EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2017-220
2018/03/07

CMS-HIN-16-022

Observation of correlated azimuthal anisotropy Fourier harmonics in pp and pPb collisions at the LHC

The CMS Collaboration*

arXiv:1709.09189v2 [nucl-ex] 6 Mar 2018

Abstract

The azimuthal anisotropy Fourier coefficients (v_n) in 8.16 TeV pPb data are extracted via long-range two-particle correlations as a function of event multiplicity and compared to corresponding results in pp and PbPb collisions. Using a four-particle cumulant technique, v_n correlations are measured for the first time in pp and pPb collisions. The v_2 and v_4 coefficients are found to be positively correlated in all collision systems. For high multiplicity pPb collisions an anticorrelation of v_2 and v_3 is observed, with a similar correlation strength as in PbPb data at the same multiplicity. The new correlation results strengthen the case for a common origin of the collectivity seen in pPb and PbPb collisions in the measured multiplicity range.

Published in Physical Review Letters as doi:10.1103/PhysRevLett.120.092301.

© 2018 CERN for the benefit of the CMS Collaboration. CC-BY-4.0 license

*See Appendix A for the list of collaboration members

Studies of multiparticle correlations provide important insights into the underlying mechanism of particle production in high-energy collisions of both protons and nuclei. A key feature of such correlations in ultrarelativistic nucleus-nucleus (AA) collisions is the observation of a pronounced structure on the near side (relative azimuthal angle $|\Delta\phi| \approx 0$) that extends over a large range in relative pseudorapidity ($|\Delta\eta|$ up to 4 units or more). This feature, known as the "ridge", has been found over a wide range of AA center-of-mass energies and system sizes at both the RHIC [1–5] and the LHC [6–10]. It is interpreted as arising primarily from the collective hydrodynamic flow of a strongly interacting, expanding medium [11, 12]. The azimuthal correlations of emitted particle pairs are frequently assessed via their Fourier decomposition, $\mathrm{d}N_{\mathrm{pair}}/\mathrm{d}\Delta\phi \propto 1 + \sum_n 2V_{n\Delta}\cos(n\Delta\phi)$, where $V_{n\Delta}$ are the two-particle Fourier coefficients. The single-particle azimuthal anisotropy Fourier coefficients v_n can be extracted as $v_n = \sqrt{V_{n\Delta}}$ if factorization is assumed [13]. The second (v_2) and third (v_3) coefficients are known as elliptic and triangular flow, respectively [12]. In hydrodynamic models, v_2 and v_3 are directly related to the initial collision geometry and its fluctuations, which influence the medium evolution [14–16]. These Fourier components provide insights into the fundamental transport properties of the medium.

The correlations of different orders of v_n coefficients have been studied in PbPb collisions at the LHC using the event-shape engineering technique [17] and the symmetric cumulant (SC) method [18–20]. It is found that the v_2 coefficient exhibits a negative correlation with the v_3 coefficient, while the correlation is positive between the v_2 and v_4 coefficients, across the full PbPb centrality range. These correlations have been shown to be sensitive probes of initial-state fluctuations (v_2 vs. v_3) and medium transport coefficients (v_2 vs. v_4) [18, 20, 21].

Strong collective azimuthal final-state anisotropies have been observed in high-multiplicity pp and pPb collisions, similar to those in AA collisions [22–34]. The origin of collectivity in these small systems is still under debate, see for example Ref. [35]. Measurements of the correlations between v_n coefficients in small systems will provide new insights on the origin and properties of the observed long-range collectivity. Quantitative hydrodynamic predictions of azimuthal correlations in pp and pPb systems still have large uncertainties, mainly due to limited knowledge of initial-state fluctuations of energy deposition at sub-nucleonic scales [35–37]. Detailed modeling of initial-state fluctuations in pp and pPb collisions [38] can be further constrained by the study of v_n coefficient correlations. For example, a positive correlation between v_2 and v_3 is predicted in pp collisions over the full multiplicity range [38], the opposite to what is observed in PbPb collisions [18]. Measuring v_n correlations in small colliding systems will help to understand if a common paradigm to describe collectivity in all hadronic systems can be found.

This Letter presents high precision measurements of anisotropy coefficients v_4 in pp at $\sqrt{s} = 13\,\mathrm{TeV}$, pPb at $\sqrt{s_{\mathrm{NN}}} = 8.16\,\mathrm{TeV}$, and PbPb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ using data from the CMS experiment. The 8.16 TeV pPb data provide access to higher multiplicities than previously experimentally accessible. The first measurement of correlations of different v_n in 13 TeV pp, 5.02 and 8.16 TeV pPb, and 5.02 TeV PbPb are also presented. The v_n coefficients are extracted via long-range ($|\Delta\eta| > 2$) two-particle correlations as a function of charged particle multiplicity. The v_n results are compared to 5.02 TeV PbPb, as well as previously published ones in 13 TeV pp [25] and 5.02 TeV pPb [34] collisions. Correlations of v_2 vs. v_3 and v_2 vs. v_4 are measured using the four-particle SC method in pp, pPb, and PbPb.

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, there are four primary subdetectors including a silicon pixel and strip tracker detector, a lead tungstate crystal elec-

tromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. The silicon tracker measures charged particles within the range $|\eta| < 2.5$. For charged particles with transverse momentum $1 < p_T < 10\,\text{GeV}/c$ and $|\eta| < 1.4$, the track resolutions are typically 1.5% in p_T and 25–90 (45–150) μm in the transverse (longitudinal) impact parameter [39]. Iron and quartz-fiber Cherenkov hadron forward (HF) calorimeters cover the range $2.9 < |\eta| < 5.2$. A detailed description of the CMS detector can be found in Ref. [40]. The detailed Monte Carlo (MC) simulation of the CMS detector response is based on GEANT4 [41].

The measurements presented in this Letter use data sets of 13 TeV pp, 5.02 and 8.16 TeV pPb, and 5.02 TeV PbPb collisions with integrated luminosities of about $2\,\text{pb}^{-1}$, $35\,\text{nb}^{-1}$, $186\,\text{nb}^{-1}$, and $1.2\,\mu\text{b}^{-1}$, respectively. When measuring the v_n coefficients in pp and pPb collisions, the same event may contain multiple independent interactions (pileup), which constitutes a background for the analysis of high-multiplicity events. The average number of collisions per bunch crossing in pp and pPb data varied between 0.1 to 1.3 and 0.1 to 0.25, respectively. A procedure similar to that described in Ref. [32] is used for identifying and rejecting events with pileup. To further suppress this contamination in the 8.16 TeV pPb data, where the pileup was more common, data from the highest luminosity periods are excluded, resulting in an integrated luminosity of about $140\,\text{nb}^{-1}$. The SC analysis is found to be insensitive to pileup within the quoted experimental uncertainties and, therefore, the pPb data sample of full recorded integrated luminosity is used. The 5.02 TeV PbPb data sample used for comparison is made of about 300 million peripheral (30–100% central) events where 100% means no overlap between the two colliding nuclei [42]. The same reconstruction algorithm is applied to the pp, pPb, and PbPb events, in order to directly compare the three systems at similar track multiplicities.

Minimum bias (MB) 8.16 TeV pPb events are triggered by energy deposits in at least one of the two HF calorimeters above a threshold of approximately 1 GeV and the presence of at least one track with $p_T > 0.4\,\text{GeV}/c$ in the pixel tracker. In order to collect a large sample of high-multiplicity pPb collisions, a dedicated trigger was implemented using the CMS level-1 (L1) and high-level trigger (HLT) systems. At L1, the total number of ECAL+HCAL energy towers above a threshold of 0.5 GeV in transverse energy (E_T) is required to be greater than a given threshold (120 and 150). Track reconstruction is performed online as part of the HLT trigger with the identical reconstruction algorithm used offline [39]. For each event, the reconstructed vertex with the highest number of associated tracks is selected as the primary vertex. The number of tracks with $|\eta| < 2.4$, $p_T > 0.4\,\text{GeV}/c$, and a distance of closest approach less than 0.12 cm to the primary vertex is determined for each event and is required to exceed a certain threshold to enrich the sample with high-multiplicity events. In addition, events are also required to contain a primary vertex within 15 cm of the nominal interaction point along the beam axis and 0.2 cm in the transverse direction. The trigger, event reconstruction and selections used in 13 TeV pp, 5.02 TeV pPb or PbPb collisions are similar to those in 8.16 TeV pPb collisions, and are described in previous correlation analyses [22, 25, 32, 43].

