[125,mmm] L. Caminada,[125,mmm] A. Ebrahimi,[125] W. Erdmann,[125] R. Horisberger,[125] Q. Ingram,[125] H. C. Kaestli,[125] D. Kotlinski,[125] C. Lange,[125] M. Missiroli,[125,mmm] L. Noehte,[125,mmm] T. Rohe,[125] A. Samalan,[125] T. K. Aarrestad,[126] M. Backhaus,[126] G. Bonomelli,[126] C. Cazzaniga,[126] K. Datta,[126] P. De Bryas Dexmiers D'archiac,[126,lll] A. De Cosa,[126] G. Dissertori,[126] M. Dittmar,[126] M. Donegà,[126] F. Eble,[126] M. Galli,[126] K. Gedia,[126] F. Glessgen,[126] C. Grab,[126] N. Härringer,[126] T. G. Harte,[126] W. Lustermann,[126] A.-M. Lyon,[126] M. Malucchi,[126] R. A. Manzoni,[126] M. Marchegiani,[126] L. Marchese,[126] A. Mascellani,[126,lll] F. Nessi-Tedaldi,[126] F. Pauss,[126] V. Perovic,[126] S. Pigazzini,[126] B. Ristic,[126] R. Seidita,[126] J. Steggemann,[126,lll] A. Tarabini,[126] D. Valsecchi,[126] R. Wallny,[126] C. Amsler,[127,nnn] P. Bärtschi,[127] M. F. Canelli,[127] G. Celotto,[127] K. Cormier,[127] M. Huwiler,[127] W. Jin,[127] A. Jofrehei,[127] B. Kilminster,[127] S. Leontsinis,[127] S. P. Liechti,[127] A. Macchiolo,[127] P. Meiring,[127] F. Meng,[127] J. Motta,[127] A. Reimers,[127] P. Robmann,[127] M. Senger,[127] E. Shokr,[127] F. Stäger,[127] R. Tramontano,[127] C. Adloff,[128,ooo] D. Bhowmik,[128] C. M. Kuo,[128] W. Lin,[128] P. K. Rout,[128] S. Taj,[128] P. C. Tiwari,[128,mm] L. Ceard,[129] K. F. Chen,[129] Z. g. Chen,[129] A. De Iorio,[129] W.-S. Hou,[129] T. h. Hsu,[129] Y. w. Kao,[129] S. Karmakar,[129] G. Kole,[129] Y. y. Li,[129] R.-S. Lu,[129] E. Paganis,[129] X. f. Su,[129] J. Thomas-Wilsker,[129] L. s. Tsai,[129] D. Tsionou,[129] H. y. Wu,[129] E. Yazgan,[129] C. Asawatangtrakuldee,[130] N. Srimanobhas,[130] V. Wachirapusitanand,[130] Y. Maghrbi,[131] D. Agyel,[132] F. Boran,[132] F. Dolek,[132] I. Dumanoglu,[132,ppp] E. Eskut,[132] Y. Guler,[132,qqq] E. Gurpinar Guler,[132,qqq] C. Isik,[132] O. Kara,[132] A. Kayis Topaksu,[132] Y. Komurcu,[132] G. Onengut,[132] K. Ozdemir,[132,rrr] A. Polatoz,[132] B. Tali,[132,sss] U. G. Tok,[132] E. Uslan,[132] I. S. Zorbakir,[132] M. Yalvac,[133,ttt] B. Akgun,[134] I. O. Atakisi,[134] E. Gülmez,[134] M. Kaya,[134,uuu] O. Kaya,[134,vvv] S. Tekten,[134,www] A. Cakir,[135] K. Cankocak,[135,ppp,xxx] S. Sen,[135,yyy] O. Aydilek,[136,zzz] B. Hacisahinoglu,[136] I. Hos,[136,aaaa] B. Kaynak,[136] S. Ozkorucuklu,[136] O. Potok,[136] H. Sert,[136] C. Simsek,[136] C. Zorbilmez,[136] S. Cerci,[137] B. Isildak,[137,bbbb] D. Sunar Cerci,[137] T. Yetkin,[137,w]

A. Boyaryntsev,[138] B. Grynyov,[138] L. Levchuk,[139] D. Anthony,[140] J. J. Brooke,[140] A. Bundock,[140] F. Bury,[140] E. Clement,[140] D. Cussans,[140] H. Flacher,[140] J. Goldstein,[140] H. F. Heath,[140] M.-L. Holmberg,[140] L. Kreczko,[140] S. Paramesvaran,[140] L. Robertshaw,[140] J. Segal,[140] V. J. Smith,[140] A. H. Ball,[141] K. W. Bell,[141] A. Belyaev,[141,cccc] C. Brew,[141] R. M. Brown,[141] D. J. A. Cockerill,[141] C. Cooke,[141] A. Elliot,[141] K. V. Ellis,[141] J. Gajownik,[141] K. Harder,[141] S. Harper,[141] J. Linacre,[141] K. Manolopoulos,[141] M. Moallemi,[141] D. M. Newbold,[141] E. Olaiya,[141] D. Petyt,[141] T. Reis,[141] A. R. Sahasransu,[141] G. Salvi,[141] T. Schuh,[141] C. H. Shepherd-Themistocleous,[141] I. R. Tomalin,[141] K. C. Whalen,[141] T. Williams,[141] I. Andreou,[142] R. Bainbridge,[142] P. Bloch,[142] O. Buchmuller,[142] C. A. Carrillo Montoya,[142] D. Colling,[142] J. S. Dancu,[142] I. Das,[142] P. Dauncey,[142] G. Davies,[142] M. Della Negra,[142] S. Fayer,[142] G. Fedi,[142] G. Hall,[142] H. R. Hoorani,[142] A. Howard,[142] G. Iles,[142] C. R. Knight,[142] P. Krueper,[142] J. Langford,[142] K. H. Law,[142] J. León Holgado,[142] L. Lyons,[142] A.-M. Magnan,[142] B. Maier,[142] S. Mallios,[142] A. Mastronikolis,[142] M. Mieskolainen,[142] J. Nash,[142,dddd] M. Pesaresi,[142] P. B. Pradeep,[142] B. C. Radburn-Smith,[142] A. Richards,[142] A. Rose,[142] L. Russell,[142] K. Savva,[142] C. Seez,[142] R. Shukla,[142] A. Tapper,[142] K. Uchida,[142] G. P. Uttley,[142] T. Virdee,[142,ee] M. Vojinovic,[142] N. Wardle,[142] D. Winterbottom,[142] J. E. Cole,[143] A. Khan,[143] P. Kyberd,[143] I. D. Reid,[143] S. Abdullin,[144] A. Brinkerhoff,[144] E. Collins,[144] M. R. Darwish,[144] J. Dittmann,[144] K. Hatakeyama,[144] V. Hegde,[144] J. Hiltbrand,[144] B. McMaster,[144] J. Samudio,[144] S. Sawant,[144] C. Sutantawibul,[144] J. Wilson,[144] R. Bartek,[145] A. Dominguez,[145] S. Raj,[145] A. E. Simsek,[145] S. S. Yu,[145] B. Bam,[146] A. Buchot