EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2017-098
2017/09/20

CMS-EXO-16-030

Search for low mass vector resonances decaying to quark-antiquark pairs in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$

The CMS Collaboration*

arXiv:1705.10532v2 [hep-ex] 19 Sep 2017

Abstract

A search is reported for a narrow vector resonance decaying to quark-antiquark pairs in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$, collected with the CMS detector at the LHC. The data sample corresponds to an integrated luminosity of $2.7\,\text{fb}^{-1}$. The vector resonance is produced at large transverse momenta, with its decay products merged into a single jet. The resulting signature is a peak over background in the distribution of the invariant mass of the jet. The results are interpreted in the framework of a leptophobic vector resonance and no evidence is found for such particles in the mass range of 100–300 GeV. Upper limits at 95% confidence level on the production cross section are presented in a region of mass-coupling phase space previously unexplored at the LHC. The region below 140 GeV has not been explored by any previous experiments.

Published in Physical Review Letters as doi:10.1103/PhysRevLett.119.111802.

© 2017 CERN for the benefit of the CMS Collaboration. CC-BY-3.0 license

*See Appendix A for the list of collaboration members

Over the past half-century, searches for narrow resonances in the dijet invariant mass spectrum have been an important part of the physics program at every collider. Such searches are well motivated within the many classes of theories beyond the current standard model (SM) that predict resonances with significant couplings to quarks [1–11]. The first searches for such particles at the UA1 [12] and UA2 [13, 14] experiments at the CERN S$\overline{\text{p}}$pS have been extended to larger values of resonance masses by the CDF [15–19] and D0 [20–22] experiments at the Fermilab Tevatron, and by the ATLAS [23–32] and CMS [33–45] experiments at the CERN LHC.

In this Letter, we report on a search for vector (Z') resonances decaying to quark-antiquark pairs ($q\bar{q}$) using the data collected in pp collisions at $\sqrt{s} = 13\,\text{TeV}$ by the CMS detector, corresponding to an integrated luminosity of $2.7\,\text{fb}^{-1}$. This search concentrates on the mass region of 100–300 GeV, exploring for the first time masses below 140 GeV [13, 14]. To access this mass regime, we present a new analysis technique exploiting novel jet substructure techniques and associated production with a jet. The search is interpreted in the framework of a leptophobic vector resonance and can also be reinterpreted in terms of searches for generic vector-like resonances decaying to quarks. [46].

With the increase in collision energy and beam intensity at hadron colliders, there has been a loss of search sensitivity for lighter resonances with couplings to quarks and gluons. The main experimental difficulties originate from the large increase in the cross section of multijet backgrounds at small resonance masses, and the more restrictive trigger requirements needed to reduce the data recording rate because of limited resources for event processing and storage. To overcome these difficulties, we require events to have a jet with large transverse momentum (p_{T}) from initial-state radiation (ISR) produced in association with the resonance. This ISR constraint provides enough energy in the event to satisfy the trigger. Combinatorial backgrounds are reduced by requiring the resonance be reconstructed within a single jet. The jet is required to have the two-prong structure expected from signal. The dominant background is from SM events comprised of jets produced through quantum chromodynamics (QCD). This multijet background is estimated by inverting the two-prong substructure requirement, which is specifically designed to be uncorrelated with the jet mass. By searching for new particles produced in association with an ISR jet, we are able to search for new resonances in a coupling and mass regime to which previous searches were insensitive.

A detailed description of the CMS detector, together with a definition of the coordinate system and the relevant kinematic variables, can be found in Ref. [47]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections, reside within the solenoid. Forward calorimeters extend the pseudorapidity (η) [47] coverage provided by the barrel and endcap detectors. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid.

We employ the CMS particle-flow (PF) algorithm [48, 49] to reconstruct and identify each individual particle through an optimized combination of information from the various elements of the CMS detector. The energy of a photon is obtained directly from the ECAL measurement, corrected for losses in detector sensitivity due to zero suppression near signal threshold. The energy of an electron is determined from a combination of its momentum at the primary interaction vertex determined using the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of a muon is obtained from the curvature of the corresponding track. The energy of a charged hadron is obtained from a combination of its momentum mea-

sured in the tracker and the matching of ECAL and HCAL energy depositions, corrected for the response function of the calorimeters to hadronic showers. The energy of a neutral hadron is obtained from the corresponding corrected ECAL and HCAL energies.

The benchmark Z' signal events are simulated at leading order (LO) using the MADGRAPH5_aMC@NLO 2.2.1 generator [50]; PYTHIA 8.205 generator [51, 52] and GEANT4 [53]. The dominant SM backgrounds arise from multijets, $W \to q\bar{q}$, and $Z \to q\bar{q}$ sources. These backgrounds are simulated at LO using the MADGRAPH5_aMC@NLO 2.2.1 generator and hadronized with PYTHIA using the CUETP8M1 tune [54]. To events containing W and Z bosons, we apply higher-order QCD and Electroweak (EWK) corrections to improve modeling of the high p_T W and Z events, following [55–59]. Owing to the similarity between the signal process and the SM W and Z topologies, the next-to-leading-order (NLO) QCD corrections and associated uncertainties applied to the W and Z simulations are also applied to the signal simulation. The NLO EWK corrections are not applied since such corrections are different for leptophobic Z' signal production.

To isolate the Z' signal and overcome trigger restrictions, we select a high-p_T signal jet, which typically recoils against another high-p_T ISR jet. We use a logical "or" of trigger requirements that selects on the total hadronic transverse energy in the event and, in some cases, additionally select on the mass of the jet after removing remnants of soft radiation, with the jet trimming technique [60]. Jets at the trigger level are reconstructed using the anti-k_T algorithm [61, 62] with a distance parameter of 0.8, and are referred to as AK8 jets.

