Azimuthal Correlations within Exclusive Dijets with Large Momentum Transfer in Photon-Lead Collisions

A. Tumasyan *et al.*[*]
(CMS Collaboration)

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The structure of nucleons is multidimensional and depends on the transverse momenta, spatial geometry, and polarization of the constituent partons. Such a structure can be studied using high-energy photons produced in ultraperipheral heavy-ion collisions. The first measurement of the azimuthal angular correlations of exclusively produced events with two jets in photon-lead interactions at large momentum transfer is presented, a process that is considered to be sensitive to the underlying nuclear gluon polarization. This study uses a data sample of ultraperipheral lead-lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, corresponding to an integrated luminosity of 0.38 nb^{-1}, collected with the CMS experiment at the LHC. The measured second harmonic of the correlation between the sum and difference of the two jet transverse momentum vectors is found to be positive, and rising, as the dijet transverse momentum increases. A well-tuned model that has been successful at describing a wide range of proton scattering data from the HERA experiments fails to describe the observed correlations, suggesting the presence of gluon polarization effects.

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Considerable experimental and theoretical effort is being devoted to the study of the momentum distribution of gluons in nuclei [1,2]. The aim of such studies is to determine whether the distribution of low momentum gluons saturates, constituting a new state of matter. Accumulating evidence since early studies at BNL RHIC [3–6] points to a reduction of the density of low momentum gluons in heavy nuclei, as compared to the density in individual protons, at high energies. While experimental work has so far focused on one-dimensional studies, the gluon distribution is intrinsically multidimensional, depending on radial distance to the nucleus center, transverse momentum, and polarization [7].

Recent theoretical studies relate the polarization of gluons within nuclei to angular correlations of final-state jets produced in photon-hadron interactions [8–19]. The cross section for diffractive dijet production depends on the orientation of the quark-antiquark color dipole with respect to the radial distance. This orientation dependence results in an azimuthal decorrelation of the nominally back-to-back jets that comprise the dijet. The nature of gluon polarization in nuclei is of great interest, yet remains almost completely unexplored. While the gluon polarization density matrices have been theoretically classified, estimates of the magnitude of gluon polarization effects vary widely [8–16]. Theory predicts that the distribution of elliptically polarized gluons [12] can be probed with the second Fourier moment $\langle \cos(2\Phi) \rangle$ of the distribution of the azimuthal angle Φ between the sum and the difference of the two jet transverse momentum vectors of a dijet [9]. In this approach, the observed moment measures a fundamental correlation of gluon polarizations with their transverse momenta.

After a preliminary version of the current results was shown, a calculation based on final-state radiation was found to result in a nonzero value for this harmonic, giving an alternative explanation for any observed correlations [20]. Initial-state radiation from parton showers could also lead to a decorrelation. Experimental measurements are essential to resolve the possible effects and to gain insight into the magnitude of gluon polarization within nuclei.

Photon-nucleus interactions can be produced using ultrarelativistic heavy-ion beams. At the CERN Large Hadron Collider, high-energy lead (Pb) beams produce a large flux of virtual photons that can interact with an oncoming lead nucleus [21–23], in so-called ultraperipheral heavy-ion collisions (UPCs). The CMS Collaboration has recently studied UPC exclusive vector meson photoproduction and photon-photon scattering [24–27]. The ALICE, ATLAS, and LHCb Collaborations have also recently reported on UPC measurements [28–30]. The CDF and ZEUS Collaborations have studied exclusive dijet production in proton-antiproton [31] and diffractive electron-proton collisions [32], respectively. While there are no published results on dijet production in photon-nucleus interactions, this

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

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process has generated considerable interest in the context of the future Electron-Ion Collider [2].

This Letter reports on the first measurement of $\langle\cos(2\Phi)\rangle$ for exclusive dijet events produced at large momentum transfer and with a large rapidity gap in photon-lead collisions. In such events, the dijet and the incoming photon are typically moving in the same direction and are produced when the incoming photon fluctuates into a small color dipole, in comparison to the size of the nucleus. This dipole can then probe the interior of the Pb nucleus. Tabulated results are provided in the HEPData record for this analysis [33].

The central feature of the CMS apparatus is a superconducting solenoid of 6m 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 (ECAL), and a brass and scintillator hadron calorimeter (HCAL). ECAL provides coverage in pseudorapidity $|\eta| < 1.48$ in a barrel region and $1.48 < |\eta| < 3.0$ in two end cap (EE) regions, while HCAL covers $|\eta| < 1.3$ for the barrel and $1.3 < |\eta| < 3.0$ for the two end cap (HE) sections, respectively. Detector elements in ECAL and HCAL are grouped into "towers." Hadron forward (HF) calorimeters extend the η coverage provided by the barrel and end cap detectors to $3.0 < |\eta| < 5.2$. The data sample is collected with a two-level trigger system [34]: at the hardware level, events are selected by custom hardware processors, while a subsequent software trigger uses fast versions of the off-line reconstruction code. A 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. [35].

The analysis uses a data sample of lead-lead collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV corresponding to an integrated luminosity of 0.38 nb^{-1} collected in fall 2015. The average number of inelastic PbPb collisions per bunch crossing is about 0.01. Events are selected with a dedicated trigger designed to record a wide variety of photon-lead processes. The hardware trigger requires a transverse energy of at least 5 GeV in any of the ECAL towers, and at least one of the two HF calorimeters is required to not have a signal above the noise threshold. The software-based trigger requires at least one reconstructed track in the pixel detector. Since the charged particle multiplicities are low, events are reconstructed in the same way as if they were pp collisions [36]. The primary vertex is required to be within 20 cm of the nominal center of the detector along the beam direction.

By combining information from all subdetectors, a particle-flow (PF) algorithm [37] attempts to identify all stable particles in an event, classifying them as electrons, muons, photons, and charged or neutral hadrons. Jets are reconstructed from these PF candidates using the anti-k_T algorithm [38] with a distance parameter of 0.4, as implemented in the FASTJET package [39]. The jet energy is calibrated by applying a multiplicative factor to relate, on average, the energy of the detector jet to that of the corresponding generator-level particle jet (energy scale correction). The leading (subleading) jet is required to have a $p_T > 30(20)$ GeV.

The symmetry of the PbPb system leads to dijet events where the jets can travel in either direction through CMS. For the events of interest, the dijet is expected to be predominantly in the photon direction. This is taken as the "forward" direction. Events that have any additional jets with $p_T > 20$ GeV in either the forward or backward direction are rejected. While the expected yield for three jet events is negligible, dijet events with a nonjet-related PF candidate of more than 6 GeV in the forward hemisphere are rejected. Events are discarded if they have an energy deposit in any of the calorimeter towers in the forward and backward rapidity hemispheres above the noise threshold (3.9, 3.0 and 3.2 GeV in HF, HE and EE, respectively) [27].

Diffractive dijets are characterized by events with a large rapidity gap. A pseudorapidity gap is defined with $\Delta\eta^F = 2.4 - \eta_{\mathrm{max}}$, where 2.4 is the upper limit of the tracker and η_{max} is the maximum pseudorapidity of any high-purity charged track as defined in Ref. [40] and having $p_T > 0.2$ GeV. A similar backward pseudorapidity gap $\Delta\eta^B$ is defined for the opposite η hemisphere. It is required that $\Delta\eta^B > \Delta\eta^F$ and that $\Delta\eta^B$ is greater than 1.2, effectively selecting dijet events that are located in the forward direction with a large rapidity gap as measured using the tracker. Finally, one of the jets must be within one unit of pseudorapidity of the track defining the backward rapidity gap. Event samples with the dijet detected in either hemisphere of CMS are statistically independent and consistent with each other within 1% for the $\langle\cos(2\Phi)\rangle$ value. The samples are combined using the convention for defining the forward direction as described above. This means that we invert the rapidity sign for the sample having a backward going dijet. A total of 6785 dijet events remain after applying the above requirements.

In this analysis, the RAPGAP (version 3.303) [41] Monte Carlo (MC) generator, which was developed to explore electron-proton (ep) collisions, is used for comparisons with the experimental results, for detector acceptance and resolution corrections, and for studying sources of systematic uncertainties. The exclusive dijet production model used in RAPGAP is based on the boson-gluon fusion process for diffractive electron-proton collisions, supplemented with initial and final-state parton showers. The diffractive parton distribution functions are set to the "H1 2006 fit-A" model. Finally, the generated photon energy spectrum has been reweighted to follow that of the Weizsacker-Williams photon flux distribution in lead nuclei described in Ref. [42]. The simulated events are processed and reconstructed in the same way as the collision data. GEANT4 [43] is used to account for the detector response. For the simulated events, 94% have the interacting photon and the dijet in the same hemisphere and, of these, 99% pass the selection criteria described above.