For all data sets analyzed, primary tracks, i.e. tracks that originate at the primary vertex and satisfy the high-purity criteria of Ref. [39], are used to perform the correlation measurements as well as to define event categories based on the charged-particle multiplicity ($N_{\text{trk}}^{\text{offline}}$). In addition, the impact parameter significance of the tracks with respect to the primary vertex in the longitudinal and the transverse direction are required to be less than 3 standard deviations. The relative p_T uncertainty must be less than 10%. To ensure high tracking efficiency, only tracks with $|\eta| < 2.4$ and $p_T > 0.3\,\text{GeV}/c$ are used in this analysis [39].

The pp, pPb, and PbPb data are compared in classes of $N_{\text{trk}}^{\text{offline}}$, where $N_{\text{trk}}^{\text{offline}}$ is the number

of primary tracks with $|\eta| < 2.4$ and $p_{\mathrm{T}} > 0.4\,\mathrm{GeV}/c$. The event classes are the same as in Refs. [24, 25].

The analysis techniques for two-particle correlations, averaged over $0.3 < p_{\mathrm{T}} < 3.0\,\mathrm{GeV}/c$, are identical to those used in Refs. [6, 7, 24, 26, 30, 32, 34]. The results are compared to published 5.02 TeV pPb [24] data. The v_4 coefficient in pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ is also measured, while the v_2 and v_3 coefficients have been obtained from Ref. [25]. The SC technique was first introduced by the ALICE Collaboration [18] and is based on four-particle correlations using cumulants. The main difference between the standard cumulant calculation and SC lies in the fact that the former is used to compute diagonal v_n terms and the latter is used for correlations between different coefficient orders. The framework for the calculation is the same as the one used in standard cumulant analysis and is based on the generic code distributed by Bilandzic et al. [44].

To study the correlation between the Fourier coefficients n and m, one can build 2- and 4-particle correlators with:

$$\langle\langle 2\rangle\rangle_n \equiv \left\langle\left\langle e^{i(n\phi_1 - n\phi_2)}\right\rangle\right\rangle \qquad \langle\langle 4\rangle\rangle_{n,m} \equiv \left\langle\left\langle e^{i(n\phi_1 + m\phi_2 - n\phi_3 - m\phi_4)}\right\rangle\right\rangle, \tag{1}$$

where $\langle\langle \ldots \rangle\rangle$ denotes the average correlations over all events. The final observable, the SC, is defined as follows:

$$SC(n,m) = \langle\langle 4\rangle\rangle_{n,m} - \langle\langle 2\rangle\rangle_n \langle\langle 2\rangle\rangle_m. \tag{2}$$

Expressed as a function of v_n, the symmetric cumulant $SC(n,m)$ measures correlations of Fourier coefficients between the order of m and n:

$$SC(n,m) = \left\langle v_n^2 v_m^2 \right\rangle - \left\langle v_n^2 \right\rangle \left\langle v_m^2 \right\rangle, \tag{3}$$

where $\langle \ldots \rangle$ denotes the average over all events. In this analysis, we compute a SC for events belonging to the same event multiplicity class ($N_{\mathrm{trk}}^{\mathrm{offline}}$) and with the same number of tracks entering in the calculation (i.e., $N_{\mathrm{trk}}^{\mathrm{ref}}$ with $0.3 < p_{\mathrm{T}} < 3.0\,\mathrm{GeV}/c$). Then, the different SCs are combined into larger bins by using the total number of 4-particle combinations as a weight, i.e., in an event with track multiplicity M, this weight equals $M(M-1)(M-2)(M-3)$. This weighting procedure is necessary to reduce the impact of multiplicity fluctuations, which are particularly relevant at low multiplicity [24, 25].

The systematic uncertainties of the experimental procedure are evaluated as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$ by varying the conditions in extracting v_n coefficients and SCs for both 8.16 TeV pPb and 5.02 TeV PbPb samples. For 13 TeV pp and 5.02 TeV pPb, the systematic uncertainties are taken from Refs. [25, 34]. Systematic uncertainties due to tracking inefficiency and misreconstructed track rate are studied by varying the track quality requirements. The selection thresholds on the significance of the transverse and longitudinal track impact parameter divided by their uncertainties are varied from 2 to 5 standard deviations. In addition, the relative p_{T} uncertainty is varied from 5% to 10%. The resulting systematic uncertainty is found to be 1–2% for v_n and SCs depending on multiplicity in both colliding systems. The sensitivity of the results to the primary vertex position along the beam axis (z_{vtx}) is quantified by comparing events with different z_{vtx} locations from -15 to $+15$ cm. The magnitude of this systematic effect is estimated to be 1–2%, depending on multiplicity, and is independent of colliding system and method (v_n or SC). For the 8.16 TeV pPb sample, two additional sources of systematic uncertainties are investigated. To study potential trigger biases, a comparison to high-multiplicity pPb data for a given multiplicity range that have been collected by a lower threshold trigger with 100% efficiency is performed. This uncertainty is found to be less than 1%. The possible contamination by

residual pileup interactions is also studied by varying the pileup selection of events in the performed analysis, from no pileup rejection at all to selecting events with only one reconstructed vertex. For v_n results, this effect is more important at high multiplicities (3%) than at low ones (0.1%). For the SC method, it is independent of multiplicity and estimated to be 1%. The total systematic uncertainty is estimated to be 1.7–4.1% for v_n depending on multiplicity and 1.8% for SCs.

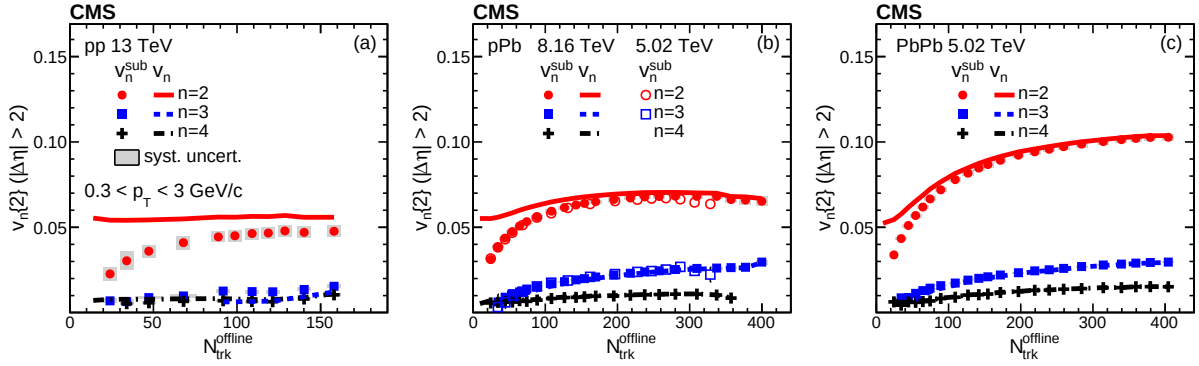

Figure 1: The v_2, v_3 [25], and v_4 coefficients from long-range two-particle correlations as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$ in 13 TeV pp (a), 5.02 TeV [32] and 8.16 TeV pPb (b), and 5.02 TeV PbPb collisions (c). The results corrected by low-multiplicity subtraction are denoted as v_n^{sub}. The lines show the v_n results before subtraction of low-multiplicity correlations. The gray boxes represent systematic uncertainties.