Perraguin,[146] R. Chudasama,[146] S. I. Cooper,[146] C. Crovella,[146] G. Fidalgo,[146] S. V. Gleyzer,[146] A. Khukhunaishvili,[146] K. Matchev,[146] E. Pearson,[146] C. U. Perez,[146] P. Rumerio,[146,eeee] E. Usai,[146] R. Yi,[146] G. De Castro,[147] Z. Demiragli,[147] C. Erice,[147] C. Fangmeier,[147] C. Fernandez Madrazo,[147] E. Fontanesi,[147] D. Gastler,[147] F. Golf,[147] S. Jeon,[147] J. O'cain,[147] I. Reed,[147] J. Rohlf,[147] K. Salyer,[147] D. Sperka,[147] D. Spitzbart,[147] I. Suarez,[147] A. Tsatsos,[147] A. G. Zecchinelli,[147] G. Barone,[148] G. Benelli,[148] D. Cutts,[148] S. Ellis,[148] L. Gouskos,[148] M. Hadley,[148] U. Heintz,[148] K. W. Ho,[148] J. M. Hogan,[148,ffff] T. Kwon,[148] G. Landsberg,[148] K. T. Lau,[148] J. Luo,[148] S. Mondal,[148] T. Russell,[148] S. Sagir,[148,gggg] X. Shen,[148] M. Stamenkovic,[148] N. Venkatasubramanian,[148] S. Abbott,[149] B. Barton,[149] C. Brainerd,[149] R. Breedon,[149] H. Cai,[149] M. Calderon De La Barca Sanchez,[149] M. Chertok,[149] M. Citron,[149] J. Conway,[149] P. T. Cox,[149] R. Erbacher,[149] F. Jensen,[149] O. Kukral,[149] G. Mocellin,[149] M. Mulhearn,[149] S. Ostrom,[149] W. Wei,[149] S. Yoo,[149] K. Adamidis,[150] M. Bachtis,[150] D. Campos,[150] R. Cousins,[150] A. Datta,[150] G. Flores Avila,[150] J. Hauser,[150] M. Ignatenko,[150] M. A. Iqbal,[150] T. Lam,[150] Y. f. Lo,[150] E. Manca,[150] A. Nunez Del Prado,[150] D. Saltzberg,[150] V. Valuev,[150] R. Clare,[151] J. W. Gary,[151] G. Hanson,[151] A. Aportela,[152] A. Arora,[152] J. G. Branson,[152] S. Cittolin,[152] S. Cooperstein,[152] D. Diaz,[152] J. Duarte,[152] L. Giannini,[152] Y. Gu,[152] J. Guiang,[152] R. Kansal,[152] V. Krutelyov,[152] R. Lee,[152] J. Letts,[152] M. Masciovecchio,[152] F. Mokhtar,[152] S. Mukherjee,[152] M. Pieri,[152] D. Primosch,[152] M. Quinnan,[152] V. Sharma,[152] M. Tadel,[152] E. Vourliotis,[152] F. Würthwein,[152] Y. Xiang,[152] A. Yagil,[152] A. Barzdukas,[153] L. Brennan,[153] C. Campagnari,[153] K. Downham,[153] C. Grieco,[153] M. M. Hussain,[153] J. Incandela,[153] J. Kim,[153] A. J. Li,[153] P. Masterson,[153] H. Mei,[153] J. Richman,[153] S. N. Santpur,[153] U. Sarica,[153] R. Schmitz,[153] F. Setti,[153] J. Sheplock,[153] D. Stuart,[153] T. Á. Vámi,[153] X. Yan,[153] D. Zhang,[153] A. Albert,[154] S. Bhattacharya,[154] A. Bornheim,[154] O. Cerri,[154] J. Mao,[154] H. B. Newman,[154] G. Reales Gutiérrez,[154] T. Sievert,[154] M. Spiropulu,[154] J. R. Vlimant,[154] R. A. Wynne,[154] S. Xie,[154] R. Y. Zhu,[154] J. Alison,[155] S. An,[155] P. Bryant,[155] M. Cremonesi,[155] V. Dutta,[155] E. Y. Ertorer,[155] T. Ferguson,[155] T. A. Gómez Espinosa,[155] A. Harilal,[155] A. Kallil Tharayil,[155] M. Kanemura,[155] C. Liu,[155] T. Mudholkar,[155] S. Murthy,[155] P. Palit,[155] K. Park,[155] M. Paulini,[155] A. Roberts,[155] A. Sanchez,[155] W. Terrill,[155] J. P. Cumalat,[156] W. T. Ford,[156] A. Hart,[156] A. Hassani,[156] J. Pearkes,[156] C. Savard,[156] N. Schonbeck,[156] K. Stenson,[156] K. A. Ulmer,[156] S. R. Wagner,[156] N. Zipper,[156] D. Zuolo,[156] J. Alexander,[157] X. Chen,[157] D. J. Cranshaw,[157] J. Dickinson,[157] J. Fan,[157] X. Fan,[157] J. Grassi,[157] S. Hogan,[157] P. Kotamnives,[157] J. Monroy,[157] G. Niendorf,[157] M. Oshiro,[157] J. R. Patterson,[157] M. Reid,[157] A. Ryd,[157] J. Thom,[157] P. Wittich,[157] R. Zou,[157] M. Albrow,[158] M. Alyari,[158] O. Amram,[158] G. Apollinari,[158] A. Apresyan,[158] L. A. T. Bauerdick,[158] D. Berry,[158] J. Berryhill,[158] P. C. Bhat,[158] K. Burkett,[158] J. N. Butler,[158] A. Canepa,[158] G. B. Cerati,[158] H. W. K. Cheung,[158] F. Chlebana,[158] C. Cosby,[158] G. Cummings,[158] I. Dutta,[158] V. D. Elvira,[158] J. Freeman,[158] A. Gandrakota,[158] Z. Gecse,[158] L. Gray,[158] D. Green,[158] A. Grummer,[158] S. Grünendahl,[158] D. Guerrero,[158] O. Gutsche,[158] R. M. Harris,[158] T. C. Herwig,[158] J. Hirschauer,[158]