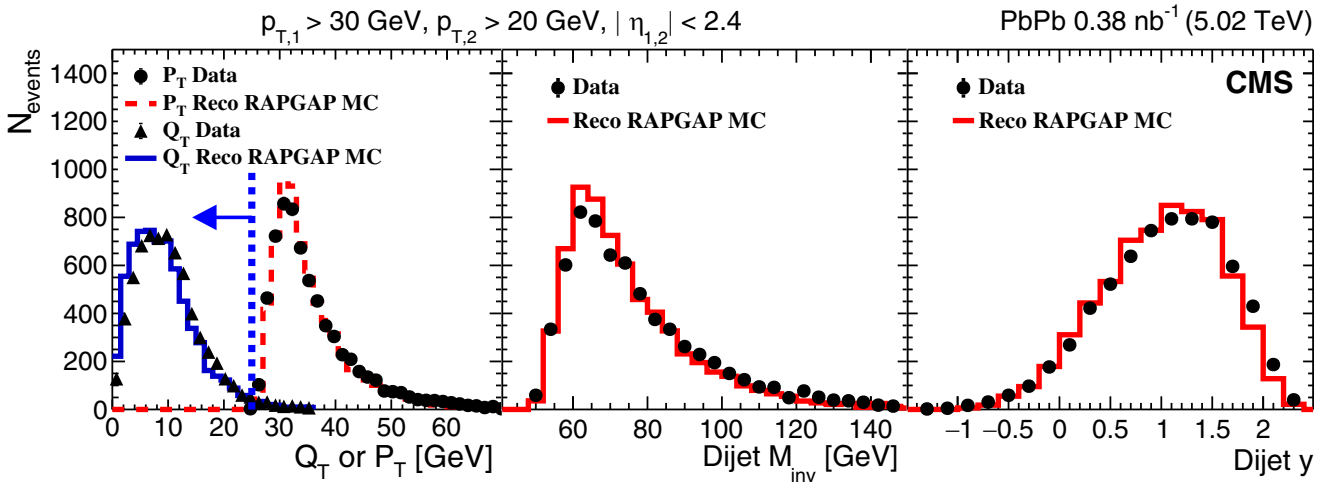


FIG. 1. Magnitudes of the vector sum (Q_T) and vector difference (P_T) of the two jets (left). The dashed blue line illustrates the $Q_T < 25$ GeV requirement. Invariant mass (center) and rapidity (right) of the dijet candidates after all selection requirements. The lines show the RAPGAP MC generated events including detector resolution effects. The statistical uncertainties are covered by the symbol size.

Based on the transverse momenta of the two jets relative to the beam axis, $\vec{p}_{T,1}$ and $\vec{p}_{T,2}$, the vector sum $\vec{Q}_T$ and vector difference $\vec{P}_T$ are defined, with $\vec{Q}_T = \vec{p}_{T,1} + \vec{p}_{T,2}$ and $\vec{P}_T = \frac{1}{2}(\vec{p}_{T,1} - \vec{p}_{T,2})$ [8]. Theoretical calculations have focused on the "back-to-back" regime, i.e., $P_T > Q_T$ [44]. This requirement results in the rejection of 47 events (0.7% of the sample). Figure 1 shows the distributions of dijet Q_T, P_T, invariant mass, and rapidity for both data and reconstructed MC events. The good agreement between data and MC for the invariant mass and rapidity distributions suggests that the rescaling of the photon flux from ep to PbPb is reasonable. The measured Q_T distribution has its maximum at 9 GeV, which is well within the large momentum transfer regime.

To calculate the second moment of the azimuthal angle anisotropy $\langle\cos(2\Phi)\rangle$, the angle Φ is obtained from the relation $\vec{P}_T \cdot \vec{Q}_T = |\vec{P}_T||\vec{Q}_T|\cos(\Phi)$. For the angular correlation measurements, the $\vec{p}_{T,1}$ and $\vec{p}_{T,2}$ vectors used to calculate $\vec{Q}_T$ and $\vec{P}_T$ are assigned randomly to the leading and subleading jets on an event-by-event basis. The dijet angular correlations are distorted compared to the underlying distributions by the acceptance and finite resolution of the detector. To correct for these effects, an unfolding procedure is used to estimate the parton-level distributions. The TUNFOLD [45] software package with the Tikhonov regularization method is used, where the strength of the regularization parameter is determined with the L-curve scan method by minimizing the average global correlation coefficient. The response matrix is evaluated by using simulated dijet events that pass all of the analysis requirements. The unfolding of the $dN/d\Phi$ distribution is performed for five equal intervals in $0 < Q_T < 25$ GeV. The $\langle\cos(2\Phi)\rangle$ value is then calculated as a function of Q_T.

The following sources of systematic uncertainties on $\langle\cos(2\Phi)\rangle$ are considered: jet energy scale (JES) correction, JES nonclosure (JESNC), jet energy resolution (JER), jet η resolution (JPR), jet azimuthal angular resolution (JAR), trigger efficiency (TR), and the purity estimation (PUR). The uncertainty in the JES is 2% for jets with p_T of 20 GeV, as reported in Refs. [36,46]. After the nominal correction factors are applied, a small nonclosure remains between the generator-level JES and that of the reconstructed jets. The systematic uncertainty from this effect is estimated by applying first a residual correction to the JES in simulation and then the dedicated selection requirements. The deviation from the nominal result is taken as an estimate of the systematic uncertainty. The simulation provides a JER of 14% for 20 GeV jets, decreasing slightly as a function of jet p_T, consistent with Refs. [36,46]. The JAR and JPR are found to be $0.025 \pm 0.005(\text{stat})$ and $0.015 \pm 0.005(\text{stat})$, respectively, and are almost independent of p_T and η in the phase space relevant to this measurement. The uncertainties related to JER and JAR are estimated from the differences between the resolution in data and MC as done in Ref. [46]. For this estimate, the detector-level jets in the simulation are broadened in order to account for the observed resolution in data. The $\langle\cos(2\Phi)\rangle$ uncertainty related to the JPR is found to be negligible.

The uncertainty related to the purity of the signal (PUR) is estimated by varying the nominal pseudorapidity gap requirement between 0 and 2, and by varying the requirement for the minimal distance in pseudorapidity between the track defining the backward pseudorapidity gap and the nearest jet, which has a nominal value of 1.0, from 0.8 to 1.2. Increasing the threshold on the total energy of the PF candidates outside the jet cones from 6.0 to 6.6 GeV has a

TABLE I. Table of $\langle\cos(2\Phi)\rangle$ systematic uncertainties (absolute values). The individual components are discussed in the text.

Q_T (GeV)	JES	JESNC	JER	JAR	PUR	TR	Total
0–5	0.018	0.004	0.002	0.004	0.002	0.004	0.019
5–10	0.012	0.006	0.005	0.003	0.002	0.003	0.015
10–15	0.010	0.008	0.007	0.002	0.002	0.001	0.014
15–20	0.009	0.008	0.014	0.002	0.002	0.001	0.018
20–25	0.005	0.018	0.056	0.001	0.002	0.002	0.059

negligible effect on the purity uncertainty. The uncertainty associated with the trigger efficiency is related to the component that requires the transverse energy in one of the ECAL towers to be larger than 5 GeV. This requirement tends to slightly increase the fraction of electromagnetic energy in the jets. To account for this effect, simulated events are weighted by the trigger efficiency as a function of jet p_T on an event-by-event basis. This weighting reproduces the effect of the trigger efficiency on the measured $\langle\cos(2\Phi)\rangle$ values. The other elements forming the trigger, discussed above, are fully efficient. The uncertainties related to the calorimeter exclusivity selections and to the unfolding procedure are negligible. The various components of the $\langle\cos(2\Phi)\rangle$ distribution systematic uncertainties are summarized in Table I.