Measurements of v_2, v_3, and v_4 coefficients for $0.3 < p_{\mathrm{T}} < 3\,\mathrm{GeV}/c$ extracted from long-range two-particle correlations are shown in Fig. 1, as a function of multiplicity in 13 TeV pp, 5.02 and 8.16 TeV pPb, and 5.02 TeV PbPb collisions. The contribution to v_n coefficients from back-to-back jet correlations are corrected by subtracting correlations from very low-multiplicity events (v_n^{sub}), as done in Refs. [25, 32]. The v_n results before subtraction are also shown as lines in Fig. 1. For $N_{\mathrm{trk}}^{\mathrm{offline}} > 200$, the low-multiplicity subtraction has very small effect in pPb and PbPb collisions. At low multiplicity, this correction plays a larger role, in particular for pp collisions where dijet correlations are expected to be the main source of correlations.

By comparison with 5.02 TeV pPb data, the new 8.16 TeV pPb results extend the measurements of v_n coefficients to a higher-multiplicity region, due to the higher collision energy and integrated luminosity. The v_2 coefficient increases with $N_{\mathrm{trk}}^{\mathrm{offline}}$, saturating for $N_{\mathrm{trk}}^{\mathrm{offline}} > 200$. Finite v_4, which are about 50% smaller than the v_3 coefficients for $N_{\mathrm{trk}}^{\mathrm{offline}} > 100$, are also observed in all three systems.

Measurements of symmetric cumulants $SC(2,3)$ and $SC(2,4)$ for $0.3 < p_{\mathrm{T}} < 3\,\mathrm{GeV}/c$ from four-particle correlations are shown in Fig. 2, as a function of multiplicity in 13 TeV pp, 5.02 and 8.16 TeV pPb, and 5.02 TeV PbPb, to further study the correlations of different v_n coefficients.

In pp collisions, both $SC(2,3)$ and $SC(2,4)$ decrease as $N_{\mathrm{trk}}^{\mathrm{offline}}$ increases. The $SC(2,4)$ values always remain positive, while there is an indication of a transition to negative values for $SC(2,3)$ at $N_{\mathrm{trk}}^{\mathrm{offline}} > 110$ but the measurement is not precise enough to draw a firm conclusion. For pPb and PbPb data at sufficiently high multiplicities (e.g., $N_{\mathrm{trk}}^{\mathrm{offline}} > 60$), clear negative values of $SC(2,3)$ are observed, while $SC(2,4)$ values are positive. The PbPb data are consistent with results reported at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV [18].

In hydrodynamic models, correlations of v_2 and v_3 can be directly related to the initial eccentricity correlations [18, 20, 21]. Theoretical studies of v_n correlations in small colliding systems were performed based on purely eccentricity correlations [38]. An anticorrelation of v_2 and

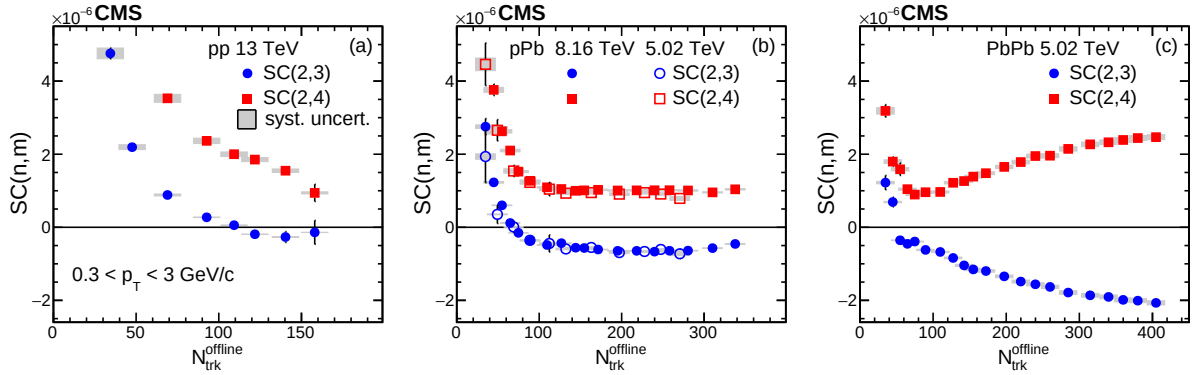

Figure 2: The SCs for the second and third coefficient (red points) and the second and fourth coefficient (blue points) as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$ in 13 TeV pp (a), 5.02 TeV and 8.16 TeV pPb (b), and 5.02 TeV PbPb collisions (c). The gray boxes represent systematic uncertainties.

v_3 in pPb collisions has been predicted at high multiplicities [38], which is consistent with the experimental observation. A positive correlation of v_2 and v_3 is predicted over the full multiplicity range in pp collisions [38], while a hint of anticorrelation is seen in the data at high multiplicity. However, larger pp data samples are needed to draw a definitive conclusion. At low $N_{\mathrm{trk}}^{\mathrm{offline}}$ ranges ($N_{\mathrm{trk}}^{\mathrm{offline}} < 100$) for all three systems, both $SC(2,3)$ and $SC(2,4)$ have positive values, which increase as $N_{\mathrm{trk}}^{\mathrm{offline}}$ decreases. It should be noted that, in the low multiplicity region, short-range few-body correlations such as jets are likely to have a dominant contribution, which need to be properly accounted for before comparing to models of long-range collective correlations. Indeed, the jet contribution at low $N_{\mathrm{trk}}^{\mathrm{offline}}$ might be different in pp, pPb and PbPb and lead to slightly different behaviors of the SCs in this multiplicity range as observed in the data. Finally, calculations from initial state gluon correlations in the color-glass condensate framework have also been shown to capture the signs of the v_n correlation data [45, 46], although it remains to be seen if the magnitude of correlations in the measured multiplicity region can be quantitatively reproduced. Recently, new methods have been proposed to suppress the contribution from jets down to low multiplicities by introducing sub-events in the cumulant calculation [47, 48]. Future studies using these methods will be of high interest to better understand the short-range correlation contribution to correlation measurements at low multiplicity.

The absolute magnitudes of $SC(2,3)$ and $SC(2,4)$ are found to be larger in PbPb than in pPb system at high multiplicities. This may be related to the different magnitude of v_n coefficients as indicated in Fig. 1. To investigate the intrinsic correlation between v_n coefficients and compare across different collision systems in a more quantitative way, $SC(2,3)$ and $SC(2,4)$ are normalized by $\langle (v_2^{\mathrm{sub}})^2 \rangle \langle (v_3^{\mathrm{sub}})^2 \rangle$ and $\langle (v_2^{\mathrm{sub}})^2 \rangle \langle (v_4^{\mathrm{sub}})^2 \rangle$, respectively, based on the v_n values from two-particle correlations in Fig. 1. As the two-particle correlation v_n^{sub} with a rapidity gap is used for the normalization, the results might be affected by the event-plane decorrelation measured in Ref. [49] at the level of a few percent. Nevertheless, all systems would be affected consistently such that the conclusions from the results would not be modified. In addition, the short-range correlation contribution is suppressed with different approaches in the numerator (SC) and the denominator ($\langle v_n^2 \rangle \langle v_m^2 \rangle$). The impact of the short-range correlation was investigated by using the unsubtracted v_n for the normalization. As expected, at high multiplicity, the results remain unchanged. The resulting normalized SCs in all three colliding systems are shown in Fig. 3.