After the trigger selection, the AK8 jets are reconstructed by clustering particle candidates in the event. To mitigate the effect of additional interactions in the same or adjacent bunch crossings (pileup), the pileup per particle identification (PUPPI) algorithm [63] is used, prior to jet clustering, to weight the PF candidates on the likelihood of coming from the primary interaction vertex. Other corrections are applied to jet energies as a function of jet η and p_T to match the detector response and to bring data and simulation into agreement. We require at least one AK8 jet to have $p_T > 500\,\text{GeV}$ and to satisfy $|\eta| < 2.5$ to be fully efficient with respect to the trigger requirements. We veto events containing identified and isolated electrons or muons with $p_T > 10\,\text{GeV}$, and $|\eta| < 2.5$ or 2.4, respectively, to reduce backgrounds from SM EWK processes.

The Lorentz-boosted $Z' \to q\bar{q}$ system is reconstructed as a single high-p_T jet, where the decay products have merged into one object, assumed to be the jet of highest p_T in the event. From simulation studies, approximately 70% of Z' signal events satisfy this assumption. The most important variable is the soft drop jet mass (m_{SD}), which employs soft drop grooming [64, 65], a technique used to remove soft and wide-angle radiation in jets. The variable m_{SD} enhances the peak at the Z' mass for signal events and the same act of soft drop grooming reduces the masses from background quark- and gluon-initiated events. For computing m_{SD}, we use a soft radiation fraction selection greater than $z = 0.1$ and an angular exponent parameter of $\beta = 0$.

Since the $Z' \to q\bar{q}$ jet has a two-prong structure, we use substructure tools developed to identify jets from hadronically decaying W bosons. We use a variable based on the N-subjettiness ratio τ_2/τ_1 [66], also referred to as τ_{21}, which is used in other searches to determine a jet's consistency with having a two-prong structure [67–69]. However, any chosen cutoff τ_{21} value sculpts the jet mass distributions in a way that depends on the p_T of the jet, and causes a complex mass distribution that peaks at high jet mass. This limits its usefulness when searching for resonant peaks over a large range in p_T. We therefore employ a transformation of τ_{21} to τ_{21}^{DDT}, where DDT stands for designed decorrelated tagger [70]. It is a generic technique to reduce mass correlations of the observable in multijet events. We specifically deploy it here through a linear

transformation between τ_{21} and a dimensionless jet mass variable [71], $\rho^{\mathrm{DDT}} = \ln[m_{\mathrm{SD}}^2/(\mu_0 p_{\mathrm{T}})]$, where the scale $\mu_0 = 1\,\mathrm{GeV}$. We determine the optimal transformation from simulation to be $\tau_{21}^{\mathrm{DDT}} = \tau_{21} + 0.063\,\rho^{\mathrm{DDT}}$. Events are selected by requiring $\tau_{21}^{\mathrm{DDT}} < 0.38$.

The dominant background comes from multijet events. For each Z′ mass point, we estimate this background using sidebands of kinematic distributions in the data, in order to minimize reliance on the simulation. We use both ρ^{DDT} and τ_{21}^{DDT} background-dominated sideband regions and take advantage of the lack of correlation between τ_{21}^{DDT} and ρ^{DDT}. The method is illustrated in Fig. 1(left), where the mean in the distribution of τ_{21}^{DDT} is plotted as a function of ρ^{DDT} for different bins in jet p_{T}. Both τ_{21}^{DDT} and p_{T} have little dependence on ρ^{DDT} in range from 0 to 4 corresponding to $30\,\mathrm{GeV} < m_{\mathrm{SD}} < 300\,\mathrm{GeV}$. Figure 1(right) illustrates the strategy for estimating the multijet background. We define the pass-to-fail ratio, $R_{p/f}$, as the ratio of yields in the pass region ($\tau_{21}^{\mathrm{DDT}} < 0.38$) to the yields in the fail region ($\tau_{21}^{\mathrm{DDT}} > 0.38$). We rescale multijet events from the fail region using $R_{p/f}$ parameterized in p_{T} and ρ^{DDT} to predict the mulijet signal region background:

$$P_{\mathrm{pass}}^{\mathrm{multijet}}(p_{\mathrm{T}}, \rho^{\mathrm{DDT}}) = R_{p/f}(p_{\mathrm{T}}, \rho^{\mathrm{DDT}})\, P_{\mathrm{fail}}^{\mathrm{multijet}}(p_{\mathrm{T}}, \rho^{\mathrm{DDT}}) \tag{1}$$

where $P_{\mathrm{pass}}^{\mathrm{multijet}}$ and $P_{\mathrm{fail}}^{\mathrm{multijet}}$ are the passing and failing multijet distributions. We determine $R_{p/f}$ by fitting the ratio of data events in the pass to fail regions over the (ρ^{DDT}, p_{T}) space. With this method, we fit for any residual correlations between τ_{21}^{DDT} and ρ^{DDT}, modeling them as polynomial functions. Fitting $R_{p/f}$, in place of the normalization, allows the region where the trigger selection is not fully efficient to be exploited; therefore we begin the $R_{p/f}$ fit in this region at a jet $p_{\mathrm{T}} > 350\,\mathrm{GeV}$. Prior to performing the fit, we subtract the W and Z boson contributions expected from simulation, at NLO, to estimate only nonresonant contributions such as the multijet background. To avoid a bias induced by a given Z′ signal, we exclude a window from the $R_{p/f}$ fit centered about the given Z′ m_{SD} of width $\pm 10\%\, m_{Z'}$, which corresponds approximately to the jet mass resolution. The missing strip in the $R_{p/f}$ shape in Fig. 1 (right) reflects this window. Fits are therefore performed as a function of Z′ mass to estimate the background. The two-dimensional $R_{p/f}$ depends slightly on the chosen mass hypothesis, as different windows in jet mass are excluded for each Z′ mass. Finally, the mass distribution in data is tested for the presence of signal using the multijet prediction along with the simulated W and Z predictions.