Figure 2 (left) shows the unfolded angular distribution $dN/d\Phi$ for $Q_T < 25$ GeV. The $dN/d\Phi$ distribution peaks at 0 and π, implying a positive value of $\langle\cos(2\Phi)\rangle$. This phenomenon is not a trivial acceptance effect as demonstrated by performing the analysis upon pairs of jets from different events, yielding the expected negative value of $\langle\cos(2\Phi)\rangle$ [13]. Figure 2 (right) shows that $\langle\cos(2\Phi)\rangle$ rises steadily with Q_T. The data have been compared to two different calculations that ignore the effect of elliptically polarized gluons. A calculation by Hatta *et al.* [20], which assumes soft gluon radiation from final-state jets as the dominant effect of the azimuthal anisotropy, has $\langle\cos(2\Phi)\rangle$ initially rising, but then plateauing for $Q_T > 1$ GeV. A calculation based on the RAPGAP model [41], which is tuned to HERA results, predicts that $\langle\cos(2\Phi)\rangle$ rises with Q_T, but overshoots the data by a factor of 3–5. The Dokshitzer-Gribov-Lipatov-Altarelli-Parisi–based initial-state parton shower in RAPGAP produces a finite transverse momentum of the incoming parton, and this leads to a decorrelation of the resulting dijet constituents. Such decorrelations are also observed in data for the azimuthal angular difference between two jets in proton-proton collisions [19] and are qualitatively described by parton shower production. The decorrelation observed here can also be driven by parton showers, but since heavy ions are involved, there could be further decorrelation effects at small Bjorken x, which are not simulated in RAPGAP. Such broadening of the azimuthal distribution for dijet events has been linked to gluon saturation effects when comparing

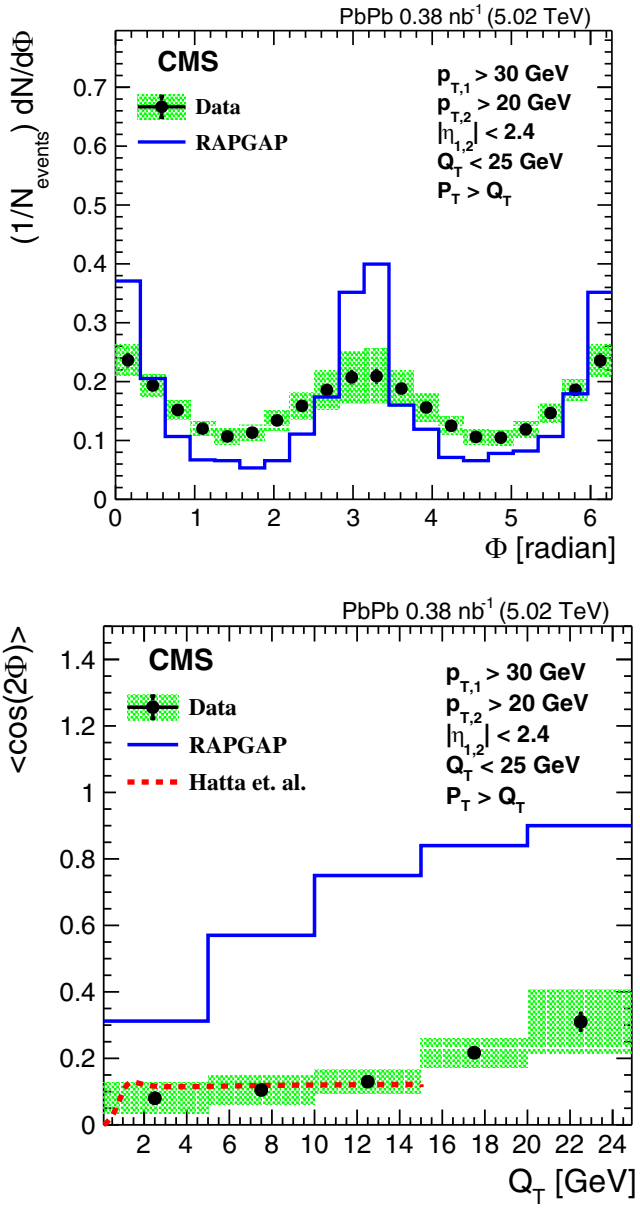


FIG. 2. The unfolded $1/N_{\text{events}} dN/d\Phi$ distribution (upper) and the unfolded $\langle\cos(2\Phi)\rangle$ values as a function of Q_T (lower). The corresponding distributions from the RAPGAP simulation at the generator level (blue lines) and theoretical calculation by Hatta *et al.* [20] for $\langle\cos(2\Phi)\rangle$ (red dashed lines) are also shown for $Q_T < 15$ GeV, consistent with the back-to-back limit in their calculation. The dijet events are found predominantly in the forward direction, with $0 < \eta_{\text{jet}} < 2.4$. Both the statistical (error bars) and systematic (green boxes) uncertainties are shown.

proton-lead to proton-proton events [47]. The broadening claimed in this analysis corresponds to the comparison between photon-lead (data) and photon-proton (RAPGAP) interactions.

In summary, the exclusive production of two jets in photon-lead interactions with a large rapidity gap has been studied for the first time. The dijet events are characterized

by a large momentum transfer. The second harmonic of the angular correlation between the sum and difference of the two jet transverse momenta is found to be positive and rising, with dijet transverse momentum in the measured range 0–25 GeV. An *a posteriori* calculation that includes the effect of soft gluons from final-state radiation describes the average magnitude of the correlations, but does not rise with the magnitude of the dijet total momentum Q_T to the extent found with the CMS data. A model [41] that has been successful at describing a wide range of proton scattering data from the HERA experiments overestimates the strength of the correlations, suggesting the presence of gluon polarization effects. This experiment calls for new theoretical calculations to quantify the theoretical implications and opens a new direction for probing the high-energy limit of strong interactions.

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[1] J. L. Albacete and C. Marquet, Gluon saturation and initial conditions for relativistic heavy ion collisions, Prog. Part. Nucl. Phys. **76**, 1 (2014).

[2] R. Abdul Khalek *et al.*, Science requirements and detector concepts for the Electron-Ion Collider: EIC yellow report, Nucl. Phys. **A1026**, 122447 (2022).

[3] I. Arsene *et al.* (BRAHMS Collaboration), Evolution of the Nuclear Modification Factors with Rapidity and Centrality in $d+\mathrm{Au}$ Collisions at $\sqrt{s_{\mathrm{NN}}}=200$ GeV, Phys. Rev. Lett. **93**, 242303 (2004).

[4] J. Adams *et al.* (STAR Collaboration), Forward Neutral Pion Production in $p+p$ and $d+\mathrm{Au}$ Collisions at $\sqrt{s_{\mathrm{NN}}}=200$ GeV, Phys. Rev. Lett. **97**, 152302 (2006).

[5] A. Adare *et al.* (PHENIX Collaboration), Suppression of Back-to-Back Hadron Pairs at Forward Rapidity in $d+\mathrm{Au}$ Collisions at $\sqrt{s_{\mathrm{NN}}}=200$ GeV, Phys. Rev. Lett. **107**, 172301 (2011).

[6] B. Alver *et al.* (PHOBOS Collaboration), High Transverse Momentum Triggered Correlations over a Large Pseudorapidity Acceptance in $\mathrm{Au}+\mathrm{Au}$ Collisions at $\sqrt{s_{\mathrm{NN}}}=200$ GeV, Phys. Rev. Lett. **104**, 062301 (2010).

[7] M. Diehl, Introduction to GPDs and TMDs, Eur. Phys. J. A **52**, 149 (2016).

[8] T. Altinoluk, N. Armesto, G. Beuf, and A. H. Rezaeian, Diffractive dijet production in deep inelastic scattering and photon-hadron collisions in the color glass condensate, Phys. Lett. B **758**, 373 (2016).

[9] Y. Hatta, B.-W. Xiao, and F. Yuan, Probing the Small-x Gluon Tomography in Correlated Hard Diffractive Dijet Production in Deep Inelastic Scattering, Phys. Rev. Lett. **116**, 202301 (2016).

[10] Y. Hagiwara, Y. Hatta, R. Pasechnik, M. Tasevsky, and O. Teryaev, Accessing the gluon Wigner distribution in ultraperipheral pA collisions, Phys. Rev. D **96**, 034009 (2017).

[11] Y. Hatta, B.-W. Xiao, and F. Yuan, Gluon tomography from deeply virtual Compton scattering at small x, Phys. Rev. D **95**, 114026 (2017).

[12] H. Mantysaari, N. Mueller, and B. Schenke, Diffractive dijet production and Wigner distributions from the color glass condensate, Phys. Rev. D **99**, 074004 (2019).

[13] A. Dumitru, V. Skokov, and T. Ullrich, Measuring the Weizsacker-Williams distribution of linearly polarized gluons at an electron-ion collider through dijet azimuthal asymmetries, Phys. Rev. C **99**, 015204 (2019).

[14] Y. Hagiwara, Y. Hatta, and T. Ueda, Wigner, Husimi, and generalized transverse momentum dependent distributions in the color glass condensate, Phys. Rev. D **94**, 094036 (2016).

[15] Y. Hagiwara, Y. Hatta, B.-W. Xiao, and F. Yuan, Elliptic flow in small systems due to elliptic gluon distributions?, Phys. Lett. B **771**, 374 (2017).

[16] J. Zhou, Elliptic gluon generalized transverse-momentum-dependent distribution inside a large nucleus, Phys. Rev. D **94**, 114017 (2016).