B. Jayatilaka,[158] S. Jindariani,[158] M. Johnson,[158] U. Joshi,[158] T. Klijnsma,[158] B. Klima,[158] K. H. M. Kwok,[158] S. Lammel,[158] C. Lee,[158] D. Lincoln,[158] R. Lipton,[158] T. Liu,[158] K. Maeshima,[158] D. Mason,[158] P. McBride,[158] P. Merkel,[158] S. Mrenna,[158] S. Nahn,[158] J. Ngadiuba,[158] D. Noonan,[158] S. Norberg,[158] V. Papadimitriou,[158] N. Pastika,[158] K. Pedro,[158] C. Pena,[158,hhhh] F. Ravera,[158] A. Reinsvold Hall,[158,iiii] L. Ristori,[158] M. Safdari,[158] E. Sexton-Kennedy,[158] N. Smith,[158] A. Soha,[158] L. Spiegel,[158] S. Stoynev,[158] J. Strait,[158] L. Taylor,[158] S. Tkaczyk,[158] N. V. Tran,[158] L. Uplegger,[158] E. W. Vaandering,[158] C. Wang,[158] I. Zoi,[158] C. Aruta,[159] P. Avery,[159] D. Bourilkov,[159] P. Chang,[159] V. Cherepanov,[159] R. D. Field,[159] C. Huh,[159] E. Koenig,[159] M. Kolosova,[159] J. Konigsberg,[159] A. Korytov,[159] N. Menendez,[159] G. Mitselmakher,[159] K. Mohrman,[159] A. Muthirakalayil Madhu,[159] N. Rawal,[159] S. Rosenzweig,[159] V. Sulimov,[159] Y. Takahashi,[159] J. Wang,[159] T. Adams,[160] A. Al Kadhim,[160] A. Askew,[160] S. Bower,[160] R. Hashmi,[160] R. S. Kim,[160] S. Kim,[160] T. Kolberg,[160] G. Martinez,[160] H. Prosper,[160] P. R. Prova,[160] M. Wulansatiti,[160] R. Yohay,[160] J. Zhang,[160] B. Alsufyani,[161] S. Butalla,[161] S. Das,[161] T. Elkafrawy,[161,jjjj] M. Hohlmann,[161] M. Lavinsky,[161] E. Yanes,[161] M. R. Adams,[162] N. Barnett,[162] A. Baty,[162] C. Bennett,[162] R. Cavanaugh,[162] R. Escobar Franco,[162] O. Evdokimov,[162] C. E. Gerber,[162] H. Gupta,[162] M. Hawksworth,[162] A. Hingrajiya,[162] D. J. Hofman,[162] J. h. Lee,[162] D. S. Lemos,[162] C. Mills,[162] S. Nanda,[162] B. Ozek,[162] T. Phan,[162] D. Pilipovic,[162] R. Pradhan,[162] E. Prifti,[162] P. Roy,[162] T. Roy,[162] N. Singh,[162] M. B. Tonjes,[162] N. Varelas,[162] M. A. Wadud,[162] Z. Ye,[162] J. Yoo,[162] M. Alhusseini,[163] D. Blend,[163] K. Dilsiz,[163,kkkk] L. Emediato,[163] G. Karaman,[163] O. K. Köseyan,[163] J.-P. Merlo,[163] A. Mestvirishvili,[163,llll] O. Neogi,[163] H. Ogul,[163,mmmm] Y. Onel,[163] A. Penzo,[163] C. Snyder,[163] E. Tiras,[163,nnnn] B. Blumenfeld,[164] J. Davis,[164] A. V. Gritsan,[164] L. Kang,[164] S. Kyriacou,[164] P. Maksimovic,[164] M. Roguljic,[164] J. Roskes,[164] S. Sekhar,[164] M. Swartz,[164] A. Abreu,[165] L. F. Alcerro Alcerro,[165] J. Anguiano,[165] S. Arteaga Escatel,[165] P. Baringer,[165] A. Bean,[165] Z. Flowers,[165] D. Grove,[165] J. King,[165] G. Krintiras,[165] M. Lazarovits,[165] C. Le Mahieu,[165] J. Marquez,[165] M. Murray,[165] M. Nickel,[165] S. Popescu,[165,oooo] C. Rogan,[165] C. Royon,[165] S. Rudrabhatla,[165] S. Sanders,[165] C. Smith,[165] G. Wilson,[165] B. Allmond,[166] R. Gujju Gurunadha,[166] A. Ivanov,[166] K. Kaadze,[166] Y. Maravin,[166] J. Natoli,[166] D. Roy,[166] G. Sorrentino,[166] A. Baden,[167] A. Belloni,[167] J. Bistany-riebman,[167] S. C. Eno,[167] N. J. Hadley,[167] S. Jabeen,[167] R. G. Kellogg,[167] T. Koeth,[167] B. Kronheim,[167] S. Lascio,[167] P. Major,[167] A. C. Mignerey,[167] S. Nabili,[167] C. Palmer,[167] C. Papageorgakis,[167] M. M. Paranjpe,[167] E. Popova,[167,pppp] A. Shevelev,[167] L. Wang,[167] L. Zhang,[167] C. Baldenegro Barrera,[168] J. Bendavid,[168] H. Bossi,[168] S. Bright-Thonney,[168] I. A. Cali,[168] Y. C. Chen,[168] P. c. Chou,[168] M. D'Alfonso,[168] J. Eysermans,[168] C. Freer,[168] G. Gomez-Ceballos,[168] M. Goncharov,[168] G. Grosso,[168] P. Harris,[168] D. Hoang,[168] D. Kovalskyi,[168] J. Krupa,[168] J. Lang,[168] L. Lavezzo,[168] Y.-J. Lee,[168] K. Long,[168] C. Mcginn,[168] A. Novak,[168] M. I. Park,[168] C. Paus,[168] C. Reissel,[168] C. Roland,[168] G. Roland,[168] S. Rothman,[168] T. A. Sheng,[168] G. S. F. Stephans,[168] D. Walter,[168] Z. Wang,[168] B. Wyslouch,[168] T. J. Yang,[168] B. Crossman,[169] C. Kapsiak,[169] M. Krohn,[169] D. Mahon,[169] J. Mans,[169] B. Marzocchi,[169] M. Revering,[169] R. Rusack,[169] O. Sancar,[169] R. Saradhy,[169] N. Strobbe,[169] K. Bloom,[170] D. R. Claes,[170] G. Haza,[170] J. Hossain,[170] C. Joo,[170] I. Kravchenko,[170] A. Rohilla,[170] J. E. Siado,[170] W. Tabb,[170] A. Vagnerini,[170] A. Wightman,[170] F. Yan,[170] D. Yu,[170] H. Bandyopadhyay,[171] L. Hay,[171] H. w. Hsia,[171] I. Iashvili,[171] A. Kalogeropoulos,[171] A. Kharchilava,[171] A. Mandal,[171] M. Morris,[171] D. Nguyen,[171] S. Rappoccio,[171] H. Rejeb