The uncertainties in the method described above arise from three sources. The first uncertainty arises from residual systematic effects in the method, as determined from a self-consistency check in simulated events. This systematic effect is correlated across all jet mass bins. The second is due to the uncertainty in the $R_{p/f}$ shape from the fit parameter uncertainties, also correlated across all jet mass bins. The third source originates from uncorrelated statistical uncertainties in the size of the fail sample and the statistical uncertainties in the self-consistency test.

Smaller backgrounds from resonant SM processes (W/Z +jets) are estimated from simulation, but with corrections for the mass shapes and efficiencies evaluated from data as discussed below. The expectations for all SM background processes (multijets, W/Z +jets) are determined for jet masses from 30 to 330 GeV. Including the region near the W and Z boson masses provides a constraint on the mass distribution of the Z′ and its normalization by determining the W/Z +jets contribution in situ.

The systematic effects on shapes and normalizations of the W, Z, and signal distributions are correlated. We constrain the jet mass scale, jet mass resolution, and τ_{21}^{DDT} selection efficiency using a sample of merged W boson jets in semileptonic $\mathrm{t\bar{t}}$ events in data. Using the same τ_{21}^{DDT} selection as in the analysis provides passing and failing regions for merged W boson jets in data

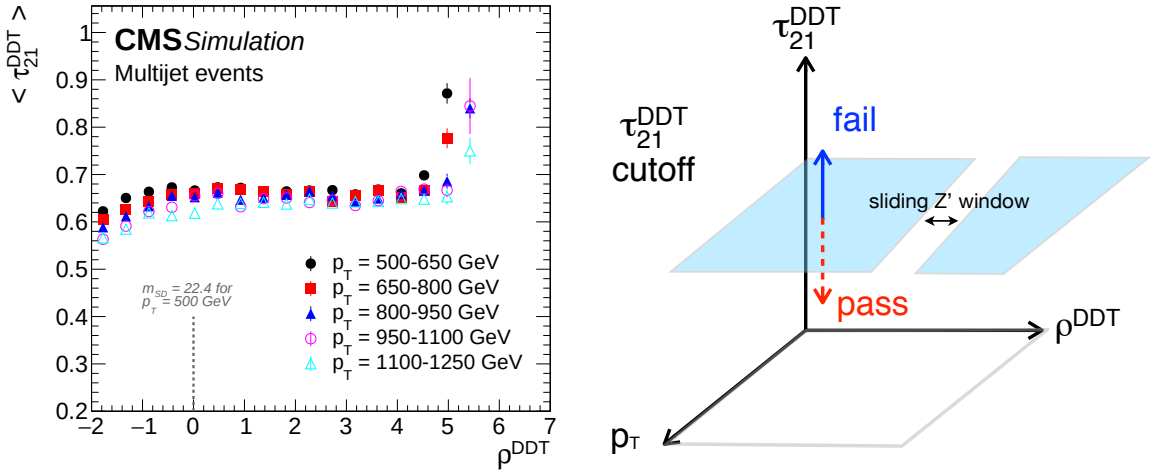

Figure 1: The average of τ_{21}^{DDT} versus ρ^{DDT} for different bins in jet p_T (left). A schematic of the method used to estimate the background (right). After a τ_{21}^{DDT} selection is applied, the multijet event distributions in the passing region are predicted from their distributions in the failing region with the use of a pass-to-fail ratio extracted through a 2-dimensional fit in (ρ^{DDT}, p_T) space. Events in a sliding window around the desired Z′ mass point are vetoed when determining the pass-to-fail ratio.

and in simulation. A simultaneous fit to the two samples in m_{SD} is performed to extract the tagging efficiency of a merged W boson jet, its jet mass scale, and the resolution in simulation and in data. Scale factors relating data and simulation are then computed and applied to the simulation. These scale factors and their uncertainties determine the initial distributions for the W, Z, and signal that are further constrained in the final fit in situ using the presence of the W and Z peaks in the jet mass distribution. Finally, additional systematic uncertainties are applied to the W, Z, and Z′ signal yields that are associated with higher-order corrections to the boson p_T distributions, jet energy scale [72], the modeling of pileup and the integrated beam luminosity [73]. A quantitative summary of the systematic effects considered is shown in Table 1.

Table 1: Summary of the systematic uncertainties for signal and background. Uncertainties due to the finite size of the simulated samples are applied only to the Z′ signal. Electroweak uncertainties are applied only to the W/Z boson processes. Dashes (—) indicate the uncertainty does not apply.

Systematic effect	Multijet	SM W/Z and Z′
Multijet fit parameters	1–4%	—
Multijet bin-by-bin statistics	1–20%	—
Multijet fit closure	1–12%	—
W boson tagging scale factor	—	20%
NLO QCD p_T corrections	—	8–12%
Jet energy/mass resolution	—	10%
Simulation sample size	—	1-30%
Integated luminosity	—	2.7%
Pileup	—	<1%
Jet energy/mass scale	—	1%

To validate the background estimation method and its associated systematic uncertainties, studies are performed on simulated events by injecting a signal and testing for a bias in the

extracted signal cross section. No significant bias is observed. We combine the estimates of various SM background processes, and search for a Z′ resonance in the 100–300 GeV mass range, while the SM backgrounds are estimated in the 30–330 GeV mass range. Figure 2 shows the soft drop jet mass distribution with a background calculated for the Z′ search at a mass of 135 GeV. Expected background contributions from the W and Z bosons are clearly visible in the data.