[17] M. Strikman, R. Vogt, and S. N. White, Probing Small-x Parton Densities in Ultraperipheral AA and pA Collisions at the CERN Large Hadron Collider, Phys. Rev. Lett. **96**, 082001 (2006).

[18] V. Guzey and M. Klasen, Diffractive dijet photoproduction in ultraperipheral collisions at the LHC in next-to-leading order QCD, J. High Energy Phys. 04 (2016) 158.

[19] P. Kotko, K. Kutak, S. Sapeta, A. M. Stasto, and M. Strikman, Estimating nonlinear effects in forward dijet production in ultra-peripheral heavy ion collisions at the LHC, Eur. Phys. J. C **77**, 353 (2017).

[20] Y. Hatta, B.-W. Xiao, F. Yuan, and J. Zhou, Anisotropy in Dijet Production in Exclusive and Inclusive Processes, Phys. Rev. Lett. **126**, 142001 (2021).

[21] A. J. Baltz, G. Baur, D. Denterria, L. Frankfurt, F. Gelis, V. Guzey, K. Hencken, Y. Kharlov, M. Klasen, and S. Klein, The physics of ultraperipheral collisions at the LHC, Phys. Rep. **458**, 1 (2008).

[22] J. G. Contreras and J. D. Tapia Takaki, Ultra-peripheral heavy-ion collisions at the LHC, Int. J. Mod. Phys. A **30**, 1542012 (2015).

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

[24] CMS Collaboration, Coherent $J/\psi(1S)$ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the CMS experiment, Phys. Lett. B **772**, 489 (2017).

[25] CMS Collaboration, Measurement of exclusive $\rho(770)$ photoproduction in ultraperipheral pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Eur. Phys. J. C **79**, 702 (2019).

[26] CMS Collaboration, Measurement of exclusive Υ photoproduction from protons in pPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Eur. Phys. J. C **79**, 277 (2019).

[27] CMS Collaboration, Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Lett. B **797**, 134826 (2019).

[28] ALICE Collaboration, Coherent $J/\psi(1S)$ photoproduction in ultra-peripheral PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, Phys. Lett. B **718**, 1273 (2013).

[29] ATLAS Collaboration, Observation of Light-by-Light Scattering in Ultraperipheral PbPb Collisions with the ATLAS Detector, Phys. Rev. Lett. **123**, 052001 (2019).

[30] LHCb Collaboration, Central exclusive production of $J/\psi(1S)$ and $\psi(2S)$ mesons in pp collisions at $\sqrt{s} = 13$ TeV, J. High Energy Phys. 10 (2018) 167.

[31] T. Aaltonen *et al.* (CDF Collaboration), Observation of exclusive dijet production at the Fermilab tevatron $p\bar{p}$ collider, Phys. Rev. D **77**, 052004 (2008).

[32] H. Abramowicz *et al.* (ZEUS Collaboration), Production of exclusive dijets in diffractive deep inelastic scattering at HERA, Eur. Phys. J. C **76**, 16 (2016).

[33] CMS Collaboration, HEPData record for this analysis (2022), 10.17182/hepdata.95235.

[34] CMS Collaboration, The CMS trigger system, J. Instrum. **12**, P01020 (2017).

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

[36] CMS Collaboration, Constraining Gluon Distributions in Nuclei Using Dijets in Proton-Proton and Proton-Lead Collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, Phys. Rev. Lett. **121**, 062002 (2018).

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

[38] M. Cacciari, G. P. Salam, and G. Soyez, The anti-k_T jet clustering algorithm, J. High Energy Phys. 04 (2008) 063.

[39] M. Cacciari, G. P. Salam, and G. Soyez, FASTJET user manual, Eur. Phys. J. C **72**, 1896 (2012).

[40] CMS Collaboration, CMS tracking performance results from early LHC operation, Eur. Phys. J. C **70**, 1165 (2010).

[41] H. Jung, Hard diffractive scattering in high-energy ep collisions and the Monte Carlo generator RAPGAP, Comput. Phys. Commun. **86**, 147 (1995).

[42] S. R. Klein, J. Nystrand, J. Seger, Y. Gorbunov, and J. Butterworth, STARlight: A Monte Carlo simulation program for ultra-peripheral collisions of relativistic ions, Comput. Phys. Commun. **212**, 258 (2017).

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

[44] S. R. Klein and H. Mantysaari, Imaging the nucleus with high-energy photons, Nat. Rev. Phys. **1**, 662 (2019).

[45] S. Schmitt, TUunfold: An algorithm for correcting migration effects in high energy physics, J. Instrum. **7**, T10003 (2012).

[46] CMS Collaboration, Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV, J. Instrum. **12**, P02014 (2017).

[47] A. van Hameren, P. Kotko, K. Kutak, and S. Sapeta, Broadening and saturation effects in dijet azimuthal correlations in pp and pPb collisions at $\sqrt{s} = 5.02$ TeV, Phys. Lett. B **795**, 511 (2019).

A. Tumasyan,[1] W. Adam,[2] T. Bergauer,[2] M. Dragicevic,[2] A. Escalante Del Valle,[2] R. Frühwirth,[2,b] M. Jeitler,[2,b] N. Krammer,[2] L. Lechner,[2] D. Liko,[2] I. Mikulec,[2] F. M. Pitters,[2] N. Rad,[2] J. Schieck,[2,b] R. Schöfbeck,[2] M. Spanring,[2] S. Templ,[2] W. Waltenberger,[2] C.-E. Wulz,[2,b] M. Zarucki,[2] M. R. Darwish,[3,c] E. A. De Wolf,[3] D. Di Croce,[3] T. Janssen,[3] T. Kello,[3,d] A. Lelek,[3] M. Pieters,[3] H. Rejeb Sfar,[3] H. Van Haevermaet,[3] P. Van Mechelen,[3] S. Van Putte,[3] N. Van Remortel,[3] F. Blekman,[4] E. S. Bols,[4] S. S. Chhibra,[4] J. D'Hondt,[4] J. De Clercq,[4] D. Lontkovskyi,[4] S. Lowette,[4] I. Marchesini,[4] S. Moortgat,[4] A. Morton,[4] D. Müller,[4] Q. Python,[4] S. Tavernier,[4] W. Van Doninck,[4] P. Van Mulders,[4] D. Beghin,[5] B. Bilin,[5] B. Clerbaux,[5] G. De Lentdecker,[5] B. Dorney,[5] L. Favart,[5] A. Grebenyuk,[5] A. K. Kalsi,[5] I. Makarenko,[5] L. Moureaux,[5] L. Pétré,[5] A. Popov,[5] N. Postiau,[5] E. Starling,[5] L. Thomas,[5] C. Vander Velde,[5] P. Vanlaer,[5] D. Vannerom,[5] L. Wezenbeek,[5] T. Cornelis,[6] D. Dobur,[6] M. Gruchala,[6] I. Khvastunov,[6,e] M. Niedziela,[6] C. Roskas,[6] K. Skovpen,[6] M. Tytgat,[6] W. Verbeke,[6] B. Vermassen,[6] M. Vit,[6] G. Bruno,[7] F. Bury,[7] C. Caputo,[7] P. David,[7] C. Delaere,[7] M. Delcourt,[7] I. S. Donertas,[7] A. Giammanco,[7] V. Lemaitre,[7] K. Mondal,[7] J. Prisciandaro,[7] A. Taliercio,[7] M. Teklishyn,[7]