The normalized $SC(2,3)$ values are found to be very similar between pPb and PbPb systems at high multiplicities. Together with the v_n results in Fig. 1, these measurements strongly suggest

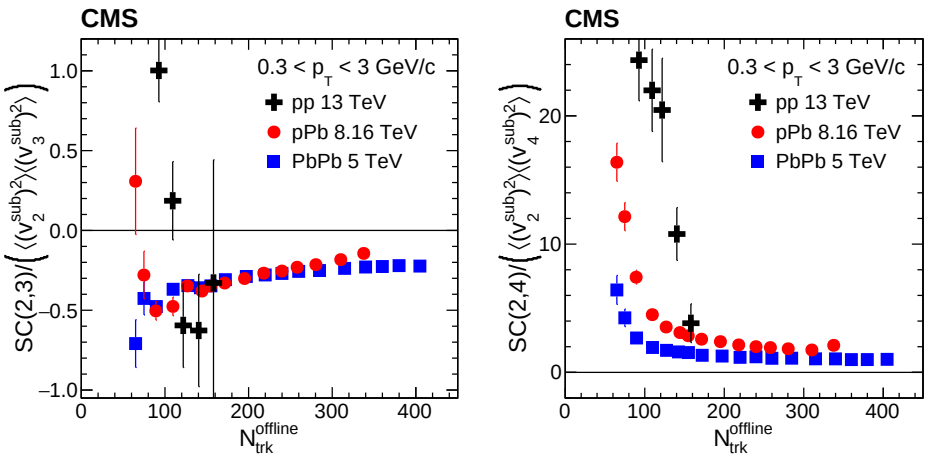

Figure 3: The SCs for the second and third coefficients (left) and the second and fourth coefficients (right) normalized by $\langle (v_2^{\mathrm{sub}})^2 \rangle \langle (v_3^{\mathrm{sub}})^2 \rangle$ and $\langle (v_2^{\mathrm{sub}})^2 \rangle \langle (v_4^{\mathrm{sub}})^2 \rangle$ from two-particle correlations. The results are shown as a function of $N_{\mathrm{trk}}^{\mathrm{offline}}$ in 13 TeV pp, 8.16 TeV pPb, and 5.02 TeV PbPb collisions.

a unified paradigm to explain collective behavior observed in large and small hadronic collisions. In the context of hydrodynamic models, the $SC(2,3)$ data in pPb and PbPb collisions suggest similar fluctuations of initial-state energy density of the collective medium [18]. This common behavior may even apply to pp collisions for $N_{\mathrm{trk}}^{\mathrm{offline}} > 120$, where $SC(2,3)$ tends to converge to a unified value for all three systems, although statistical uncertainties are still too large to draw a firm conclusion. The $SC(2,4)$, on the other hand, shows a clear dependence on the system size with a larger value for smaller systems. The observed difference between $SC(2,4)$ values in pPb and PbPb collisions may point to a different contribution of initial-state fluctuations or transport properties of the medium such as the shear viscosity to entropy ratio [18]. Further calculations of $SC(2,3)$ and $SC(2,4)$ with full hydrodynamic evolution would be needed for a quantitative comparison to the small system data.

In summary, the first measurements of azimuthal anisotropy Fourier coefficients and correlations of different coefficients in 8.16 TeV pPb collisions are presented based on data collected by the CMS experiment at the LHC. The v_2, v_3, and v_4 Fourier coefficients are extracted from long-range two-particle correlations in classes of event multiplicity, and are found to be consistent with 5.02 TeV pPb data. The pPb results are compared to those in 13 TeV pp and 5.02 TeV PbPb. Using a four-particle cumulant technique, correlations of different coefficient orders are obtained, where a negative (positive) correlation is observed between v_2 and v_3 (v_4) in pPb collisions. This behavior is similar to what is observed in the PbPb system, where the result is attributed to the hydrodynamic flow of a strongly interacting medium. Normalized correlation coefficients for v_2 and v_3 are found to be quantitatively similar between pPb and PbPb, while for v_2 and v_4 the results are larger in pPb than in PbPb. The corresponding result in pp collisions shows a similar trend at high multiplicity but the statistical uncertainties are too large to make a quantitative statement. The results presented in this Letter provide further evidence of a similar origin of collectivity observed in small and large hadronic systems and impose constraints on theoretical model calculations.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other

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

References

[1] STAR Collaboration, "Distributions of charged hadrons associated with high transverse momentum particles in pp and Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200\,\mathrm{GeV}$", *Phys. Rev. Lett.* **95** (2005) 152301, doi:10.1103/PhysRevLett.95.152301, arXiv:nucl-ex/0501016.

[2] STAR Collaboration, "Long range rapidity correlations and jet production in high energy nuclear collisions", *Phys. Rev. C* **80** (2009) 064912, doi:10.1103/PhysRevC.80.064912, arXiv:0909.0191.

[3] PHOBOS Collaboration, "System size dependence of cluster properties from two-particle angular correlations in Cu+Cu and Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200\,\mathrm{GeV}$", *Phys. Rev. C* **81** (2010) 024904, doi:10.1103/PhysRevC.81.024904, arXiv:0812.1172.

[4] PHOBOS Collaboration, "High transverse momentum triggered correlations over a large pseudorapidity acceptance in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200\,\mathrm{GeV}$", *Phys. Rev. Lett.* **104** (2010) 062301, doi:10.1103/PhysRevLett.104.062301, arXiv:0903.2811.

[5] STAR Collaboration, "Three-particle coincidence of the long range pseudorapidity correlation in high energy nucleus-nucleus collisions", *Phys. Rev. Lett.* **105** (2010) 022301, doi:10.1103/PhysRevLett.105.022301, arXiv:0912.3977.

[6] CMS Collaboration, "Long-range and short-range dihadron angular correlations in central PbPb collisions at a nucleon-nucleon center of mass energy of 2.76 TeV", *JHEP* **07** (2011) 076, doi:10.1007/JHEP07(2011)076, arXiv:1105.2438.

[7] CMS Collaboration, "Centrality dependence of dihadron correlations and azimuthal anisotropy harmonics in PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV", *Eur. Phys. J. C* **72** (2012) 2012, doi:10.1140/epjc/s10052-012-2012-3, arXiv:1201.3158.

[8] ALICE Collaboration, "Harmonic decomposition of two-particle angular correlations in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76\,\mathrm{TeV}$", *Phys. Lett. B* **708** (2012) 249, doi:10.1016/j.physletb.2012.01.060, arXiv:1109.2501.

[9] ATLAS Collaboration, "Measurement of the azimuthal anisotropy for charged particle production in $\sqrt{s_{\rm NN}}$ = 2.76 TeV lead-lead collisions with the ATLAS detector", *Phys. Rev. C* **86** (2012) 014907, doi:10.1103/PhysRevC.86.014907, arXiv:1203.3087.

[10] CMS Collaboration, "Studies of azimuthal dihadron correlations in ultra-central PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *JHEP* **02** (2014) 088, doi:10.1007/JHEP02(2014)088, arXiv:1312.1845.

[11] J.-Y. Ollitrault, "Anisotropy as a signature of transverse collective flow", *Phys. Rev. D* **46** (1992) 229, doi:10.1103/PhysRevD.46.229.

[12] B. Alver and G. Roland, "Collision geometry fluctuations and triangular flow in heavy-ion collisions", *Phys. Rev. C* **81** (2010) 054905, doi:10.1103/PhysRevC.81.054905, arXiv:1003.0194. Erratum: doi:10.1103/PhysRevC.82.039903.

[13] S. Voloshin and Y. Zhang, "Flow study in relativistic nuclear collisions by Fourier expansion of azimuthal particle distributions", *Z. Phys. C* **70** (1996) 665, doi:10.1007/s002880050141, arXiv:hep-ph/9407282.

[14] B. H. Alver, C. Gombeaud, M. Luzum, and J.-Y. Ollitrault, "Triangular flow in hydrodynamics and transport theory", *Phys. Rev. C* **82** (2010) 034913, doi:10.1103/PhysRevC.82.034913, arXiv:1007.5469.

[15] B. Schenke, S. Jeon, and C. Gale, "Elliptic and triangular flow in event-by-event D=3+1 viscous hydrodynamics", *Phys. Rev. Lett.* **106** (2011) 042301, doi:10.1103/PhysRevLett.106.042301, arXiv:1009.3244.

[16] Z. Qiu, C. Shen, and U. Heinz, "Hydrodynamic elliptic and triangular flow in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Lett. B* **707** (2012) 151, doi:10.1016/j.physletb.2011.12.041, arXiv:1110.3033.

[17] ATLAS Collaboration, "Measurement of the correlation between flow harmonics of different order in lead-lead collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with the ATLAS detector", *Phys. Rev. C* **92** (2015) 034903, doi:10.1103/PhysRevC.92.034903, arXiv:1504.01289.