Sfar,[171] A. Williams,[171] P. Young,[171] G. Alverson,[172] E. Barberis,[172] J. Bonilla,[172] B. Bylsma,[172] M. Campana,[172] J. Dervan,[172] Y. Haddad,[172] Y. Han,[172] I. Israr,[172] A. Krishna,[172] P. Levchenko,[172] J. Li,[172] M. Lu,[172] N. Manganelli,[172] R. Mccarthy,[172] D. M. Morse,[172] T. Orimoto,[172] A. Parker,[172] L. Skinnari,[172] C. S. Thoreson,[172] E. Tsai,[172] D. Wood,[172] S. Dittmer,[173] K. A. Hahn,[173] D. Li,[173] Y. Liu,[173] M. Mcginnis,[173] Y. Miao,[173] D. G. Monk,[173] M. H. Schmitt,[173] A. Taliercio,[173] M. Velasco,[173] J. Wang,[173] G. Agarwal,[174] R. Band,[174] R. Bucci,[174] S. Castells,[174] A. Das,[174] R. Goldouzian,[174] M. Hildreth,[174] K. Hurtado Anampa,[174] T. Ivanov,[174] C. Jessop,[174] A. Karneyeu,[174] K. Lannon,[174] J. Lawrence,[174] N. Loukas,[174] L. Lutton,[174] J. Mariano,[174] N. Marinelli,[174] I. Mcalister,[174] T. McCauley,[174] C. Mcgrady,[174] C. Moore,[174] Y. Musienko,[174,x] H. Nelson,[174] M. Osherson,[174] A. Piccinelli,[174] R. Ruchti,[174] A. Townsend,[174] Y. Wan,[174] M. Wayne,[174] H. Yockey,[174] M. Zarucki,[174] L. Zygala,[174] A. Basnet,[175] M. Carrigan,[175] R. De Los Santos,[175] L. S. Durkin,[175] C. Hill,[175] M. Joyce,[175] M. Nunez Ornelas,[175] K. Wei,[175] D. A. Wenzl,[175] B. L. Winer,[175] B. R. Yates,[175] H. Bouchamaoui,[176] K. Coldham,[176] P. Das,[176] G. Dezoort,[176] P. Elmer,[176] P. Fackeldey,[176] A. Frankenthal,[176]

B. Greenberg,[176] N. Haubrich,[176] K. Kennedy,[176] G. Kopp,[176] S. Kwan,[176] Y. Lai,[176] D. Lange,[176] A. Loeliger,[176] D. Marlow,[176] I. Ojalvo,[176] J. Olsen,[176] F. Simpson,[176] D. Stickland,[176] C. Tully,[176] L. H. Vage,[176] S. Malik,[177] R. Sharma,[177] A. S. Bakshi,[178] S. Chandra,[178] R. Chawla,[178] A. Gu,[178] L. Gutay,[178] M. Jones,[178] A. W. Jung,[178] M. Liu,[178] G. Negro,[178] N. Neumeister,[178] G. Paspalaki,[178] S. Piperov,[178] J. F. Schulte,[178] A. K. Virdi,[178] F. Wang,[178] A. Wildridge,[178] W. Xie,[178] Y. Yao,[178] Y. Zhong,[178] J. Dolen,[179] N. Parashar,[179] A. Pathak,[179] D. Acosta,[180] A. Agrawal,[180] T. Carnahan,[180] K. M. Ecklund,[180] P. J. Fernández Manteca,[180] S. Freed,[180] P. Gardner,[180] F. J. M. Geurts,[180] T. Huang,[180] I. Krommydas,[180] N. Lewis,[180] W. Li,[180] J. Lin,[180] O. Miguel Colin,[180] B. P. Padley,[180] R. Redjimi,[180] J. Rotter,[180] E. Yigitbasi,[180] Y. Zhang,[180] A. Bodek,[181] P. de Barbaro,[181] R. Demina,[181] J. L. Dulemba,[181] A. Garcia-Bellido,[181] H. S. Hare,[181] O. Hindrichs,[181] N. Parmar,[181] P. Parygin,[181,pppp] R. Taus,[181] B. Chiarito,[182] J. P. Chou,[182] S. V. Clark,[182] D. Gadkari,[182] Y. Gershtein,[182] E. Halkiadakis,[182] M. Heindl,[182] C. Houghton,[182] D. Jaroslawski,[182] S. Konstantinou,[182] I. Laflotte,[182] A. Lath,[182] J. Martins,[182] R. Montalvo,[182] K. Nash,[182] B. Rand,[182] J. Reichert,[182] P. Saha,[182] S. Salur,[182] S. Schnetzer,[182] S. Somalwar,[182] R. Stone,[182] S. A. Thayil,[182] S. Thomas,[182] J. Vora,[182] D. Ally,[183] A. G. Delannoy,[183] S. Fiorendi,[183] J. Harris,[183] S. Higginbotham,[183] T. Holmes,[183] A. R. Kanuganti,[183] N. Karunarathna,[183] J. Lawless,[183] L. Lee,[183] E. Nibigira,[183] S. Spanier,[183] D. Aebi,[184] M. Ahmad,[184] T. Akhter,[184] K. Androsov,[184] A. Bolshov,[184] O. Bouhali,[184,qqqq] R. Eusebi,[184] J. Gilmore,[184] T. Kamon,[184] H. Kim,[184] S. Luo,[184] R. Mueller,[184] A. Safonov,[184] N. Akchurin,[185] J. Damgov,[185] Y. Feng,[185] N. Gogate,[185] Y. Kazhykarim,[185] K. Lamichhane,[185] S. W. Lee,[185] C. Madrid,[185] A. Mankel,[185] T. Peltola,[185] I. Volobouev,[185] E. Appelt,[186] Y. Chen,[186] S. Greene,[186] A. Gurrola,[186] W. Johns,[186] R. Kunnawalkam Elayavalli,[186] A. Melo,[186] D. Rathjens,[186] F. Romeo,[186] P. Sheldon,[186] S. Tuo,[186] J. Velkovska,[186] J. Viinikainen,[186] B. Cardwell,[187] H. Chung,[187] B. Cox,[187] J. Hakala,[187] R. Hirosky,[187] M. Jose,[187] A. Ledovskoy,[187] C. Mantilla,[187] C. Neu,[187] C. Ramón Álvarez,[187] S. Bhattacharya,[188] P. E. Karchin,[188] A. Aravind,[189] S. Banerjee,[189] K. Black,[189] T. Bose,[189] E. Chavez,[189] S. Dasu,[189] P. Everaerts,[189] C. Galloni,[189] H. He,[189] M. Herndon,[189] A. Herve,[189] C. K. Koraka,[189] A. Lanaro,[189] S. Lomte,[189] R. Loveless,[189] A. Mallampalli,[189] A. Mohammadi,[189] S. Mondal,[189] G. Parida,[189] L. Pétré,[189] D. Pinna,[189] A. Savin,[189] V. Shang,[189] V. Sharma,[189] W. H. Smith,[189] D. Teague,[189] H. F. Tsoi,[189] W. Vetens,[189] A. Warden,[189] S. Afanasiev,[190] V. Alexakhin,[190] Yu. Andreev,[190] T. Aushev,[190] D. Budkouski,[190] R. Chistov,[190,rrrr] M. Danilov,[190,rrrr] T. Dimova,[190,rrrr] A. Ershov,[190,rrrr] S. Gninenko,[190] I. Golutvin,[190,a] I. Gorbunov,[190] A. Gribushin,[190,rrrr] V. Karjavine,[190] M. Kirsanov,[190] V. Klyukhin,[190,rrrr] O. Kodolova,[190,ssss,pppp] V. Korenkov,[190] A. Kozyrev,[190,rrrr] N. Krasnikov,[190] A. Lanev,[190] A. Malakhov,[190] V. Matveev,[190,rrrr] A. Nikitenko,[190,tttt,ssss] V. Palichik,[190] V. Perelygin,[190] S. Petrushanko,[190,rrrr] S. Polikarpov,[190,rrrr] O. Radchenko,[190,rrrr] M. Savina,[190] V. Shalaev,[190] S. Shmatov,[190] S. Shulha,[190] Y. Skovpen,[190,rrrr] V. Smirnov,[190] O. Teryaev,[190] I. Tlisova,[190,rrrr] A. Toropin,[190] N. Voytishin,[190] B. S. Yuldashev,[190,a,uuuu] A. Zarubin,[190] and I. Zhizhin[190]

(CMS Collaboration)

[1]*Yerevan Physics Institute, Yerevan, Armenia*
[2]*Institut für Hochenergiephysik, Vienna, Austria*
[3]*Universiteit Antwerpen, Antwerpen, Belgium*
[4]*Vrije Universiteit Brussel, Brussel, Belgium*
[5]*Université Libre de Bruxelles, Bruxelles, Belgium*
[6]*Ghent University, Ghent, Belgium*
[7]*Université Catholique de Louvain, Louvain-la-Neuve, Belgium*
[8]*Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[9]*Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*
[10]*Universidade Estadual Paulista, Universidade Federal do ABC, São Paulo, Brazil*
[11]*Institute for Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences, Sofia, Bulgaria*
[12]*University of Sofia, Sofia, Bulgaria*
[13]*Instituto De Alta Investigación, Universidad de Tarapacá, Casilla 7D, Arica, Chile*
[14]*Beihang University, Beijing, China*
[15]*Department of Physics, Tsinghua University, Beijing, China*

[16]*Institute of High Energy Physics, Beijing, China*
[17]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*
[18]*State Key Laboratory of Nuclear Physics and Technology, Institute of Quantum Matter, South China Normal University, Guangzhou, China*
[19]*Sun Yat-Sen University, Guangzhou, China*
[20]*University of Science and Technology of China, Hefei, China*
[21]*Nanjing Normal University, Nanjing, China*
[22]*Institute of Modern Physics and Key Laboratory of Nuclear Physics and Ion-beam Application (MOE)—Fudan University, Shanghai, China*
[23]*Zhejiang University, Hangzhou, Zhejiang, China*
[24]*Universidad de Los Andes, Bogota, Colombia*
[25]*Universidad de Antioquia, Medellin, Colombia*
[26]*University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia*
[27]*University of Split, Faculty of Science, Split, Croatia*
[28]*Institute Rudjer Boskovic, Zagreb, Croatia*
[29]*University of Cyprus, Nicosia, Cyprus*
[30]*Charles University, Prague, Czech Republic*
[31]*Escuela Politecnica Nacional, Quito, Ecuador*
[32]*Universidad San Francisco de Quito, Quito, Ecuador*
[33]*Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt*
[34]*Center for High Energy Physics (CHEP-FU), Fayoum University, El-Fayoum, Egypt*
[35]*National Institute of Chemical Physics and Biophysics, Tallinn, Estonia*
[36]*Department of Physics, University of Helsinki, Helsinki, Finland*
[37]*Helsinki Institute of Physics, Helsinki, Finland*
[38]*Lappeenranta-Lahti University of Technology, Lappeenranta, Finland*
[39]*IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France*
[40]*Laboratoire Leprince-Ringuet, CNRS/IN2P3, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France*
[41]*Université de Strasbourg, CNRS, IPHC UMR 7178, Strasbourg, France*
[42]*Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France*
[43]*Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France*
[44]*Georgian Technical University, Tbilisi, Georgia*
[45]*RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany*
[46]*RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany*
[47]*RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany*
[48]*Deutsches Elektronen-Synchrotron, Hamburg, Germany*
[49]*University of Hamburg, Hamburg, Germany*
[50]*Karlsruher Institut fuer Technologie, Karlsruhe, Germany*
[51]*Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece*
[52]*National and Kapodistrian University of Athens, Athens, Greece*
[53]*National Technical University of Athens, Athens, Greece*
[54]*University of Ioánnina, Ioánnina, Greece*
[55]*HUN-REN Wigner Research Centre for Physics, Budapest, Hungary*
[56]*MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary*
[57]*Faculty of Informatics, University of Debrecen, Debrecen, Hungary*
[58]*HUN-REN ATOMKI—Institute of Nuclear Research, Debrecen, Hungary*