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Petrov,[12] T. Cheng,[13] W. Fang,[13,d] Q. Guo,[13] H. Wang,[13] L. Yuan,[13] M. Ahmad,[14] G. Bauer,[14] Z. Hu,[14] Y. Wang,[14] K. Yi,[14,j,k] E. Chapon,[15] G. M. Chen,[15,l] H. S. Chen,[15,l] M. Chen,[15] T. Javaid,[15,l] A. Kapoor,[15] D. Leggat,[15] H. Liao,[15] Z.-A. Liu,[15,m] R. Sharma,[15] A. Spiezia,[15] J. Tao,[15] J. Thomas-Wilsker,[15] J. Wang,[15] H. Zhang,[15] S. Zhang,[15,l] J. Zhao,[15] A. Agapitos,[16] Y. Ban,[16] C. Chen,[16] Q. Huang,[16] A. Levin,[16] Q. Li,[16] M. Lu,[16] X. Lyu,[16] Y. Mao,[16] S. J. Qian,[16] D. Wang,[16] Q. Wang,[16] J. Xiao,[16] Z. You,[17] X. Gao,[18,d] M. Xiao,[19] C. Avila,[20] A. Cabrera,[20] C. Florez,[20] J. Fraga,[20] A. Sarkar,[20] M. A. Segura Delgado,[20] J. Jaramillo,[21] J. Mejia Guisao,[21] F. Ramirez,[21] J. D. Ruiz Alvarez,[21] C. A. Salazar González,[21] N. Vanegas Arbelaez,[21] D. Giljanovic,[22] N. Godinovic,[22] D. Lelas,[22] I. Puljak,[22] Z. Antunovic,[23] M. Kovac,[23] T. Sculac,[23] V. Brigljevic,[24] D. 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Bernet,[38] G. Boudoul,[38] C. Camen,[38] A. Carle,[38] N. Chanon,[38] D. Contardo,[38] P. Depasse,[38] H. El Mamouni,[38] J. Fay,[38] S. Gascon,[38] M. Gouzevitch,[38] B. Ille,[38] Sa. Jain,[38] I. B. Laktineh,[38] H. Lattaud,[38] A. Lesauvage,[38] M. Lethuillier,[38] L. Mirabito,[38] K. Shchablo,[38] L. Torterotot,[38] G. Touquet,[38] M. Vander Donckt,[38] S. Viret,[38] I. Bagaturia,[39,v] Z. Tsamalaidze,[39,n] L. Feld,[40] K. Klein,[40] M. Lipinski,[40] D. Meuser,[40] A. Pauls,[40] M. P. Rauch,[40] J. Schulz,[40] M. Teroerde,[40] D. Eliseev,[41] M. Erdmann,[41] P. Fackeldey,[41] B. Fischer,[41] S. Ghosh,[41] T. Hebbeker,[41] K. Hoepfner,[41] H. Keller,[41] L. Mastrolorenzo,[41] M. Merschmeyer,[41] A. Meyer,[41] G. Mocellin,[41] S. Mondal,[41] S. Mukherjee,[41] D. Noll,[41] A. Novak,[41] T. Pook,[41] A. Pozdnyakov,[41] Y. Rath,[41] H. Reithler,[41] J. Roemer,[41] A. Schmidt,[41] S. C. Schuler,[41] A. Sharma,[41] S. Wiedenbeck,[41] S. Zaleski,[41] C. Dziwok,[42] G. Flügge,[42] W. Haj Ahmad,[42,w] O. Hlushchenko,[42] T. Kress,[42] A. Nowack,[42] C. Pistone,[42] O. Pooth,[42] D. Roy,[42] H. Sert,[42] A. Stahl,[42,x] T. Ziemons,[42] H. Aarup Petersen,[43] M. Aldaya Martin,[43] P. Asmuss,[43] I. Babounikau,[43] S. Baxter,[43] O. Behnke,[43] A. Bermúdez Martínez,[43] A. A. Bin Anuar,[43] K. Borras,[43,y] V. Botta,[43] D. Brunner,[43] A. Campbell,[43] A. Cardini,[43] P. Connor,[43] S. Consuegra Rodríguez,[43] V. Danilov,[43] A. De Wit,[43] M. M. Defranchis,[43] L. Didukh,[43] D. Domínguez Damiani,[43] G. Eckerlin,[43] D. Eckstein,[43] L. I. Estevez Banos,[43] E. Gallo,[43,z] A. Geiser,[43] A. Giraldi,[43] A. Grohsjean,[43] M. Guthoff,[43] A. Harb,[43] A. Jafari,[43,aa] N. Z. Jomhari,[43] A. Kasem,[43,y] M. Kasemann,[43] H. Kaveh,[43] C. Kleinwort,[43] J. Knolle,[43] D. Krücker,[43] W. Lange,[43] T. Lenz,[43] J. Lidrych,[43] K. Lipka,[43] W. Lohmann,[43,bb] T. Madlener,[43] R. Mankel,[43] I.-A. Melzer-Pellmann,[43] J. Metwally,[43]

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Apresyan,[149] A. Apyan,[149] S. Banerjee,[149] L. A. T. Bauerdick,[149] A. Beretvas,[149] D. Berry,[149] J. Berryhill,[149] P. C. Bhat,[149] K. Burkett,[149] J. N. Butler,[149] A. Canepa,[149] G. B. Cerati,[149] H. W. K. Cheung,[149] F. Chlebana,[149] M. Cremonesi,[149] V. D. Elvira,[149] J. Freeman,[149] Z. Gecse,[149] L. Gray,[149] D. Green,[149] S. Grünendahl,[149] O. Gutsche,[149] R. M. Harris,[149] S. Hasegawa,[149] R. Heller,[149] T. C. Herwig,[149] J. Hirschauer,[149] B. Jayatilaka,[149] S. Jindariani,[149] M. Johnson,[149] U. Joshi,[149] P. Klabbers,[149] T. Klijnsma,[149] B. Klima,[149] M. J. Kortelainen,[149] S. Lammel,[149] D. Lincoln,[149] R. Lipton,[149] M. Liu,[149] T. Liu,[149] J. Lykken,[149] K. Maeshima,[149] D. Mason,[149] P. McBride,[149] P. Merkel,[149] S. Mrenna,[149] S. Nahn,[149] V. O'Dell,[149] V. Papadimitriou,[149] K. Pedro,[149] C. Pena,[149,bbbb] O. Prokofyev,[149] F. Ravera,[149] A. Reinsvold Hall,[149] L. Ristori,[149] B. Schneider,[149] E. Sexton-Kennedy,[149] N. Smith,[149]