[18] ALICE Collaboration, "Correlated event-by-event fluctuations of flow harmonics in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV", *Phys. Rev. Lett.* **117** (2016) 182301, doi:10.1103/PhysRevLett.117.182301, arXiv:1604.07663.

[19] A. Bilandzic et al., "Generic framework for anisotropic flow analyses with multiparticle azimuthal correlations", *Phys. Rev. C* **89** (2014) 064904, doi:10.1103/PhysRevC.89.064904, arXiv:1312.3572.

[20] X. Zhu, Y. Zhou, H. Xu, and H. Song, "Correlations of flow harmonics in 2.76A TeV Pb–Pb collisions", *Phys. Rev. C* **95** (2017) 044902, doi:10.1103/PhysRevC.95.044902, arXiv:1608.05305.

[21] G. Giacalone, L. Yan, J. Noronha-Hostler, and J.-Y. Ollitrault, "Symmetric cumulants and event-plane correlations in Pb+Pb collisions", *Phys. Rev. C* **94** (2016) 014906, doi:10.1103/PhysRevC.94.014906, arXiv:1605.08303.

[22] CMS Collaboration, "Observation of long-range near-side angular correlations in proton-proton collisions at the LHC", *JHEP* **09** (2010) 091, doi:10.1007/JHEP09(2010)091, arXiv:1009.4122.

[23] ATLAS Collaboration, "Observation of long-range elliptic azimuthal anisotropies in $\sqrt{s} = 13$ and 2.76 TeV pp collisions with the ATLAS detector", *Phys. Rev. Lett.* **116** (2016) 172301, doi:10.1103/PhysRevLett.116.172301, arXiv:1509.04776.

[24] CMS Collaboration, "Measurement of long-range near-side two-particle angular correlations in pp collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **116** (2016) 172302, doi:10.1103/PhysRevLett.116.172302, arXiv:1510.03068.

[25] CMS Collaboration, "Evidence for collectivity in pp collisions at the LHC", *Phys. Lett. B* **765** (2017) 193, doi:10.1016/j.physletb.2016.12.009, arXiv:1606.06198.

[26] CMS Collaboration, "Observation of long-range near-side angular correlations in proton-lead collisions at the LHC", *Phys. Lett. B* **718** (2013) 795, doi:10.1016/j.physletb.2012.11.025, arXiv:1210.5482.

[27] ALICE Collaboration, "Long-range angular correlations on the near and away side in pPb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", *Phys. Lett. B* **719** (2013) 29, doi:10.1016/j.physletb.2013.01.012, arXiv:1212.2001.

[28] ATLAS Collaboration, "Observation of Associated Near-side and Away-side Long-range Correlations in $\sqrt{s_{\rm NN}} = 5.02$ TeV Proton-lead Collisions with the ATLAS Detector", *Phys. Rev. Lett.* **110** (2013) 182302, doi:10.1103/PhysRevLett.110.182302, arXiv:1212.5198.

[29] LHCb Collaboration, "Measurements of long-range near-side angular correlations in $\sqrt{s_{\rm NN}} = 5$ TeV proton-lead collisions in the forward region", *Phys. Lett. B* **762** (2016) 473, doi:10.1016/j.physletb.2016.09.064, arXiv:1512.00439.

[30] CMS Collaboration, "Long-range two-particle correlations of strange hadrons with charged particles in pPb and PbPb collisions at LHC energies", *Phys. Lett. B* **742** (2015) 200, doi:10.1016/j.physletb.2015.01.034, arXiv:1409.3392.

[31] ALICE Collaboration, "Long-range angular correlations of π, K and p in p–Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV", *Phys. Lett. B* **726** (2013) 164, doi:10.1016/j.physletb.2013.08.024, arXiv:1307.3237.

[32] CMS Collaboration, "Multiplicity and transverse momentum dependence of two- and four-particle correlations in pPb and PbPb collisions", *Phys. Lett. B* **724** (2013) 213, doi:10.1016/j.physletb.2013.06.028, arXiv:1305.0609.

[33] ATLAS Collaboration, "Measurement of long-range pseudorapidity correlations and azimuthal harmonics in $\sqrt{s_{\rm NN}} = 5.02$ TeV proton-lead collisions with the ATLAS detector", *Phys. Rev. C* **90** (2014) 044906, doi:10.1103/PhysRevC.90.044906, arXiv:1409.1792.

[34] CMS Collaboration, "Evidence for collective multi-particle correlations in pPb collisions", *Phys. Rev. Lett.* **115** (2015) 012301, doi:10.1103/PhysRevLett.115.012301, arXiv:1502.05382.

[35] K. Dusling, W. Li, and B. Schenke, "Novel collective phenomena in high-energy proton-proton and proton-nucleus collisions", *Int. J. Mod. Phys. E* **25** (2016) 1630002, doi:10.1142/S0218301316300022, arXiv:1509.07939.

[36] S. Schlichting and B. Schenke, "The shape of the proton at high energies", *Phys. Lett. B* **739** (2014) 313, doi:10.1016/j.physletb.2014.10.068, arXiv:1407.8458.

[37] P. Bożek, W. Broniowski, and M. Rybczyński, "Wounded quarks in A+A, p+A, and p+p collisions", *Phys. Rev. C* **94** (2016) 014902, doi:10.1103/PhysRevC.94.014902, arXiv:1604.07697.

[38] K. Welsh, J. Singer, and U. W. Heinz, "Initial state fluctuations in collisions between light and heavy ions", *Phys. Rev. C* **94** (2016) 024919, doi:10.1103/PhysRevC.94.024919, arXiv:1605.09418.

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

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

[41] GEANT4 Collaboration, "Geant4 — a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[42] M. L. Miller, K. Reygers, S. J. Sanders, and P. Steinberg, "Glauber modeling in high energy nuclear collisions", *Ann. Rev. Nucl. Part. Sci.* **57** (2007) 205, doi:10.1146/annurev.nucl.57.090506.123020, arXiv:nucl-ex/0701025.

[43] CMS Collaboration, "Observation of charge-dependent azimuthal correlations in pPb collisions and its implication for the search for the chiral magnetic effect", *Phys. Rev. Lett.* **118** (2017) 122301, doi:10.1103/PhysRevLett.118.122301, arXiv:1610.00263.

[44] A. Bilandzic, R. Snellings, and S. Voloshin, "Flow analysis with cumulants: Direct calculations", *Phys. Rev. C* **83** (2011) 044913, doi:10.1103/PhysRevC.83.044913, arXiv:1010.0233.

[45] K. Dusling, M. Mace, and R. Venugopalan, "Multiparticle collectivity from initial state correlations in high energy proton-nucleus collisions", *Phys. Rev. Lett.* **120** (2018) 042002, doi:10.1103/PhysRevLett.120.042002, arXiv:1705.00745.

[46] K. Dusling, M. Mace, and R. Venugopalan, "Parton model description of multiparticle azimuthal correlations in pA collisions", *Phys. Rev. D* **97** (2018) 016014, doi:10.1103/PhysRevD.97.016014, arXiv:1706.06260.

[47] P. Di Francesco, M. Guilbaud, M. Luzum, and J.-Y. Ollitrault, "Systematic procedure for analyzing cumulants at any order", *Phys. Rev. C* **95** (2017) 044911, doi:10.1103/PhysRevC.95.044911, arXiv:1612.05634.

[48] J. Jia, M. Zhou, and A. Trzupek, "Revealing long-range multiparticle collectivity in small collision systems via subevent cumulants", *Phys. Rev. C* **96** (2017) 034906, doi:10.1103/PhysRevC.96.034906, arXiv:1701.03830.

[49] CMS Collaboration, "Evidence for transverse momentum and pseudorapidity dependent event plane fluctuations in PbPb and pPb collisions", *Phys. Rev. C* **92** (2015) 034911, doi:10.1103/PhysRevC.92.034911, arXiv:1503.01692.