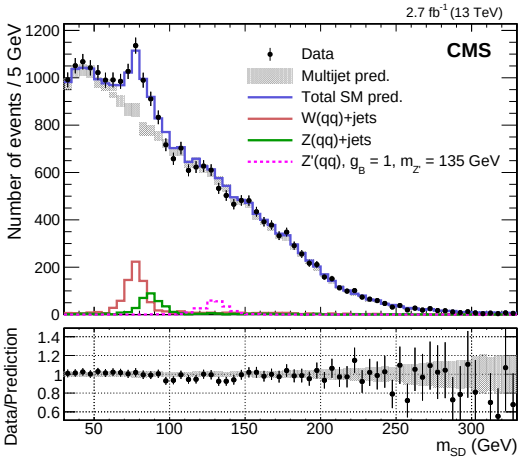

Figure 2: Soft drop jet mass distribution after final selection. Data are shown as black points. The multijet background, including uncertainties, is shown as gray boxes, while the sum of the SM processes is given by the blue line. Contributions from the SM W/Z boson and a hypothetical Z′ signal at a mass of 135 GeV are also indicated. In the bottom panel, we show the ratio of the data to the background prediction, including uncertainties.

The number of events in data is consistent with the predicted backgrounds from SM processes. Results are obtained from combined signal and background binned likelihood fits to the jet mass distribution, such as the one shown in Fig. 2. The results are interpreted as upper limits on the production cross section for signal in terms of 95% confidence level (CL) upper limits computed using the modified frequentist approach (CL_s), taking the likelihood as the test statistic [74, 75] in the asymptotic approximation [76]. Systematic uncertainties are treated as nuisance parameters that are modeled through log-normal priors. The probability of the downward fluctuation of the data at a Z′ signal mass of 100 GeV is less than 0.15% and corresponds to a local 2.8σ effect. We attribute this to a statistical fluctuation in data. Studies of the background model are performed by injecting simulated signal events and we find negligible biases in the fitted signal strength. An alternative background estimate is also studied by fitting directly the jet mass distribution, results are consistent within 1 σ.

Upper limits on signal cross sections are translated into the coupling of the Z′ boson to quarks (g_q) as a function of $m_{Z'}$. In Fig. 3, we compare our results with previous results from the UA2, CDF, ATLAS, and CMS experiments. The limits from the UA2 and CDF experiments, and the indirect constraints from the $Z \to q\bar{q}$ width are obtained following the approach described in Ref. [77]. We exclude coupling values of g_q from 0.071 to 0.260 over the selected Z′ mass range.

In summary, a search by CMS for a vector (Z′) resonance decaying to a $q\bar{q}$ pair in the mass range from 100-300 GeV has been presented. The results are interpreted in the framework of a leptophobic vector resonance model. No excess above the SM prediction is observed, and 95% confidence level upper limits are set on the coupling of the Z′ to quarks as a function of the Z′ mass. These limits are the most stringent to date for masses less than 300 GeV. For masses below 140 GeV, these are the only available direct limits.

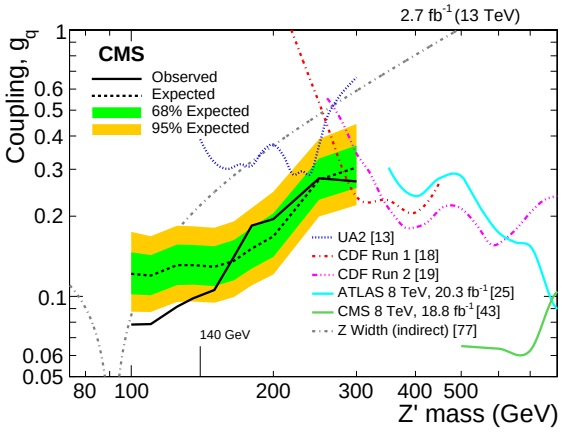

Figure 3: Upper limits on g_q as a function of the Z' mass at 95% CL [78]. Limits from other relevant searches are shown. An indirect constraint from the width of the SM Z boson is also given.

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] E. Eichten, I. Hinchliffe, K. D. Lane, and C. Quigg, "Supercollider physics", *Rev. Mod. Phys.* **56** (1984) 579, doi:10.1103/RevModPhys.56.579.

[2] P. H. Frampton and S. L. Glashow, "Chiral color: An alternative to the standard model", *Phys. Lett. B* **190** (1987) 157, doi:10.1016/0370-2693(87)90859-8.

[3] U. Baur, I. Hinchliffe, and D. Zeppenfeld, "Excited quark production at hadron colliders", *Int. J. Mod. Phys. A* **2** (1987) 1285, doi:10.1142/S0217751X87000661.

[4] J. L. Hewett and T. G. Rizzo, "Low-energy phenomenology of superstring inspired E(6) models", *Phys. Rept.* **183** (1989) 193, doi:10.1016/0370-1573(89)90071-9.

[5] U. Baur, M. Spira, and P. M. Zerwas, "Excited quark and lepton production at hadron colliders", *Phys. Rev. D* **42** (1990) 815, doi:10.1103/PhysRevD.42.815.

[6] E. H. Simmons, "Coloron phenomenology", *Phys. Rev. D* **55** (1997) 1678, doi:10.1103/PhysRevD.55.1678, arXiv:hep-ph/9608269.

[7] L. Randall and R. Sundrum, "An alternative to compactification", *Phys. Rev. Lett.* **83** (1999) 4690, doi:10.1103/PhysRevLett.83.4690, arXiv:hep-th/9906064.

[8] S. Cullen, M. Perelstein, and M. E. Peskin, "TeV strings and collider probes of large extra dimensions", *Phys. Rev. D* **62** (2000) 055012, doi:10.1103/PhysRevD.62.055012, arXiv:hep-ph/0001166.