[59]*Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary*
[60]*Panjab University, Chandigarh, India*
[61]*University of Delhi, Delhi, India*
[62]*Indian Institute of Technology Kanpur, Kanpur, India*
[63]*Saha Institute of Nuclear Physics, HBNI, Kolkata, India*
[64]*Indian Institute of Technology Madras, Madras, India*
[65]*Tata Institute of Fundamental Research-A, Mumbai, India*
[66]*Tata Institute of Fundamental Research-B, Mumbai, India*
[67]*National Institute of Science Education and Research, An OCC of Homi Bhabha National Institute, Bhubaneswar, Odisha, India*
[68]*Indian Institute of Science Education and Research (IISER), Pune, India*
[69]*Isfahan University of Technology, Isfahan, Iran*
[70]*Institute for Research in Fundamental Sciences (IPM), Tehran, Iran*
[71]*University College Dublin, Dublin, Ireland*
[72a]*INFN Sezione di Bari, Bari, Italy*

[72b]*Università di Bari, Bari, Italy*
[72c]*Politecnico di Bari, Bari, Italy*
[73a]*INFN Sezione di Bologna, Bologna, Italy*
[73b]*Università di Bologna, Bologna, Italy*
[74a]*INFN Sezione di Catania, Catania, Italy*
[74b]*Università di Catania, Catania, Italy*
[75a]*INFN Sezione di Firenze, Firenze, Italy*
[75b]*Università di Firenze, Firenze, Italy*
[76]*INFN Laboratori Nazionali di Frascati, Frascati, Italy*
[77a]*INFN Sezione di Genova, Genova, Italy*
[77b]*Università di Genova, Genova, Italy*
[78a]*INFN Sezione di Milano-Bicocca, Milano, Italy*
[78b]*Università di Milano-Bicocca, Milano, Italy*
[79a]*INFN Sezione di Napoli, Napoli, Italy*
[79b]*Università di Napoli "Federico II," Napoli, Italy*
[79c]*Università della Basilicata, Potenza, Italy*
[79d]*Scuola Superiore Meridionale (SSM), Napoli, Italy*
[80a]*INFN Sezione di Padova, Padova, Italy*
[80b]*Università di Padova, Padova, Italy*
[81a]*INFN Sezione di Pavia, Pavia, Italy*
[81b]*Università di Pavia, Pavia, Italy*
[82a]*INFN Sezione di Perugia, Perugia, Italy*
[82b]*Università di Perugia, Perugia, Italy*
[83a]*INFN Sezione di Pisa, Pisa, Italy*
[83b]*Università di Pisa, Pisa, Italy*
[83c]*Scuola Normale Superiore di Pisa, Pisa, Italy*
[83d]*Università di Siena, Siena, Italy*
[84a]*INFN Sezione di Roma, Roma, Italy*
[84b]*Sapienza Università di Roma, Roma, Italy*
[85a]*INFN Sezione di Torino, Torino, Italy*
[85b]*Università di Torino, Torino, Italy*
[85c]*Università del Piemonte Orientale, Novara, Italy*
[86a]*INFN Sezione di Trieste, Trieste, Italy*
[86b]*Università di Trieste, Trieste, Italy*
[87]*Kyungpook National University, Daegu, Korea*
[88]*Department of Mathematics and Physics—GWNU, Gangneung, Korea*
[89]*Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea*
[90]*Hanyang University, Seoul, Korea*
[91]*Korea University, Seoul, Korea*
[92]*Kyung Hee University, Department of Physics, Seoul, Korea*
[93]*Sejong University, Seoul, Korea*
[94]*Seoul National University, Seoul, Korea*
[95]*University of Seoul, Seoul, Korea*
[96]*Yonsei University, Department of Physics, Seoul, Korea*
[97]*Sungkyunkwan University, Suwon, Korea*
[98]*College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait*
[99]*Kuwait University—College of Science—Department of Physics, Safat, Kuwait*
[100]*Riga Technical University, Riga, Latvia*
[101]*University of Latvia (LU), Riga, Latvia*
[102]*Vilnius University, Vilnius, Lithuania*
[103]*National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia*
[104]*Universidad de Sonora (UNISON), Hermosillo, Mexico*
[105]*Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico*
[106]*Universidad Iberoamericana, Mexico City, Mexico*
[107]*Benemerita Universidad Autonoma de Puebla, Puebla, Mexico*
[108]*University of Montenegro, Podgorica, Montenegro*
[109]*University of Canterbury, Christchurch, New Zealand*
[110]*National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan*
[111]*AGH University of Krakow, Krakow, Poland*
[112]*National Centre for Nuclear Research, Swierk, Poland*

[113]Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[114]Warsaw University of Technology, Warsaw, Poland
[115]Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
[116]Faculty of Physics, University of Belgrade, Belgrade, Serbia
[117]VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[118]Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[119]Universidad Autónoma de Madrid, Madrid, Spain
[120]Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