A The CMS Collaboration

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

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

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

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

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

Université Libre de Bruxelles, Bruxelles, Belgium
H. Brun, B. Clerbaux, G. De Lentdecker, H. Delannoy, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, J. Luetic, T. Maerschalk, A. Marinov, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, D. Vannerom, R. Yonamine, F. Zenoni, F. Zhang[2]

Ghent University, Ghent, Belgium
A. Cimmino, T. Cornelis, D. Dobur, A. Fagot, M. Gul, I. Khvastunov, D. Poyraz, C. Roskas, S. Salva, M. Tytgat, W. Verbeke, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
H. Bakhshiansohi, O. Bondu, S. Brochet, G. Bruno, C. Caputo, A. Caudron, S. De Visscher, C. Delaere, M. Delcourt, B. Francois, A. Giammanco, A. Jafari, M. Komm, G. Krintiras, V. Lemaitre, A. Magitteri, A. Mertens, M. Musich, K. Piotrzkowski, L. Quertenmont, M. Vidal Marono, S. Wertz

Université de Mons, Mons, Belgium
N. Beliy

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
W.L. Aldá Júnior, F.L. Alves, G.A. Alves, L. Brito, M. Correa Martins Junior, C. Hensel, A. Moraes, M.E. Pol, P. Rebello Teles

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

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

Institute for Nuclear Research and Nuclear Energy of Bulgaria Academy of Sciences
A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Misheva, M. Rodozov, M. Shopova, S. Stoykova, G. Sultanov

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

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

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

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

Universidad de Los Andes, Bogota, Colombia
C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, C.F. González Hernández, J.D. Ruiz Alvarez

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

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

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

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

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

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

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
R.K. Dewanjee, M. Kadastik, L. Perrini, M. Raidal, A. Tiko, C. Veelken

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

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, T. Järvinen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, E. Tuominen, J. Tuominiemi, E. Tuovinen

Lappeenranta University of Technology, Lappeenranta, Finland
J. Talvitie, T. Tuuva

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

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

Université de Strasbourg, CNRS, IPHC UMR 7178, F-67000 Strasbourg, France
J.-L. Agram[12], J. Andrea, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte[12], X. Coubez, J.-C. Fontaine[12], D. Gelé, U. Goerlach, M. Jansová, A.-C. Le Bihan, N. Tonon, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, C. Bernet, G. Boudoul, R. Chierici, D. Contardo, P. Depasse, H. El Mamouni, J. Fay, L. Finco, S. Gascon, M. Gouzevitch, G. Grenier, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, A. Popov[13], V. Sordini, M. Vander Donckt, S. Viret

Georgian Technical University, Tbilisi, Georgia
T. Toriashvili[14]

Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[7]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, L. Feld, M.K. Kiesel, K. Klein, M. Lipinski, M. Preuten, C. Schomakers, J. Schulz, T. Verlage, V. Zhukov[13]

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
A. Albert, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, M. Hamer, T. Hebbeker, C. Heidemann, K. Hoepfner, S. Knutzen, M. Merschmeyer, A. Meyer, P. Millet, S. Mukherjee, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, D. Teyssier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
G. Flügge, B. Kargoll, T. Kress, A. Künsken, J. Lingemann, T. Müller, A. Nehrkorn, A. Nowack, C. Pistone, O. Pooth, A. Stahl[15]

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, K. Beernaert, O. Behnke, U. Behrens, A. Bermúdez Martínez, A.A. Bin Anuar, K. Borras[16], V. Botta, A. Campbell, P. Connor, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Eckerlin, D. Eckstein, T. Eichhorn,

E. Eren, E. Gallo[17], J. Garay Garcia, A. Geiser, A. Gizhko, J.M. Grados Luyando, A. Grohsjean, P. Gunnellini, M. Guthoff, A. Harb, J. Hauk, M. Hempel[18], H. Jung, A. Kalogeropoulos, M. Kasemann, J. Keaveney, C. Kleinwort, I. Korol, D. Krücker, W. Lange, A. Lelek, T. Lenz, J. Leonard, K. Lipka, W. Lohmann[18], R. Mankel, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, E. Ntomari, D. Pitzl, A. Raspereza, B. Roland, M. Savitskyi, P. Saxena, R. Shevchenko, S. Spannagel, N. Stefaniuk, G.P. Van Onsem, R. Walsh, Y. Wen, K. Wichmann, C. Wissing, O. Zenaiev

University of Hamburg, Hamburg, Germany
S. Bein, V. Blobel, M. Centis Vignali, T. Dreyer, E. Garutti, D. Gonzalez, J. Haller, A. Hinzmann, M. Hoffmann, A. Karavdina, R. Klanner, R. Kogler, N. Kovalchuk, S. Kurz, T. Lapsien, I. Marchesini, D. Marconi, M. Meyer, M. Niedziela, D. Nowatschin, F. Pantaleo[15], T. Peiffer, A. Perieanu, C. Scharf, P. Schleper, A. Schmidt, S. Schumann, J. Schwandt, J. Sonneveld, H. Stadie, G. Steinbrück, F.M. Stober, M. Stöver, H. Tholen, D. Troendle, E. Usai, L. Vanelderen, A. Vanhoefer, B. Vormwald

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
M. Akbiyik, C. Barth, S. Baur, E. Butz, R. Caspart, T. Chwalek, F. Colombo, W. De Boer, A. Dierlamm, B. Freund, R. Friese, M. Giffels, D. Haitz, F. Hartmann[15], S.M. Heindl, U. Husemann, F. Kassel[15], S. Kudella, H. Mildner, M.U. Mozer, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, M. Schröder, I. Shvetsov, G. Sieber, H.J. Simonis, R. Ulrich, S. Wayand, M. Weber, T. Weiler, S. Williamson, C. Wöhrmann, R. Wolf

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

National and Kapodistrian University of Athens, Athens, Greece
G. Karathanasis, S. Kesisoglou, A. Panagiotou, N. Saoulidou

National Technical University of Athens, Athens, Greece
K. Kousouris

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

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
M. Csanad, N. Filipovic, G. Pasztor, G.I. Veres[19]

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, D. Horvath[20], Á. Hunyadi, F. Sikler, V. Veszpremi, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Karancsi[21], A. Makovec, J. Molnar, Z. Szillasi

Institute of Physics, University of Debrecen, Debrecen, Hungary
M. Bartók[19], P. Raics, Z.L. Trocsanyi, B. Ujvari

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

National Institute of Science Education and Research, Bhubaneswar, India
S. Bahinipati[22], S. Bhowmik, P. Mal, K. Mandal, A. Nayak[23], D.K. Sahoo[22], N. Sahoo, S.K. Swain

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

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

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
R. Bhardwaj, R. Bhattacharya, S. Bhattacharya, U. Bhawandeep, S. Dey, S. Dutt, S. Dutta, S. Ghosh, N. Majumdar, A. Modak, K. Mondal, S. Mukhopadhyay, S. Nandan, A. Purohit, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan, S. Thakur

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

Bhabha Atomic Research Centre, Mumbai, India
R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty[15], P.K. Netrakanti, L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research-A, Mumbai, India
T. Aziz, S. Dugad, B. Mahakud, S. Mitra, G.B. Mohanty, N. Sur, B. Sutar

Tata Institute of Fundamental Research-B, Mumbai, India
S. Banerjee, S. Bhattacharya, S. Chatterjee, P. Das, M. Guchait, Sa. Jain, S. Kumar, M. Maity[24], G. Majumder, K. Mazumdar, T. Sarkar[24], N. Wickramage[25]

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

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
S. Chenarani[26], E. Eskandari Tadavani, S.M. Etesami[26], M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi[27], F. Rezaei Hosseinabadi, B. Safarzadeh[28], M. Zeinali