[9] L. A. Anchordoqui et al., "Dijet signals for low mass strings at the Large Hadron Collider", *Phys. Rev. Lett.* **101** (2008) 241803, doi:10.1103/PhysRevLett.101.241803, arXiv:0808.0497.

[10] T. Han, I. Lewis, and Z. Liu, "Colored resonant signals at the LHC: largest rate and simplest topology", *JHEP* **12** (2010) 085, doi:10.1007/JHEP12(2010)085, arXiv:1010.4309.

[11] R. S. Chivukula, A. Farzinnia, E. H. Simmons, and R. Foadi, "Production of massive color-octet vector bosons at next-to-leading order", *Phys. Rev. D* **85** (2012) 054005, doi:10.1103/PhysRevD.85.054005, arXiv:1111.7261.

[12] UA1 Collaboration, "Two-jet mass distributions at the CERN proton-antiproton collider", *Phys. Lett. B* **209** (1988) 127, doi:10.1016/0370-2693(88)91843-6.

[13] UA2 Collaboration, "A measurement of two jet decays of the W and Z bosons at the CERN $\bar{\text{p}}\text{p}$ collider", *Z. Phys. C* **49** (1991) 17, doi:10.1007/BF01570793.

[14] UA2 Collaboration, "A search for new intermediate vector mesons and excited quarks decaying to two jets at the CERN $\bar{\text{p}}\text{p}$ collider", *Nucl. Phys. B* **400** (1993) 3, doi:10.1016/0550-3213(93)90395-6.

[15] CDF Collaboration, "The two jet invariant mass distribution at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. D* **41** (1990) 1722, doi:10.1103/PhysRevD.41.1722.

[16] CDF Collaboration, "Search for quark compositeness, axigluons and heavy particles using the dijet invariant mass spectrum observed in $\text{p}\bar{\text{p}}$ collisions", *Phys. Rev. Lett.* **71** (1993) 2542, doi:10.1103/PhysRevLett.71.2542.

[17] CDF Collaboration, "Search for new particles decaying to dijets in $\text{p}\bar{\text{p}}$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **74** (1995) 3538, doi:10.1103/PhysRevLett.74.3538, arXiv:hep-ex/9501001.

[18] CDF Collaboration, "Search for new particles decaying to dijets at CDF", *Phys. Rev. D* **55** (1997) 5263, doi:10.1103/PhysRevD.55.R5263, arXiv:hep-ex/9702004.

[19] CDF Collaboration, "Search for new particles decaying into dijets in proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. D* **79** (2009) 112002, doi:10.1103/PhysRevD.79.112002, arXiv:0812.4036.

[20] D0 Collaboration, "Measurement of dijet angular distributions and search for quark compositeness", *Phys. Rev. Lett.* **80** (1998) 666, doi:10.1103/PhysRevLett.80.666, arXiv:hep-ex/9707016.

[21] D0 Collaboration, "The dijet mass spectrum and a search for quark compositeness in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV", *Phys. Rev. Lett.* **82** (1999) 2457, doi:10.1103/PhysRevLett.82.2457, arXiv:hep-ex/9807014.

[22] D0 Collaboration, "Search for new particles in the two jet decay channel with the D0 detector", *Phys. Rev. D* **69** (2004) 111101, doi:10.1103/PhysRevD.69.111101, arXiv:hep-ex/0308033.

[23] ATLAS Collaboration, "Search for new particles in two-jet final states in 7 TeV proton-proton collisions with the ATLAS detector at the LHC", *Phys. Rev. Lett.* **105** (2010) 161801, doi:10.1103/PhysRevLett.105.161801, arXiv:1008.2461.

[24] ATLAS Collaboration, "Search for quark contact interactions in dijet angular distributions in pp collisions at $\sqrt{s} = 7$ TeV measured with the ATLAS detector", *Phys. Lett. B* **694** (2011) 327, doi:10.1016/j.physletb.2010.10.021, arXiv:1009.5069.

[25] ATLAS Collaboration, "A search for new physics in dijet mass and angular distributions in pp collisions at $\sqrt{s} = 7$ TeV measured with the ATLAS Detector", *New J. Phys.* **13** (2011) 053044, doi:10.1088/1367-2630/13/5/053044, arXiv:1103.3864.

[26] ATLAS Collaboration, "Search for new physics in the dijet mass distribution using 1 fb^{-1} of pp collision data at $\sqrt{s}$ =7 TeV collected by the ATLAS detector", *Phys. Lett. B* **708** (2012) 37, doi:10.1016/j.physletb.2012.01.035, arXiv:1108.6311.

[27] ATLAS Collaboration, "ATLAS search for new phenomena in dijet mass and angular distributions using pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **01** (2013) 029, doi:10.1007/JHEP01(2013)029, arXiv:1210.1718.

[28] ATLAS Collaboration, "Search for new phenomena in the dijet mass distribution using pp collision data at $\sqrt{s} = 8$ TeV with the ATLAS detector", *Phys. Rev. D* **91** (2015) 052007, doi:10.1103/PhysRevD.91.052007, arXiv:1407.1376.

[29] ATLAS Collaboration, "Search for new phenomena in dijet angular distributions in proton-proton collisions at $\sqrt{s} = 8$ TeV measured with the ATLAS detector", *Phys. Rev. Lett.* **114** (2015) 221802, doi:10.1103/PhysRevLett.114.221802, arXiv:1504.00357.

[30] ATLAS Collaboration, "Search for new phenomena in dijet mass and angular distributions from pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Phys. Lett. B* **754** (2016) 302, doi:10.1016/j.physletb.2016.01.032, arXiv:1512.01530.

[31] ATLAS Collaboration, "Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Phys. Lett. B* **759** (2016) 229, doi:10.1016/j.physletb.2016.05.064, arXiv:1603.08791.

[32] ATLAS Collaboration, "Search for new phenomena in dijet events using 37 fb^{-1} of pp collision data collected at $\sqrt{s}$ =13 TeV with the ATLAS detector", (2017). arXiv:1703.09127.

[33] CMS Collaboration, "Search for dijet resonances in 7 TeV pp collisions at CMS", *Phys. Rev. Lett.* **105** (2010) 211801, doi:10.1103/PhysRevLett.105.211801, arXiv:1010.0203. [Erratum: doi:10.1103/PhysRevLett.106.029902].

[34] CMS Collaboration, "Search for quark compositeness with the dijet centrality ratio in pp collisions at $\sqrt{s} = 7$ TeV", *Phys. Rev. Lett.* **105** (2010) 262001, doi:10.1103/PhysRevLett.105.262001, arXiv:1010.4439.

[35] CMS Collaboration, "Measurement of dijet angular distributions and search for quark compositeness in pp collisions at $\sqrt{s} = 7$ TeV", *Phys. Rev. Lett.* **106** (2011) 201804, doi:10.1103/PhysRevLett.106.201804, arXiv:1102.2020.

[36] CMS Collaboration, "Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS", *Phys. Lett. B* **704** (2011) 123, doi:10.1016/j.physletb.2011.09.015, arXiv:1107.4771.

[37] CMS Collaboration, "Search for quark compositeness in dijet angular distributions from pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **05** (2012) 055, doi:10.1007/JHEP05(2012)055, arXiv:1202.5535.

[38] CMS Collaboration, "Search for narrow resonances and quantum black holes in inclusive and b-tagged dijet mass spectra from pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **01** (2013) 013, doi:10.1007/JHEP01(2013)013, arXiv:1210.2387.

[39] CMS Collaboration, "Search for narrow resonances using the dijet mass spectrum in pp collisions at $\sqrt{s} = 8$ TeV", *Phys. Rev. D* **87** (2013) 114015, doi:10.1103/PhysRevD.87.114015, arXiv:1302.4794.

[40] CMS Collaboration, "Search for quark contact interactions and extra spatial dimensions using dijet angular distributions in proton-proton collisions at $\sqrt{s} = 8$ TeV", *Phys. Lett. B* **746** (2015) 79, doi:10.1016/j.physletb.2015.04.042, arXiv:1411.2646.

[41] CMS Collaboration, "Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV", *Phys. Rev. D* **91** (2015) 052009, doi:10.1103/PhysRevD.91.052009, arXiv:1501.04198.

[42] CMS Collaboration, "Search for narrow resonances decaying to dijets in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **116** (2016) 071801, doi:10.1103/PhysRevLett.116.071801, arXiv:1512.01224.

[43] CMS Collaboration, "Search for narrow resonances in dijet final states at $\sqrt{s} = 8$ TeV with the novel CMS technique of data scouting", *Phys. Rev. Lett.* **117** (2016) 031802, doi:10.1103/PhysRevLett.117.031802, arXiv:1604.08907.

[44] CMS Collaboration, "Search for new physics with dijet angular distributions in proton-proton collisions at $\sqrt{s}$ = 13 TeV", (2017). arXiv:1703.09986.

[45] CMS Collaboration, "Search for dijet resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV and constraints on dark matter and other models", *Phys. Lett. B* (2016) doi:10.1016/j.physletb.2017.02.012, arXiv:1611.03568.

[46] B. A. Dobrescu and F. Yu, "Coupling-mass mapping of dijet peak searches", *Phys. Rev.* (2013) 035021, doi:10.1103/PhysRevD.88.035021, arXiv:1306.2629. [Erratum: doi:10.1103/PhysRevD.90.079901].

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

[48] CMS Collaboration, "Particle–flow event reconstruction in CMS and performance for jets, taus, and $E_{\mathrm{T}}^{\mathrm{miss}}$", CMS Physics Analysis Summary CMS-PAS-PFT-09-001, 2009.

[49] CMS Collaboration, "Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector", CMS Physics Analysis Summary CMS-PAS-PFT-10-001, 2010.

[50] J. Alwall et al., "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations", *JHEP* **07** (2014) 079, doi:10.1007/JHEP07(2014)079, arXiv:1405.0301.

[51] T. Sjöstrand, S. Mrenna, and P. Skands, "PYTHIA 6.4 physics and manual", *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[52] T. Sjöstrand, S. Mrenna, and P. Skands, "A brief introduction to PYTHIA 8.1", *Comput. Phys. Commun.* **178** (2008) 852, doi:10.1016/j.cpc.2008.01.036, arXiv:0710.3820.

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

[54] CMS Collaboration, "Event generator tunes obtained from underlying event and multiparton scattering measurements", *Eur. Phys. J.* **76** (2016) 155, doi:10.1140/epjc/s10052-016-3988-x, arXiv:1512.00815.

[55] CMS Collaboration, "Search for dark matter produced with an energetic jet or a hadronically decaying W or Z boson at $\sqrt{s} = 13$ TeV", (2017). arXiv:1703.01651.

[56] S. Kallweit et al., "NLO electroweak automation and precise predictions for W+multijet production at the LHC", *JHEP* **04** (2015) 012, doi:10.1007/JHEP04(2015)012, arXiv:1412.5157.

[57] S. Kallweit et al., "NLO QCD+EW predictions for V+jets including off-shell vector-boson decays and multijet merging", *JHEP* **04** (2016) 021, doi:10.1007/JHEP04(2016)021, arXiv:1511.08692.

[58] S. Kallweit et al., "NLO QCD+EW automation and precise predictions for V+multijet production", in *Proceedings, 50th Rencontres de Moriond, QCD and high energy interactions*, p. 121. 2015. arXiv:1505.05704.