[121]Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[122]University of Colombo, Colombo, Sri Lanka
[123]University of Ruhuna, Department of Physics, Matara, Sri Lanka
[124]CERN, European Organization for Nuclear Research, Geneva, Switzerland
[125]PSI Center for Neutron and Muon Sciences, Villigen, Switzerland
[126]ETH Zurich—Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
[127]Universität Zürich, Zurich, Switzerland
[128]National Central University, Chung-Li, Taiwan
[129]National Taiwan University (NTU), Taipei, Taiwan
[130]High Energy Physics Research Unit, Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok, Thailand
[131]Tunis El Manar University, Tunis, Tunisia
[132]Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
[133]Middle East Technical University, Physics Department, Ankara, Turkey
[134]Bogazici University, Istanbul, Turkey
[135]Istanbul Technical University, Istanbul, Turkey
[136]Istanbul University, Istanbul, Turkey
[137]Yildiz Technical University, Istanbul, Turkey
[138]Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine
[139]National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine
[140]University of Bristol, Bristol, United Kingdom
[141]Rutherford Appleton Laboratory, Didcot, United Kingdom
[142]Imperial College, London, United Kingdom
[143]Brunel University, Uxbridge, United Kingdom
[144]Baylor University, Waco, Texas, USA
[145]Catholic University of America, Washington, DC, USA
[146]The University of Alabama, Tuscaloosa, Alabama, USA
[147]Boston University, Boston, Massachusetts, USA
[148]Brown University, Providence, Rhode Island, USA
[149]University of California, Davis, Davis, California, USA
[150]University of California, Los Angeles, California, USA
[151]University of California, Riverside, Riverside, California, USA
[152]University of California, San Diego, La Jolla, California, USA
[153]University of California, Santa Barbara—Department of Physics, Santa Barbara, California, USA
[154]California Institute of Technology, Pasadena, California, USA
[155]Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
[156]University of Colorado Boulder, Boulder, Colorado, USA
[157]Cornell University, Ithaca, New York, USA
[158]Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[159]University of Florida, Gainesville, Florida, USA
[160]Florida State University, Tallahassee, Florida, USA
[161]Florida Institute of Technology, Melbourne, Florida, USA
[162]University of Illinois Chicago, Chicago, Illinois, USA
[163]The University of Iowa, Iowa City, Iowa, USA
[164]Johns Hopkins University, Baltimore, Maryland, USA
[165]The University of Kansas, Lawrence, Kansas, USA
[166]Kansas State University, Manhattan, Kansas, USA
[167]University of Maryland, College Park, Maryland, USA
[168]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[169]University of Minnesota, Minneapolis, Minnesota, USA
[170]University of Nebraska-Lincoln, Lincoln, Nebraska, USA
[171]State University of New York at Buffalo, Buffalo, New York, USA
[172]Northeastern University, Boston, Massachusetts, USA

[173]*Northwestern University, Evanston, Illinois, USA*
[174]*University of Notre Dame, Notre Dame, Indiana, USA*
[175]*The Ohio State University, Columbus, Ohio, USA*
[176]*Princeton University, Princeton, New Jersey, USA*
[177]*University of Puerto Rico, Mayaguez, Puerto Rico, USA*
[178]*Purdue University, West Lafayette, Indiana, USA*
[179]*Purdue University Northwest, Hammond, Indiana, USA*
[180]*Rice University, Houston, Texas, USA*
[181]*University of Rochester, Rochester, New York, USA*
[182]*Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA*
[183]*University of Tennessee, Knoxville, Tennessee, USA*
[184]*Texas A&M University, College Station, Texas, USA*
[185]*Texas Tech University, Lubbock, Texas, USA*
[186]*Vanderbilt University, Nashville, Tennessee, USA*
[187]*University of Virginia, Charlottesville, Virginia, USA*
[188]*Wayne State University, Detroit, Michigan, USA*
[189]*University of Wisconsin—Madison, Madison, Wisconsin, USA*
[190]*Authors affiliated with an institute covered by a cooperation agreement with CERN*

[a]Deceased.
[b]Also at Yerevan State University, Yerevan, Armenia.
[c]Also at TU Wien, Vienna, Austria.
[d]Also at Ghent University, Ghent, Belgium.
[e]Also at Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil.
[f]Also at FACAMP—Faculdades de Campinas, Sao Paulo, Brazil.