University College Dublin, Dublin, Ireland
M. Felcini, M. Grunewald

INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], C. Calabria[a,b], A. Colaleo[a], D. Creanza[a,c], L. Cristella[a,b], N. De Filippis[a,c], M. De Palma[a,b], F. Errico[a,b], L. Fiore[a], G. Iaselli[a,c], S. Lezki[a,b], G. Maggi[a,c], M. Maggi[a], G. Miniello[a,b], S. My[a,b], S. Nuzzo[a,b], A. Pompili[a,b], G. Pugliese[a,c], R. Radogna[a], A. Ranieri[a], G. Selvaggi[a,b], A. Sharma[a], L. Silvestris[a,15], R. Venditti[a], P. Verwilligen[a]

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

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

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], K. Chatterjee[a,b], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], P. Lenzi[a,b], M. Meschini[a], S. Paoletti[a], L. Russo[a,29], G. Sguazzoni[a], D. Strom[a], L. Viliani[a,b,15]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera[15]

INFN Sezione di Genova [a], Università di Genova [b], Genova, Italy
V. Calvelli[a,b], F. Ferro[a], E. Robutti[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a], L. Brianza[a,b], F. Brivio[a,b], V. Ciriolo[a,b], M.E. Dinardo[a,b], S. Fiorendi[a,b], S. Gennai[a], A. Ghezzi[a,b], P. Govoni[a,b], M. Malberti[a,b], S. Malvezzi[a], R.A. Manzoni[a,b], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], K. Pauwels[a,b], D. Pedrini[a], S. Pigazzini[a,b,30], S. Ragazzi[a,b], N. Redaelli[a], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli 'Federico II' [b], Napoli, Italy, Università della Basilicata [c], Potenza, Italy, Università G. Marconi [d], Roma, Italy
S. Buontempo[a], N. Cavallo[a,c], S. Di Guida[a,d,15], F. Fabozzi[a,c], F. Fienga[a,b], A.O.M. Iorio[a,b], W.A. Khan[a], L. Lista[a], S. Meola[a,d,15], P. Paolucci[a,15], C. Sciacca[a,b], F. Thyssen[a]

INFN Sezione di Padova [a], Università di Padova [b], Padova, Italy, Università di Trento [c], Trento, Italy
P. Azzi[a], N. Bacchetta[a], L. Benato[a,b], D. Bisello[a,b], A. Boletti[a,b], R. Carlin[a,b], A. Carvalho Antunes De Oliveira[a,b], P. Checchia[a], P. De Castro Manzano[a], T. Dorigo[a], U. Dosselli[a], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino[a], S. Lacaprara[a], M. Margoni[a,b], A.T. Meneguzzo[a,b], N. Pozzobon[a,b], P. Ronchese[a,b], R. Rossin[a,b], F. Simonetto[a,b], E. Torassa[a], M. Zanetti[a,b], P. Zotto[a,b], G. Zumerle[a,b]

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

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

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
K. Androsov[a], P. Azzurri[a,15], G. Bagliesi[a], T. Boccali[a], L. Borrello, R. Castaldi[a], M.A. Ciocci[a,b], R. Dell'Orso[a], G. Fedi[a], L. Giannini[a,c], A. Giassi[a], M.T. Grippo[a,29], F. Ligabue[a,c], T. Lomtadze[a], E. Manca[a,c], G. Mandorli[a,c], L. Martini[a,b], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], A. Savoy-Navarro[a,31], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Sapienza Università di Roma [b], Rome, Italy
L. Barone[a,b], F. Cavallari[a], M. Cipriani[a,b], D. Del Re[a,b,15], E. Di Marco[a,b], M. Diemoz[a], S. Gelli[a,b], E. Longo[a,b], F. Margaroli[a,b], B. Marzocchi[a,b], P. Meridiani[a], G. Organtini[a,b], R. Paramatti[a,b], F. Preiato[a,b], S. Rahatlou[a,b], C. Rovelli[a], F. Santanastasio[a,b]

INFN Sezione di Torino [a], Università di Torino [b], Torino, Italy, Università del Piemonte Orientale [c], Novara, Italy
N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], N. Bartosik[a], R. Bellan[a,b], C. Biino[a], N. Cartiglia[a], F. Cenna[a,b], M. Costa[a,b], R. Covarelli[a,b], A. Degano[a,b], N. Demaria[a], B. Kiani[a,b], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], E. Monteil[a,b], M. Monteno[a],

M.M. Obertino[a,b], L. Pacher[a,b], N. Pastrone[a], M. Pelliccioni[a], G.L. Pinna Angioni[a,b], F. Ravera[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], K. Shchelina[a,b], V. Sola[a], A. Solano[a,b], A. Staiano[a], P. Traczyk[a,b]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
S. Belforte[a], M. Casarsa[a], F. Cossutti[a], G. Della Ricca[a,b], A. Zanetti[a]

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

Chonbuk National University, Jeonju, Korea
A. Lee

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

Hanyang University, Seoul, Korea
J.A. Brochero Cifuentes, J. Goh, T.J. Kim

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

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

University of Seoul, Seoul, Korea
M. Choi, H. Kim, J.H. Kim, J.S.H. Lee, I.C. Park

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

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

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia
I. Ahmed, Z.A. Ibrahim, M.A.B. Md Ali[32], F. Mohamad Idris[33], W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
Reyes-Almanza, R, Ramirez-Sanchez, G., Duran-Osuna, M. C., H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz[34], Rabadan-Trejo, R. I., R. Lopez-Fernandez, J. Mejia Guisao, A. Sanchez-Hernandez

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

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

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

University of Auckland, Auckland, New Zealand
D. Krofcheck

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

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

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

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
K. Bunkowski, A. Byszuk[35], K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, A. Pyskir, M. Walczak

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

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, A. Lanev, A. Malakhov, V. Matveev[36,37], V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, N. Voytishin, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
Y. Ivanov, V. Kim[38], E. Kuznetsova[39], P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

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

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, A. Stepennov, M. Toms, E. Vlasov, A. Zhokin

Moscow Institute of Physics and Technology, Moscow, Russia
T. Aushev, A. Bylinkin[37]

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
R. Chistov[40], M. Danilov[40], P. Parygin, D. Philippov, S. Polikarpov, E. Tarkovskii, E. Zhemchugov

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin[37], I. Dremin[37], M. Kirakosyan[37], A. Terkulov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Baskakov, A. Belyaev, E. Boos, A. Ershov, A. Gribushin, A. Kaminskiy[41], O. Kodolova, V. Korotkikh, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev, I. Vardanyan

Novosibirsk State University (NSU), Novosibirsk, Russia
V. Blinov[42], Y.Skovpen[42], D. Shtol[42]

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

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[43], P. Cirkovic, D. Devetak, M. Dordevic, J. Milosevic, V. Rekovic, M. Stojanovic

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

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

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

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

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, E. Auffray, P. Baillon, A.H. Ball, D. Barney, M. Bianco, P. Bloch, A. Bocci, C. Botta, T. Camporesi, R. Castello, M. Cepeda, G. Cerminara, E. Chapon, Y. Chen, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, A. De Roeck, M. Dobson, B. Dorney, T. du Pree, M. Dünser, N. Dupont, A. Elliott-Peisert, P. Everaerts, F. Fallavollita, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, A. Gilbert, K. Gill, F. Glege, D. Gulhan, P. Harris, J. Hegeman, V. Innocente, P. Janot, O. Karacheban[18], J. Kieseler, H. Kirschenmann, V. Knünz, A. Kornmayer[15], M.J. Kortelainen, C. Lange, P. Lecoq, C. Lourenço, M.T. Lucchini, L. Malgeri, M. Mannelli, A. Martelli, F. Meijers, J.A. Merlin, S. Mersi, E. Meschi, P. Milenovic[44], F. Moortgat, M. Mulders, H. Neugebauer, J. Ngadiuba, S. Orfanelli, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, A. Racz, T. Reis, G. Rolandi[45], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, M. Selvaggi, A. Sharma, P. Silva, P. Sphicas[46], A. Stakia, J. Steggemann, M. Stoye, M. Tosi, D. Treille, A. Triossi, A. Tsirou, V. Veckalns[47], M. Verweij, W.D. Zeuner