[59] M. Schönherr et al., "NLO QCD+EW for V+jets", in *Proceedings, 4th Large Hadron Collider Physics Conference (LHCP 2016)*, p. 058. Lund, Sweden, June, 2016. arXiv:1609.01445. [PoS(LHCP2016)058].

[60] D. Krohn, J. Thaler, and L.-T. Wang, "Jet trimming", *JHEP* **02** (2010) 084, doi:10.1007/JHEP02(2010)084, arXiv:0912.1342.

[61] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_t jet clustering algorithm", *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

[62] M. Cacciari, G. P. Salam, and G. Soyez, "FastJet User Manual", *Eur. Phys. J.* **C72** (2012) 1896, doi:10.1140/epjc/s10052-012-1896-2, arXiv:1111.6097.

[63] D. Bertolini, P. Harris, M. Low, and N. Tran, "Pileup per particle identification", *JHEP* **10** (2014) 059, doi:10.1007/JHEP10(2014)059, arXiv:1407.6013.

[64] M. Dasgupta, A. Fregoso, S. Marzani, and G. P. Salam, "Towards an understanding of jet substructure", *JHEP* **09** (2013) 029, doi:10.1007/JHEP09(2013)029, arXiv:1307.0007.

[65] A. J. Larkoski, S. Marzani, G. Soyez, and J. Thaler, "Soft drop", *JHEP* **05** (2014) 146, doi:10.1007/JHEP05(2014)146, arXiv:1402.2657.

[66] J. Thaler and K. Van Tilburg, "Identifying boosted objects with N-subjettiness", *JHEP* **03** (2011) 015, doi:10.1007/JHEP03(2011)015, arXiv:1011.2268.

[67] CMS Collaboration, "Identification techniques for highly boosted W bosons that decay into hadrons", *JHEP* **12** (2014) 017, doi:10.1007/JHEP12(2014)017, arXiv:1410.4227.

[68] CMS Collaboration, "Search for massive resonances decaying into pairs of boosted bosons in semi-leptonic final states at $\sqrt{s} = 8$ TeV", *JHEP* **08** (2014) 174, doi:10.1007/JHEP08(2014)174, arXiv:1405.3447.

[69] CMS Collaboration, "Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays in pp collisions at $\sqrt{s} = 8$ TeV", *JHEP* **08** (2014) 173, doi:10.1007/JHEP08(2014)173, arXiv:1405.1994.

[70] J. Dolen et al., "Thinking outside the ROCs: Designing Decorrelated Taggers (DDT) for jet substructure", *JHEP* **05** (2016) 156, doi:10.1007/JHEP05(2016)156, arXiv:1603.00027.

[71] G. P. Salam, "Towards jetography", *Eur. Phys. J. C* **67** (2010) 637, doi:10.1140/epjc/s10052-010-1314-6, arXiv:0906.1833.

[72] CMS Collaboration, "Determination of jet energy calibration and transverse momentum resolution in CMS", *JINST* **6** (2011) 11002, doi:10.1088/1748-0221/6/11/P11002, arXiv:1107.4277.

[73] CMS Collaboration, "CMS luminosity measurement for the 2015 data taking period", CMS Physics Analysis Summary CMS-PAS-LUM-15-001, 2016.

[74] T. Junk, "Confidence level computation for combining searches with small statistics", *Nucl. Instrum. Meth. A* **434** (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.

[75] A. L. Read, "Presentation of search results: the CL_s technique", *J. Phys. G* **28** (2002) 2693, doi:10.1088/0954-3899/28/10/313.

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

[77] B. A. Dobrescu and C. Frugiuele, "Hidden GeV-scale interactions of quarks", *Phys. Rev. Lett.* **113** (2014) 061801, doi:10.1103/PhysRevLett.113.061801, arXiv:1404.3947.

[78] G. Busoni et al., "Recommendations on presenting LHC searches for missing transverse energy signals using simplified s-channel models of dark matter", (2016). arXiv:1603.04156.

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, J. Strauss, 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, M. Van De Klundert, 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, A. Olbrechts, 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, 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, Z. Liu, F. Romeo, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, E. Yazgan, H. 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, 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[6], M. Finger Jr.[6]

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
A.A. Abdelalim[7,8], Y. Mohammed[9], E. Salama[10,11]

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, 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, S. Regnard, 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
D. Lomidze

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, S. Beranek, L. Feld, M.K. Kiesel, K. Klein, M. Lipinski, M. Preuten, C. Schomakers, J. Schulz, T. Verlage

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
A. Albert, M. Brodski, 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, M. Olschewski, K. Padeken, 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, 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, R. Placakyte, 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, A.R. Draeger, 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, A. Gilbert, 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
S. Kesisoglou, A. Panagiotou, N. Saoulidou

University of Ioánnina, Ioánnina, Greece
I. Evangelou, C. Foudas, P. Kokkas, 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

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, D. Horvath[19], Á. Hunyadi, F. Sikler, V. Veszpremi, G. Vesztergombi[20], 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[20], 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, U. Bhawandeep, 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, V. Sharma

Saha Institute of Nuclear Physics, HBNI, Kolkata, India
R. Bhardwaj, R. Bhattacharya, S. Bhattacharya, 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, B. Parida, 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], C. Caputo[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,b], 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], L. Brigliadori[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], L. Guiducci[a,b], S. Marcellini[a], G. Masetti[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], 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
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], 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,15], 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], F. Fallavollita[a,b], A. Magnani[a,b], P. Montagna[a,b], S.P. Ratti[a,b], V. Re[a], M. Ressegotti, 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, D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], R. Leonardi[a,b], E. Manoni, G. Mantovani[a,b], V. Mariani[a,b], M. Menichelli[a], A. Rossi, A. Saha[a], 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], J. Bernardini[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], 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, G. Ryu