A. Soha,[149] W. J. Spalding,[149] L. Spiegel,[149] J. Strait,[149] L. Taylor,[149] S. Tkaczyk,[149] N. V. Tran,[149] L. Uplegger,[149] E. W. Vaandering,[149] H. A. Weber,[149] A. Woodard,[149] D. Acosta,[150] P. Avery,[150] D. Bourilkov,[150] L. Cadamuro,[150] V. Cherepanov,[150] F. Errico,[150] R. D. Field,[150] D. Guerrero,[150] B. M. Joshi,[150] M. Kim,[150] J. Konigsberg,[150] A. Korytov,[150] K. H. Lo,[150] K. Matchev,[150] N. Menendez,[150] G. Mitselmakher,[150] D. Rosenzweig,[150] K. Shi,[150] J. Sturdy,[150] J. Wang,[150] X. Zuo,[150] T. Adams,[151] A. Askew,[151] D. Diaz,[151] R. Habibullah,[151] S. Hagopian,[151] V. Hagopian,[151] K. F. Johnson,[151] R. Khurana,[151] T. Kolberg,[151] G. Martinez,[151] H. Prosper,[151] C. Schiber,[151] R. Yohay,[151] J. Zhang,[151] M. M. Baarmand,[152] S. Butalla,[152] T. Elkafrawy,[152,cccc] M. Hohlmann,[152] D. Noonan,[152] M. Rahmani,[152] M. Saunders,[152] F. Yumiceva,[152] M. R. Adams,[153] L. Apanasevich,[153] H. Becerril Gonzalez,[153] R. Cavanaugh,[153] X. Chen,[153] S. Dittmer,[153] O. Evdokimov,[153] C. E. Gerber,[153] D. A. Hangal,[153] D. J. Hofman,[153] C. Mills,[153] G. Oh,[153] T. Roy,[153] M. B. Tonjes,[153] N. Varelas,[153] J. Viinikainen,[153] X. Wang,[153] Z. Wu,[153] Z. Ye,[153] M. Alhusseini,[154] K. Dilsiz,[154,dddd] S. Durgut,[154] R. P. Gandrajula,[154] M. Haytmyradov,[154] V. Khristenko,[154] O. K. Köseyan,[154] J.-P. Merlo,[154] A. Mestvirishvili,[154,eeee] A. Moeller,[154] J. Nachtman,[154] H. Ogul,[154,ffff] Y. Onel,[154] F. Ozok,[154,gggg] A. Penzo,[154] C. Snyder,[154] E. Tiras,[154,hhhh] J. Wetzel,[154] O. Amram,[155] B. Blumenfeld,[155] L. Corcodilos,[155] M. Eminizer,[155] A. V. Gritsan,[155] S. Kyriacou,[155] P. Maksimovic,[155] C. Mantilla,[155] J. Roskes,[155] M. Swartz,[155] T. Á. Vámi,[155] C. Baldenegro Barrera,[156] P. Baringer,[156] A. Bean,[156] S. Boren,[156] J. Bowen,[156] A. Bylinkin,[156] T. Isidori,[156] S. Khalil,[156] J. King,[156] G. Krintiras,[156] A. Kropivnitskaya,[156] C. Lindsey,[156] N. Minafra,[156] M. Murray,[156] J. Ralston,[156] C. Rogan,[156] C. Royon,[156] S. Sanders,[156] E. Schmitz,[156] J. D. Tapia Takaki,[156] Q. Wang,[156] J. Williams,[156] G. Wilson,[156] S. Duric,[157] A. Ivanov,[157] K. Kaadze,[157] D. Kim,[157] Y. Maravin,[157] T. Mitchell,[157] A. Modak,[157] A. Mohammadi,[157] F. Rebassoo,[158] D. Wright,[158] E. Adams,[159] A. Baden,[159] O. Baron,[159] A. Belloni,[159] S. C. Eno,[159] Y. Feng,[159] N. J. Hadley,[159] S. Jabeen,[159] G. Y. Jeng,[159] R. G. Kellogg,[159] T. Koeth,[159] A. C. Mignerey,[159] S. Nabili,[159] M. Seidel,[159] A. Skuja,[159] S. C. Tonwar,[159] L. Wang,[159] K. Wong,[159] D. Abercrombie,[160] B. Allen,[160] R. Bi,[160] S. Brandt,[160] W. Busza,[160] I. A. Cali,[160] Y. Chen,[160] M. D'Alfonso,[160] G. Gomez-Ceballos,[160] M. Goncharov,[160] P. Harris,[160] D. Hsu,[160] M. Hu,[160] M. Klute,[160] D. Kovalskyi,[160] J. Krupa,[160] Y.-J. Lee,[160] P. D. Luckey,[160] B. Maier,[160] A. C. Marini,[160] C. Mironov,[160] S. Narayanan,[160] X. Niu,[160] C. Paus,[160] D. Rankin,[160] C. Roland,[160] G. Roland,[160] Z. Shi,[160] G. S. F. Stephans,[160] K. Sumorok,[160] K. Tatar,[160] D. Velicanu,[160] J. Wang,[160] T. W. Wang,[160] Z. Wang,[160] B. Wyslouch,[160] R. M. Chatterjee,[161] A. Evans,[161] P. Hansen,[161] J. Hiltbrand,[161] Sh. Jain,[161] M. Krohn,[161] Y. Kubota,[161] Z. Lesko,[161] J. Mans,[161] M. Revering,[161] R. Rusack,[161] R. Saradhy,[161] N. Schroeder,[161] N. Strobbe,[161] M. A. Wadud,[161] J. G. Acosta,[162] S. Oliveros,[162] K. Bloom,[163] S. Chauhan,[163] D. R. Claes,[163] C. Fangmeier,[163] L. Finco,[163] F. Golf,[163] J. R. González Fernández,[163] C. Joo,[163] I. Kravchenko,[163] J. E. Siado,[163] G. R. Snow,[163,a] W. Tabb,[163] F. Yan,[163] G. Agarwal,[164] H. Bandyopadhyay,[164] L. Hay,[164] I. Iashvili,[164] A. Kharchilava,[164] C. McLean,[164] D. Nguyen,[164] J. Pekkanen,[164] S. Rappoccio,[164] G. Alverson,[165] E. Barberis,[165] C. Freer,[165] Y. Haddad,[165] A. Hortiangtham,[165] J. Li,[165] G. Madigan,[165] B. Marzocchi,[165] D. M. Morse,[165] V. Nguyen,[165] T. Orimoto,[165] A. Parker,[165] L. Skinnari,[165] A. Tishelman-Charny,[165] T. Wamorkar,[165] B. Wang,[165] A. Wisecarver,[165] D. Wood,[165] S. Bhattacharya,[166] J. Bueghly,[166] Z. Chen,[166] A. Gilbert,[166] T. Gunter,[166] K. A. Hahn,[166] N. Odell,[166] M. H. Schmitt,[166] K. Sung,[166] M. Velasco,[166] R. Bucci,[167] N. Dev,[167] R. Goldouzian,[167] M. Hildreth,[167] K. Hurtado Anampa,[167] C. Jessop,[167] K. Lannon,[167] N. Loukas,[167] N. Marinelli,[167] I. Mcalister,[167] F. Meng,[167] K. Mohrman,[167] Y. Musienko,[167,n] R. Ruchti,[167] P. Siddireddy,[167] M. Wayne,[167] A. Wightman,[167] M. Wolf,[167] L. Zygala,[167] J. Alimena,[168] B. Bylsma,[168] B. Cardwell,[168] L. S. Durkin,[168] B. Francis,[168] C. Hill,[168] A. Lefeld,[168] B. L. Winer,[168] B. R. Yates,[168] B. Bonham,[169] P. Das,[169] G. Dezoort,[169] P. Elmer,[169] B. Greenberg,[169] N. Haubrich,[169] S. Higginbotham,[169] A. Kalogeropoulos,[169] G. Kopp,[169] S. Kwan,[169] D. Lange,[169] M. T. Lucchini,[169] J. Luo,[169] D. Marlow,[169] K. Mei,[169] I. Ojalvo,[169] J. Olsen,[169] C. Palmer,[169] P. Piroué,[169] D. Stickland,[169] C. Tully,[169] S. Malik,[170] S. Norberg,[170] V. E. Barnes,[171] R. Chawla,[171] S. Das,[171] L. Gutay,[171] M. Jones,[171] A. W. Jung,[171] G. Negro,[171] N. Neumeister,[171] C. C. Peng,[171] S. Piperov,[171] A. Purohit,[171] J. F. Schulte,[171] M. Stojanovic,[171] N. Trevisani,[171] F. Wang,[171] A. Wildridge,[171] R. Xiao,[171] W. Xie,[171] J. Dolen,[172] N. Parashar,[172] A. Baty,[173] S. Dildick,[173] K. M. Ecklund,[173] S. Freed,[173] F. J. M. Geurts,[173] M. Kilpatrick,[173] A. Kumar,[173] W. Li,[173] B. P. Padley,[173] R. Redjimi,[173] J. Roberts,[173,a] J. Rorie,[173] W. Shi,[173] A. G. Stahl Leiton,[173] A. Bodek,[174] P. de Barbaro,[174] R. Demina,[174] J. L. Dulemba,[174]