[g]Also at Universidade Estadual de Campinas, Campinas, Brazil.
[h]Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
[i]Also at University of Chinese Academy of Sciences, Beijing, China.
[j]Also at China Center of Advanced Science and Technology, Beijing, China.
[k]Also at University of Chinese Academy of Sciences, Beijing, China.
[l]Also at China Spallation Neutron Source, Guangdong, China.
[m]Present address: Henan Normal University, Xinxiang, China.
[n]Also at University of Shanghai for Science and Technology, Shanghai, China.
[o]Present address: The University of Iowa, Iowa City, Iowa, USA.
[p]Also at Center for High Energy Physics, Peking University, Beijing, China.
[q]Also at Helwan University, Cairo, Egypt.
[r]Present address: Zewail City of Science and Technology, Zewail, Egypt.
[s]Present address: British University in Egypt, Cairo, Egypt.
[t]Present address: Cairo University, Cairo, Egypt.
[u]Also at Purdue University, West Lafayette, Indiana, USA.
[v]Also at Université de Haute Alsace, Mulhouse, France.
[w]Also at Istinye University, Istanbul, Turkey.
[x]Also at an institute formerly covered by a cooperation agreement with CERN.
[y]Also at The University of the State of Amazonas, Manaus, Brazil.
[z]Also at University of Hamburg, Hamburg, Germany.
[aa]Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[bb]Also at Bergische University Wuppertal (BUW), Wuppertal, Germany.
[cc]Also at Brandenburg University of Technology, Cottbus, Germany.
[dd]Also at Forschungszentrum Jülich, Juelich, Germany.
[ee]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[ff]Also at HUN-REN ATOMKI—Institute of Nuclear Research, Debrecen, Hungary.
[gg]Present address: Universitatea Babes-Bolyai—Facultatea de Fizica, Cluj-Napoca, Romania.
[hh]Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[ii]Also at HUN-REN Wigner Research Centre for Physics, Budapest, Hungary.
[jj]Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
[kk]Also at Punjab Agricultural University, Ludhiana, India.
[ll]Also at University of Visva-Bharati, Santiniketan, India.
[mm]Also at Indian Institute of Science (IISc), Bangalore, India.
[nn]Also at Amity University Uttar Pradesh, Noida, India.
[oo]Also at UPES—University of Petroleum and Energy Studies, Dehradun, India.

[pp]Also at IIT Bhubaneswar, Bhubaneswar, India.
[qq]Also at Institute of Physics, Bhubaneswar, India.
[rr]Also at University of Hyderabad, Hyderabad, India.
[ss]Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[tt]Also at Isfahan University of Technology, Isfahan, Iran.
[uu]Also at Sharif University of Technology, Tehran, Iran.
[vv]Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
[ww]Also at Department of Physics, Faculty of Science, Arak University, Arak, Iran.
[xx]Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
[yy]Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
[zz]Also at Università degli Studi Guglielmo Marconi, Roma, Italy.
[aaa]Also at Scuola Superiore Meridionale, Università di Napoli "Federico II," Napoli, Italy.
[bbb]Also at Fermi National Accelerator Laboratory, Batavia, Illinois, USA.
[ccc]Also at Lulea University of Technology, Lulea, Sweden.
[ddd]Also at Consiglio Nazionale delle Ricerche—Istituto Officina dei Materiali, Perugia, Italy.
[eee]Also at Institut de Physique des 2 Infinis de Lyon (IP2I), Villeurbanne, France.
[fff]Also at Department of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Malaysia.
[ggg]Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
[hhh]Also at INFN Sezione di Torino, Università di Torino, Torino, Italy and Università del Piemonte Orientale, Novara, Italy.
[iii]Also at Trincomalee Campus, Eastern University, Nilaveli, Sri Lanka.
[jjj]Also at Saegis Campus, Nugegoda, Sri Lanka.
[kkk]Also at National and Kapodistrian University of Athens, Athens, Greece.
[lll]Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
[mmm]Also at Universität Zürich, Zurich, Switzerland.
[nnn]Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
[ooo]Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
[ppp]Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
[qqq]Also at Konya Technical University, Konya, Turkey.
[rrr]Also at Izmir Bakircay University, Izmir, Turkey.
[sss]Also at Adiyaman University, Adiyaman, Turkey.
[ttt]Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey.
[uuu]Also at Marmara University, Istanbul, Turkey.
[vvv]Also at Milli Savunma University, Istanbul, Turkey.
[www]Also at Kafkas University, Kars, Turkey.
[xxx]Present address: Istanbul Okan University, Istanbul, Turkey.
[yyy]Also at Hacettepe University, Ankara, Turkey.
[zzz]Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
[aaaa]Also at Istanbul University—Cerrahpasa, Faculty of Engineering, Istanbul, Turkey.
[bbbb]Also at Yildiz Technical University, Istanbul, Turkey.
[cccc]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[dddd]Also at Monash University, Faculty of Science, Clayton, Australia.
[eeee]Also at Università di Torino, Torino, Italy.
[ffff]Also at Bethel University, St. Paul, Minnesota, USA.
[gggg]Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
[hhhh]Also at California Institute of Technology, Pasadena, California, USA.
[iiii]Also at United States Naval Academy, Annapolis, Maryland, USA.
[jjjj]Also at Ain Shams University, Cairo, Egypt.
[kkkk]Also at Bingol University, Bingol, Turkey.
[llll]Also at Georgian Technical University, Tbilisi, Georgia.
[mmmm]Also at Sinop University, Sinop, Turkey.
[nnnn]Also at Erciyes University, Kayseri, Turkey.
[oooo]Also at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania.
[pppp]Present address: Another institute formerly covered by a cooperation agreement with CERN.
[qqqq]Also at Texas A&M University at Qatar, Doha, Qatar.
[rrrr]Also at another institute formerly covered by a cooperation agreement with CERN.
[ssss]Also at Yerevan Physics Institute, Yerevan, Armenia.
[tttt]Also at Imperial College, London, United Kingdom.
[uuuu]Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.