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
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz[34], 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, K. Romanowska-Rybinska, 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, B. Calpas, A. Di Francesco, P. Faccioli, M. Gallinaro, J. Hollar, N. Leonardo, L. Lloret Iglesias, M.V. Nemallapudi, J. Seixas, 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

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, V. Bunichev, M. Dubinin[41], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin

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. Krychkine, 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

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, 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
J.F. de Trocóniz, M. Missiroli, D. Moran

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, I. Suárez Andrés, 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, 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, E. Di Marco[44], M. Dobson, B. Dorney, T. du Pree, M. Dünser, N. Dupont, A. Elliott-Peisert, P. Everaerts, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, F. Glege, D. Gulhan, S. Gundacker, M. Guthoff, 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[45], F. Moortgat, M. Mulders, H. Neugebauer, S. Orfanelli, L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, M. Pierini, A. Racz, T. Reis, G. Rolandi[46], M. Rovere, H. Sakulin, C. Schäfer, C. Schwick, M. Seidel, M. Selvaggi, A. Sharma, P. Silva, P. Sphicas[47], J. Steggemann, M. Stoye, M. Tosi, D. Treille, A. Triossi, A. Tsirou, V. Veckalns[48], G.I. Veres[20], M. Verweij, N. Wardle, W.D. Zeuner

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

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
F. Bachmair, 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. Schönenberger, L. Shchutska, A. Starodumov[49], V.R. Tavolaro, K. Theofilatos, M.L. Vesterbacka Olsson, R. Wallny, A. Zagozdzinska[35], D.H. Zhu

Universität Zürich, Zurich, Switzerland
T.K. Aarrestad, C. Amsler[50], L. Caminada, M.F. Canelli, A. De Cosa, S. Donato, C. Galloni, T. Hreus, B. Kilminster, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, D. Salerno, C. Seitz, 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, M. Miñano Moya, E. Paganis, A. Psallidas, J.f. Tsai

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

ukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
A. Adiguzel[51], F. Boran, S. Cerci[52], S. Damarseckin, Z.S. Demiroglu, C. Dozen, I. Dumanoglu, S. Girgis, G. Gokbulut, Y. Guler, I. Hos[53], E.E. Kangal[54], O. Kara, U. Kiminsu, M. Oglakci, G. Onengut[55], K. Ozdemir[56], D. Sunar Cerci[52], B. Tali[52], H. Topakli[57], S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
B. Bilin, G. Karapinar[58], K. Ocalan[59], M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, M. Kaya[60], O. Kaya[61], S. Tekten, E.A. Yetkin[62]

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, P. Sorokin

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[63], S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, D. Smith, V.J. Smith

Rutherford Appleton Laboratory, Didcot, United Kingdom
K.W. Bell, A. Belyaev[64], 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
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,

D. Futyan, 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[49], 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[65], T. Virdee[15], 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

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, M. Squires, 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, 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[66], 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, A. Patterson, 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, S. Das, 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, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA
A. Ackert, T. Adams, A. Askew, S. Hagopian, V. Hagopian, K.F. Johnson, T. Kolberg, T. Perry, H. Prosper, A. Santra, 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[67], W. Clarida, K. Dilsiz[68], S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya[69], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul[70], Y. Onel, F. Ozok[71], 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, C. Mantilla, 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, R. Stringer, 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, R.-J. Wang, 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
A. Benaglia, 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. 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[72], A. Castaneda Hernandez[72], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon[73], 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, P. Sheldon, S. Tuo, J. Velkovska, Q. Xu

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

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

University of Wisconsin - Madison, Madison, WI, USA
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 Joint Institute for Nuclear Research, Dubna, Russia
7: Also at Helwan University, Cairo, Egypt
8: Now at Zewail City of Science and Technology, Zewail, Egypt
9: Now at Fayoum University, El-Fayoum, Egypt
10: Also at British University in Egypt, Cairo, Egypt
11: Now at Ain Shams 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 Institute of Nuclear Research ATOMKI, Debrecen, Hungary
20: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, 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 California Institute of Technology, Pasadena, USA
42: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
43: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
44: Also at INFN Sezione di Roma; Sapienza Università di Roma, Rome, Italy
45: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
46: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
47: Also at National and Kapodistrian University of Athens, Athens, Greece
48: Also at Riga Technical University, Riga, Latvia
49: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
50: Also at Stefan Meyer Institute for Subatomic Physics (SMI), Vienna, Austria
51: Also at Istanbul University, Faculty of Science, Istanbul, Turkey
52: Also at Adiyaman University, Adiyaman, Turkey
53: Also at Istanbul Aydin University, Istanbul, Turkey
54: Also at Mersin University, Mersin, Turkey
55: Also at Cag University, Mersin, Turkey
56: Also at Piri Reis University, Istanbul, Turkey
57: Also at Gaziosmanpasa University, Tokat, Turkey
58: Also at Izmir Institute of Technology, Izmir, Turkey
59: Also at Necmettin Erbakan University, Konya, Turkey
60: Also at Marmara University, Istanbul, Turkey
61: Also at Kafkas University, Kars, Turkey
62: Also at Istanbul Bilgi University, Istanbul, Turkey
63: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
64: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
65: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
66: Also at Utah Valley University, Orem, USA
67: Also at Beykent University, Istanbul, Turkey
68: Also at Bingol University, Bingol, Turkey
69: Also at Erzincan University, Erzincan, Turkey
70: Also at Sinop University, Sinop, Turkey
71: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
72: Also at Texas A&M University at Qatar, Doha, Qatar
73: Also at Kyungpook National University, Daegu, Korea