C. Fallon,[174] T. Ferbel,[174] M. Galanti,[174] A. Garcia-Bellido,[174] O. Hindrichs,[174] A. Khukhunaishvili,[174] E. Ranken,[174] R. Taus,[174] B. Chiarito,[175] J. P. Chou,[175] A. Gandrakota,[175] Y. Gershtein,[175] E. Halkiadakis,[175] A. Hart,[175] M. Heindl,[175] E. Hughes,[175] S. Kaplan,[175] O. Karacheban,[175,bb] I. Laflotte,[175] A. Lath,[175] R. Montalvo,[175] K. Nash,[175] M. Osherson,[175] S. Salur,[175] S. Schnetzer,[175] S. Somalwar,[175] R. Stone,[175] S. A. Thayil,[175] S. Thomas,[175] H. Wang,[175] H. Acharya,[176] A. G. Delannoy,[176] S. Spanier,[176] O. Bouhali,[177,iiii] M. Dalchenko,[177] A. Delgado,[177] R. Eusebi,[177] J. Gilmore,[177] T. Huang,[177] T. Kamon,[177,jjjj] H. Kim,[177] S. Luo,[177] S. Malhotra,[177] R. Mueller,[177] D. Overton,[177] L. Perniè,[177] D. Rathjens,[177] A. Safonov,[177] N. Akchurin,[178] J. Damgov,[178] V. Hegde,[178] S. Kunori,[178] K. Lamichhane,[178] S. W. Lee,[178] T. Mengke,[178] S. Muthumuni,[178] T. Peltola,[178] S. Undleeb,[178] I. Volobouev,[178] Z. Wang,[178] A. Whitbeck,[178] E. Appelt,[179] S. Greene,[179] A. Gurrola,[179] R. Janjam,[179] W. Johns,[179] C. Maguire,[179] A. Melo,[179] H. Ni,[179] K. Padeken,[179] F. Romeo,[179] P. Sheldon,[179] S. Tuo,[179] J. Velkovska,[179] M. W. Arenton,[180] B. Cox,[180] G. Cummings,[180] J. Hakala,[180] R. Hirosky,[180] M. Joyce,[180] A. Ledovskoy,[180] A. Li,[180] C. Neu,[180] B. Tannenwald,[180] E. Wolfe,[180] P. E. Karchin,[181] N. Poudyal,[181] P. Thapa,[181] K. Black,[182] T. Bose,[182] J. Buchanan,[182] C. Caillol,[182] S. Dasu,[182] I. De Bruyn,[182] P. Everaerts,[182] C. Galloni,[182] H. He,[182] M. Herndon,[182] A. Hervé,[182] U. Hussain,[182] A. Lanaro,[182] A. Loeliger,[182] R. Loveless,[182] J. Madhusudanan Sreekala,[182] A. Mallampalli,[182] D. Pinna,[182] A. Savin,[182] V. Shang,[182] V. Sharma,[182] W. H. Smith,[182] D. Teague,[182] S. Trembath-Reichert,[182] W. Vetens,[182] S. Afanasiev,[183] V. Andreev,[183] Yu. Andreev,[183] T. Aushev,[183] M. Azarkin,[183] A. Babaev,[183] A. Belyaev,[183] V. Blinov,[183,n] E. Boos,[183] V. Borchsh,[183] P. Bunin,[183] V. Chekhovsky,[183] R. Chistov,[183,n] M. Danilov,[183,n] A. Demiyanov,[183] A. Dermenev,[183] T. Dimova,[183,n] I. Dremin,[183] V. Epshteyn,[183,kkkk] A. Ershov,[183] M. Gavrilenko,[183] G. Gavrilov,[183] V. Gavrilov,[183] S. Gninenko,[183] V. Golovtcov,[183] N. Golubev,[183] I. Golutvin,[183] I. Gorbunov,[183] A. Iuzhakov,[183] V. Ivanchenko,[183] Y. Ivanov,[183] V. Kachanov,[183] A. Kalinin,[183] A. Kamenev,[183] L. Kardapoltsev,[183,n] V. Karjavine,[183] A. Karneyeu,[183] V. Kim,[183,n] M. Kirakosyan,[183] M. Kirsanov,[183] O. Kodolova,[183,llll] D. Konstantinov,[183] V. Korotkikh,[183] N. Krasnikov,[183] E. Kuznetsova,[183,mmmm] A. Lanev,[183] A. Litomin,[183] O. Lukina,[183] N. Lychkovskaya,[183] V. Makarenko,[183] A. Malakhov,[183] V. Matveev,[183,n] V. Murzin,[183] A. Nikitenko,[183,nnnn] S. Obraztsov,[183] V. Okhotnikov,[183] V. Oreshkin,[183] A. Oskin,[183] I. Ovtin,[183,n] V. Palichik,[183] P. Parygin,[183,oooo] A. Pashenkov,[183] V. Perelygin,[183] S. Petrushanko,[183] G. Pivovarov,[183] S. Polikarpov,[183,n] V. Popov,[183] G. Safronov,[183] M. Savina,[183] V. Savrin,[183] V. Shalaev,[183] S. Shmatov,[183] S. Shulha,[183] Y. Skovpen,[183,n] I. Smirnov,[183] V. Smirnov,[183] A. Snigirev,[183] D. Sosnov,[183] A. Spiridonov,[183] A. Stepennov,[183] J. Suarez Gonzalez,[183] L. Sukhikh,[183] V. Sulimov,[183] E. Tcherniaev,[183] A. Terkulov,[183] O. Teryaev,[183] D. Tlisov,[183,a] M. Toms,[183,pppp] A. Toropin,[183] L. Uvarov,[183] A. Uzunian,[183] I. Vardanyan,[183] E. Vlasov,[183,qqqq] S. Volkov,[183] A. Vorobyev,[183] N. Voytishin,[183] B. S. Yuldashev,[183,rrrr] A. Zarubin,[183] I. Zhizhin,[183] and A. Zhokin[183]

(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]*Beihang University, Beijing, China*
[14]*Department of Physics, Tsinghua University, Beijing, China*
[15]*Institute of High Energy Physics, Beijing, China*
[16]*State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China*

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

[70b]Università di Catania, Catania, Italy
[71a]INFN Sezione di Firenze, Firenze, Italy
[71b]Università di Firenze, Firenze, Italy
[72]INFN Laboratori Nazionali di Frascati, Frascati, Italy
[73a]INFN Sezione di Genova, Genova, Italy
[73b]Università di Genova, Genova, Italy
[74a]INFN Sezione di Milano-Bicocca, Milano, Italy
[74b]Università di Milano-Bicocca, Milano, Italy
[75a]INFN Sezione di Napoli, Napoli, Italy
[75b]Università di Napoli 'Federico II', Napoli, Italy
[75c]Università della Basilicata, Potenza, Italy
[75d]Università G. Marconi, Roma, Italy
[76a]INFN Sezione di Padova, Padova, Italy
[76b]Università di Padova, Padova, Italy
[76c]Università di Trento, Trento, Italy
[77a]INFN Sezione di Pavia, Pavia, Italy
[77b]Università di Pavia, Pavia, Italy
[78a]INFN Sezione di Perugia, Perugia, Italy
[78b]Università di Perugia, Perugia, Italy
[79a]INFN Sezione di Pisa, Pisa, Italy
[79b]Università di Pisa, Pisa, Italy
[79c]Scuola Normale Superiore di Pisa, Pisa, Italy
[79d]Università di Siena, Siena, Italy
[80a]INFN Sezione di Roma, Roma, Italy
[80b]Sapienza Università di Roma, Roma, Italy
[81a]INFN Sezione di Torino, Torino, Italy
[81b]Università di Torino, Torino, Italy
[81c]Università del Piemonte Orientale, Novara, Italy
[82a]INFN Sezione di Trieste, Trieste, Italy
[82b]Università di Trieste, Trieste, Italy
[83]Kyungpook National University, Daegu, Korea
[84]Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
[85]Hanyang University, Seoul, Korea
[86]Korea University, Seoul, Korea
[87]Kyung Hee University, Department of Physics, Seoul, Korea
[88]Sejong University, Seoul, Korea
[89]Seoul National University, Seoul, Korea
[90]University of Seoul, Seoul, Korea
[91]Yonsei University, Department of Physics, Seoul, Korea
[92]Sungkyunkwan University, Suwon, Korea
[93]College of Engineering and Technology, American University of the Middle East (AUM), Dasman, Kuwait
[94]Riga Technical University, Riga, Latvia
[95]Vilnius University, Vilnius, Lithuania
[96]National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
[97]Universidad de Sonora (UNISON), Hermosillo, Mexico
[98]Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
[99]Universidad Iberoamericana, Mexico City, Mexico
[100]Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
[101]Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
[102]University of Montenegro, Podgorica, Montenegro
[103]University of Auckland, Auckland, New Zealand
[104]University of Canterbury, Christchurch, New Zealand
[105]National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
[106]AGH University of Science and Technology Faculty of Computer Science, Electronics and Telecommunications, Krakow, Poland
[107]National Centre for Nuclear Research, Swierk, Poland
[108]Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
[109]Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
[110]VINCA Institute of Nuclear Sciences, University of Belgrade, Belgrade, Serbia
[111]Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
[112]Universidad Autónoma de Madrid, Madrid, Spain

[113]Universidad de Oviedo, Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA), Oviedo, Spain
[114]Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
[115]University of Colombo, Colombo, Sri Lanka
[116]University of Ruhuna, Department of Physics, Matara, Sri Lanka
[117]CERN, European Organization for Nuclear Research, Geneva, Switzerland
[118]Paul Scherrer Institut, Villigen, Switzerland
[119]ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
[120]Universität Zürich, Zurich, Switzerland
[121]National Central University, Chung-Li, Taiwan
[122]National Taiwan University (NTU), Taipei, Taiwan
[123]Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
[124]Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
[125]Middle East Technical University, Physics Department, Ankara, Turkey
[126]Bogazici University, Istanbul, Turkey
[127]Istanbul Technical University, Istanbul, Turkey
[128]Istanbul University, Istanbul, Turkey
[129]Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkiv, Ukraine
[130]National Science Centre, Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine
[131]University of Bristol, Bristol, United Kingdom
[132]Rutherford Appleton Laboratory, Didcot, United Kingdom
[133]Imperial College, London, United Kingdom
[134]Brunel University, Uxbridge, United Kingdom
[135]Baylor University, Waco, Texas, USA
[136]Catholic University of America, Washington, DC, USA
[137]The University of Alabama, Tuscaloosa, Alabama, USA
[138]Boston University, Boston, Massachusetts, USA
[139]Brown University, Providence, Rhode Island, USA
[140]University of California, Davis, Davis, California, USA
[141]University of California, Los Angeles, California, USA
[142]University of California, Riverside, Riverside, California, USA
[143]University of California, San Diego, La Jolla, California, USA
[144]University of California, Santa Barbara - Department of Physics, Santa Barbara, California, USA
[145]California Institute of Technology, Pasadena, California, USA
[146]Carnegie Mellon University, Pittsburgh, Pennsylvania, USA
[147]University of Colorado Boulder, Boulder, Colorado, USA
[148]Cornell University, Ithaca, New York, USA
[149]Fermi National Accelerator Laboratory, Batavia, Illinois, USA
[150]University of Florida, Gainesville, Florida, USA
[151]Florida State University, Tallahassee, Florida, USA
[152]Florida Institute of Technology, Melbourne, Florida, USA
[153]University of Illinois at Chicago (UIC), Chicago, Illinois, USA
[154]The University of Iowa, Iowa City, Iowa, USA
[155]Johns Hopkins University, Baltimore, Maryland, USA
[156]The University of Kansas, Lawrence, Kansas, USA
[157]Kansas State University, Manhattan, Kansas, USA
[158]Lawrence Livermore National Laboratory, Livermore, California, USA
[159]University of Maryland, College Park, Maryland, USA
[160]Massachusetts Institute of Technology, Cambridge, Massachusetts, USA
[161]University of Minnesota, Minneapolis, Minnesota, USA
[162]University of Mississippi, Oxford, Mississippi, USA
[163]University of Nebraska-Lincoln, Lincoln, Nebraska, USA
[164]State University of New York at Buffalo, Buffalo, New York, USA
[165]Northeastern University, Boston, Massachusetts, USA
[166]Northwestern University, Evanston, Illinois, USA
[167]University of Notre Dame, Notre Dame, Indiana, USA
[168]The Ohio State University, Columbus, Ohio, USA
[169]Princeton University, Princeton, New Jersey, USA
[170]University of Puerto Rico, Mayaguez, Puerto Rico, USA
[171]Purdue University, West Lafayette, Indiana, USA
[172]Purdue University Northwest, Hammond, Indiana, USA