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

Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
L. Bäni, P. Berger, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, C. Grab,

C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, T. Klijnsma, W. Lustermann, B. Mangano, M. Marionneau, M.T. Meinhard, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, G. Perrin, L. Perrozzi, M. Quittnat, M. Reichmann, M. Schönenberger, L. Shchutska, V.R. Tavolaro, K. Theofilatos, M.L. Vesterbacka Olsson, R. Wallny, D.H. Zhu

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

National Central University, Chung-Li, Taiwan
V. Candelise, T.H. Doan, Sh. Jain, R. Khurana, C.M. Kuo, W. Lin, A. Pozdnyakov, S.S. Yu

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

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand
B. Asavapibhop, K. Kovitanggoon, G. Singh, N. Srimanobhas

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

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

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

Istanbul Technical University, Istanbul, Turkey
M.N. Agaras, S. Atay, A. Cakir, K. Cankocak

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

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

University of Bristol, Bristol, United Kingdom
R. Aggleton, F. Ball, L. Beck, J.J. Brooke, D. Burns, E. Clement, D. Cussans, O. Davignon, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, D.M. Newbold[60], S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom
A. Belyaev[61], C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams

Imperial College, London, United Kingdom
G. Auzinger, R. Bainbridge, S. Breeze, O. Buchmuller, A. Bundock, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, R. Di Maria,

A. Elwood, Y. Haddad, G. Hall, G. Iles, T. James, R. Lane, C. Laner, L. Lyons, A.-M. Magnan, S. Malik, L. Mastrolorenzo, T. Matsushita, J. Nash, A. Nikitenko[6], V. Palladino, M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, S. Summers, A. Tapper, K. Uchida, M. Vazquez Acosta[62], T. Virdee[15], N. Wardle, D. Winterbottom, J. Wright, S.C. Zenz

Brunel University, Uxbridge, United Kingdom
J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, USA
A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, H. Liu, N. Pastika, C. Smith

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

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

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

Brown University, Providence, USA
G. Benelli, D. Cutts, A. Garabedian, J. Hakala, U. Heintz, J.M. Hogan, K.H.M. Kwok, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, R. Syarif, D. Yu

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

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

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

University of California, San Diego, La Jolla, USA
J.G. Branson, S. Cittolin, M. Derdzinski, B. Hashemi, A. Holzner, D. Klein, G. Kole, V. Krutelyov, J. Letts, I. Macneill, M. Masciovecchio, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech[63], J. Wood, F. Würthwein, A. Yagil, G. Zevi Della Porta

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

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

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

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

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

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

University of Florida, Gainesville, USA
D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Brinkerhoff, A. Carnes, M. Carver, D. Curry, R.D. Field, I.K. Furic, J. Konigsberg, A. Korytov, K. Kotov, P. Ma, K. Matchev, H. Mei, G. Mitselmakher, D. Rank, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, USA
Y.R. Joshi, S. Linn, P. Markowitz, J.L. Rodriguez

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

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

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

The University of Iowa, Iowa City, USA
B. Bilki[64], W. Clarida, K. Dilsiz[65], S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya[66], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul[67], Y. Onel, F. Ozok[68], A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA

B. Blumenfeld, A. Cocoros, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, J. Roskes, U. Sarica, M. Swartz, M. Xiao, C. You

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

Kansas State University, Manhattan, USA
A. Ivanov, K. Kaadze, Y. Maravin, A. Mohammadi, L.K. Saini, N. Skhirtladze, S. Toda

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

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

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

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

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

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

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

Northeastern University, Boston, USA
G. Alverson, E. Barberis, A. Hortiangtham, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, R. Teixeira De Lima, D. Trocino, D. Wood

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

University of Notre Dame, Notre Dame, USA
N. Dev, M. Hildreth, K. Hurtado Anampa, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Loukas, N. Marinelli, F. Meng, C. Mueller, Y. Musienko[36], M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, M. Wayne, M. Wolf, A. Woodard

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

Princeton University, Princeton, USA
S. Cooperstein, O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S. Higginbotham, D. Lange, J. Luo, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, P. Piroué, D. Stickland, C. Tully

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

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

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

Rice University, Houston, USA
A. Adair, B. Akgun, Z. Chen, K.M. Ecklund, F.J.M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B.P. Padley, J. Roberts, J. Rorie, Z. Tu, J. Zabel

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

The Rockefeller University, New York, USA
R. Ciesielski, K. Goulianos, C. Mesropian

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

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

Texas A&M University, College Station, USA
O. Bouhali[69], A. Castaneda Hernandez[69], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon[70], R. Mueller, Y. Pakhotin, R. Patel, A. Perloff, L. Perniè, D. Rathjens, A. Safonov, A. Tatarinov, K.A. Ulmer

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

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

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

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

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

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
3: Also at Universidade Estadual de Campinas, Campinas, Brazil
4: Also at Universidade Federal de Pelotas, Pelotas, Brazil
5: Also at Université Libre de Bruxelles, Bruxelles, Belgium
6: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
7: Also at Joint Institute for Nuclear Research, Dubna, Russia
8: Also at Suez University, Suez, Egypt
9: Now at British University in Egypt, Cairo, Egypt
10: Also at Fayoum University, El-Fayoum, Egypt
11: Now at Helwan University, Cairo, Egypt
12: Also at Université de Haute Alsace, Mulhouse, France
13: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
14: Also at Tbilisi State University, Tbilisi, Georgia
15: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
16: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
17: Also at University of Hamburg, Hamburg, Germany
18: Also at Brandenburg University of Technology, Cottbus, Germany
19: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
21: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary
22: Also at Indian Institute of Technology Bhubaneswar, Bhubaneswar, India
23: Also at Institute of Physics, Bhubaneswar, India
24: Also at University of Visva-Bharati, Santiniketan, India
25: Also at University of Ruhuna, Matara, Sri Lanka
26: Also at Isfahan University of Technology, Isfahan, Iran
27: Also at Yazd University, Yazd, Iran
28: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
29: Also at Università degli Studi di Siena, Siena, Italy
30: Also at INFN Sezione di Milano-Bicocca; Università di Milano-Bicocca, Milano, Italy
31: Also at Purdue University, West Lafayette, USA
32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
35: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
36: Also at Institute for Nuclear Research, Moscow, Russia
37: Now at National Research Nuclear University 'Moscow Engineering Physics

Institute' (MEPhI), Moscow, Russia
38: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
39: Also at University of Florida, Gainesville, USA
40: Also at P.N. Lebedev Physical Institute, Moscow, Russia
41: Also at INFN Sezione di Padova; Università di Padova; Università di Trento (Trento), Padova, Italy
42: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
43: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
44: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
45: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
46: Also at National and Kapodistrian University of Athens, Athens, Greece
47: Also at Riga Technical University, Riga, Latvia
48: Also at Universität Zürich, Zurich, Switzerland
49: Also at Stefan Meyer Institute for Subatomic Physics (SMI), Vienna, Austria
50: Also at Adiyaman University, Adiyaman, Turkey
51: Also at Istanbul Aydin University, Istanbul, Turkey
52: Also at Mersin University, Mersin, Turkey
53: Also at Cag University, Mersin, Turkey
54: Also at Piri Reis University, Istanbul, Turkey
55: Also at Izmir Institute of Technology, Izmir, Turkey
56: Also at Necmettin Erbakan University, Konya, Turkey
57: Also at Marmara University, Istanbul, Turkey
58: Also at Kafkas University, Kars, Turkey
59: Also at Istanbul Bilgi University, Istanbul, Turkey
60: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
61: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
62: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
63: Also at Utah Valley University, Orem, USA
64: Also at Beykent University, Istanbul, Turkey
65: Also at Bingol University, Bingol, Turkey
66: Also at Erzincan University, Erzincan, Turkey
67: Also at Sinop University, Sinop, Turkey
68: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
69: Also at Texas A&M University at Qatar, Doha, Qatar
70: Also at Kyungpook National University, Daegu, Korea