[173]Rice University, Houston, Texas, USA
[174]University of Rochester, Rochester, New York, USA
[175]Rutgers, The State University of New Jersey, Piscataway, New Jersey, USA
[176]University of Tennessee, Knoxville, Tennessee, USA
[177]Texas A&M University, College Station, Texas, USA
[178]Texas Tech University, Lubbock, Texas, USA
[179]Vanderbilt University, Nashville, Tennessee, USA
[180]University of Virginia, Charlottesville, Virginia, USA
[181]Wayne State University, Detroit, Michigan, USA
[182]University of Wisconsin - Madison, Madison, Wisconsin, USA
[183]An institute or international laboratory covered by a cooperation agreement with CERN

[a]Deceased.
[b]Also at TU Wien, Vienna, Austria.
[c]Also at Institute of Basic and Applied Sciences, Faculty of Engineering, Arab Academy for Science, Technology and Maritime Transport, Alexandria, Egypt.
[d]Also at Université Libre de Bruxelles, Bruxelles, Belgium.
[e]Also at IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France.
[f]Also at Universidade Estadual de Campinas, Campinas, Brazil.
[g]Also at Federal University of Rio Grande do Sul, Porto Alegre, Brazil.
[h]Also at UFMS, Nova Andradina, Brazil.
[i]Also at Universidade Federal de Pelotas, Pelotas, Brazil.
[j]Also at Nanjing Normal University Department of Physics, Nanjing, China.
[k]Also at The University of Iowa, Iowa City, Iowa, USA.
[l]Also at University of Chinese Academy of Sciences, Beijing, China.
[m]Also at University of Chinese Academy of Sciences, Beijing, China.
[n]Also at Another institute or international laboratory covered by a cooperation agreement with CERN.
[o]Also at Cairo University, Cairo, Egypt.
[p]Also at Helwan University, Cairo, Egypt.
[q]Also at Zewail City of Science and Technology, Zewail, Egypt.
[r]Also at Suez University, Suez, Egypt.
[s]Also at British University in Egypt, Cairo, Egypt.
[t]Also at Purdue University, West Lafayette, Indiana, USA.
[u]Also at Université de Haute Alsace, Mulhouse, France.
[v]Also at Ilia State University, Tbilisi, Georgia.
[w]Also at Erzincan Binali Yildirim University, Erzincan, Turkey.
[x]Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland.
[y]Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany.
[z]Also at University of Hamburg, Hamburg, Germany.
[aa]Also at Isfahan University of Technology, Isfahan, Iran.
[bb]Also at Brandenburg University of Technology, Cottbus, Germany.
[cc]Also at Institute of Physics, University of Debrecen, Debrecen, Hungary.
[dd]Also at Physics Department, Faculty of Science, Assiut University, Assiut, Egypt.
[ee]Also at Karoly Robert Campus, MATE Institute of Technology, Gyongyos, Hungary.
[ff]Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.
[gg]Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary.
[hh]Also at Wigner Research Centre for Physics, Budapest, Hungary.
[ii]Also at G.H.G. Khalsa College, Punjab, India.
[jj]Also at Shoolini University, Solan, India.
[kk]Also at University of Hyderabad, Hyderabad, India.
[ll]Also at University of Visva-Bharati, Santiniketan, India.
[mm]Also at Indian Institute of Technology (IIT), Mumbai, India.
[nn]Also at IIT Bhubaneswar, Bhubaneswar, India.
[oo]Also at Institute of Physics, Bhubaneswar, India.
[pp]Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany.
[qq]Also at Sharif University of Technology, Tehran, Iran.
[rr]Also at Department of Physics, University of Science and Technology of Mazandaran, Behshahr, Iran.
[ss]Also at Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Bologna, Italy.
[tt]Also at Centro Siciliano di Fisica Nucleare e di Struttura Della Materia, Catania, Italy.
[uu]Also at Università di Napoli 'Federico II', Napoli, Italy.

[vv]Also at Consejo Nacional de Ciencia y Tecnología, Mexico City, Mexico.
[ww]Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia.
[xx]Also at Trincomalee Campus, Eastern University, Sri Lanka, Nilaveli, Sri Lanka.
[yy]Also at INFN Sezione di Pavia, Università di Pavia, Pavia, Italy.
[zz]Also at National and Kapodistrian University of Athens, Athens, Greece.
[aaa]Also at Universität Zürich, Zurich, Switzerland.
[bbb]Also at Ecole Polytechnique Fédérale Lausanne, Lausanne, Switzerland.
[ccc]Also at Stefan Meyer Institute for Subatomic Physics, Vienna, Austria.
[ddd]Also at Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France.
[eee]Also at Şırnak University, Sirnak, Turkey.
[fff]Also at Department of Physics, Tsinghua University, Beijing, China.
[ggg]Also at Near East University, Research Center of Experimental Health Science, Mersin, Turkey.
[hhh]Also at Beykent University, Istanbul, Turkey.
[iii]Also at Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul, Turkey.
[jjj]Also at Mersin University, Mersin, Turkey.
[kkk]Also at Izmir Bakircay University, Izmir, Turkey.
[lll]Also at Adiyaman University, Adiyaman, Turkey.
[mmm]Also at Ozyegin University, Istanbul, Turkey.
[nnn]Also at Izmir Institute of Technology, Izmir, Turkey.
[ooo]Also at Necmettin Erbakan University, Konya, Turkey.
[ppp]Also at Bozok Universitetesi Rektörlügü, Yozgat, Turkey.
[qqq]Also at Marmara University, Istanbul, Turkey.
[rrr]Also at Milli Savunma University, Istanbul, Turkey.
[sss]Also at Kafkas University, Kars, Turkey.
[ttt]Also at Istanbul Bilgi University, Istanbul, Turkey.
[uuu]Also at Hacettepe University, Ankara, Turkey.
[vvv]Also at Vrije Universiteit Brussel, Brussel, Belgium.
[www]Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[xxx]Also at IPPP Durham University, Durham, United Kingdom.
[yyy]Also at Monash University, Faculty of Science, Clayton, Australia.
[zzz]Also at Bethel University, St. Paul, Minnesota, USA.
[aaaa]Also at Karamanoğlu Mehmetbey University, Karaman, Turkey.
[bbbb]Also at California Institute of Technology, Pasadena, California, USA.
[cccc]Also at Ain Shams University, Cairo, Egypt.
[dddd]Also at Bingol University, Bingol, Turkey.
[eeee]Also at Georgian Technical University, Tbilisi, Georgia.
[ffff]Also at Sinop University, Sinop, Turkey.
[gggg]Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
[hhhh]Also at Erciyes University, Kayseri, Turkey.
[iiii]Also at Texas A&M University at Qatar, Doha, Qatar.
[jjjj]Also at Kyungpook National University, Daegu, Korea.
[kkkk]Also at Istanbul University, Istanbul, Turkey.
[llll]Also at Yerevan Physics Institute, Yerevan, Armenia.
[mmmm]Also at University of Florida, Gainesville, Florida, USA.
[nnnn]Also at Imperial College, London, United Kingdom.
[oooo]Also at University of Rochester, Rochester, New York, USA.
[pppp]Also at Baylor University, Waco, Texas, USA.
[qqqq]Also at INFN Sezione di Torino, Università di Torino, Torino, Italy, Università del Piemonte Orientale, Novara, Italy.
[rrrr]Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan.