EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP/2017-029
2017/06/26

CMS-SMP-13-008

Search for anomalous couplings in boosted $WW/WZ \to \ell\nu q\bar{q}$ production in proton-proton collisions at $\sqrt{s} = 8\,\text{TeV}$

The CMS Collaboration*

Abstract

This Letter presents a search for new physics manifested as anomalous triple gauge boson couplings in WW and WZ diboson production in proton-proton collisions. The search is performed using events containing a W boson that decays leptonically and a W or Z boson whose decay products are merged into a single reconstructed jet. The data, collected at $\sqrt{s} = 8\,\text{TeV}$ with the CMS detector at the LHC, correspond to an integrated luminosity of $19\,\text{fb}^{-1}$. No evidence for anomalous triple gauge couplings is found and the following 95% confidence level limits are set on their values: $\lambda\,([-0.011, 0.011])$, $\Delta\kappa_\gamma\,([-0.044, 0.063])$, and $\Delta g_1^Z\,([-0.0087, 0.024])$. These limits are also translated into their effective field theory equivalents: $c_{WWW}/\Lambda^2\,([-2.7, 2.7]\,\text{TeV}^{-2})$, $c_B/\Lambda^2\,([-14, 17]\,\text{TeV}^{-2})$, and $c_W/\Lambda^2\,([-2.0, 5.7]\,\text{TeV}^{-2})$.

Published in Physics Letters B as doi:10.1016/j.physletb.2017.06.009.

*See Appendix A for the list of collaboration members

1 Introduction

Measurements of electroweak diboson production can be translated into measurements of gauge boson self-couplings, which are among the most fundamental aspects of the standard model (SM). At leading order (LO), only s-channel $q\overline{q}$ annihilation diagrams have a triple-boson vertex. In WW production, the WWγ and WWZ vertices contribute, while in WZ production only the WWZ vertex is present. Physics beyond the SM can modify the couplings at these vertices, leading to observable differences in the cross section and the kinematic distributions of final state particles [1]. In the search for anomalous triple gauge couplings (aTGCs), we adopt the effective Lagrangian and LEP parametrization in Ref. [2], without form factors: $\lambda_\gamma = \lambda_Z = \lambda$, $\Delta\kappa_Z = \Delta g_1^Z - \Delta\kappa_\gamma \tan^2\theta_W$. We focus in particular on the parameters λ, $\Delta\kappa_\gamma$, and Δg_1^Z, where the deltas represent deviations from their respective SM values ($\lambda_{SM} = 0$). We also translate these into the equivalent parameters defined in an effective field theory (EFT) approach, namely c_{WWW}/Λ^2, c_W/Λ^2, and c_B/Λ^2, where Λ is the scale of new physics [3].

This Letter presents a search for new physics manifested as anomalous couplings of triple gauge boson vertices in WW or WZ diboson production from pp collisions at $\sqrt{s} = 8$ TeV at the CERN LHC. We focus on the case where one W boson decays leptonically ($W_{lep} \to \ell\nu$, with $\ell = e, \mu$), while the other vector boson V_{had} decays hadronically, giving rise to a single merged jet (J) in the final state. Previous searches in this channel at the LHC can be found in Refs. [4, 5]. Other recent searches in the leptonic channel are described in Refs. [6, 7]. The advantages of reconstructing WV pairs in the $\ell\nu q\overline{q}$ decay mode over purely leptonic final states are the larger branching fractions of W and Z bosons to quarks, and in the case of two W bosons, the ability to reconstruct their transverse momenta (p_T). These advantages are partially offset by the larger backgrounds in the $\ell\nu q\overline{q}$ channel, arising mainly from W+jets production. The sensitivity of WW production to the WWγ coupling and of both WW and WZ production to the WWZ coupling, especially at high boson p_T, makes these processes particularly useful as a probe of aTGCs.

Compared to our previous search at $\sqrt{s} = 7$ TeV [4], we have added another coupling parameter, Δg_1^Z, to the parameter space, and we focus exclusively on the Lorentz-boosted final states, where V_{had} is reconstructed as a single merged jet, since these final states are far more sensitive to an aTGC signal than the resolved two-jet states.

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter, each composed of a barrel and two endcap sections. Muons are measured in gas-ionization detectors embedded in the steel flux-return yoke outside the solenoid. The CMS detector is nearly hermetic, allowing for measurements of the missing transverse momentum (E_T^{miss}) in the event. E_T^{miss} is defined as the magnitude of the negative vector p_T sum of all reconstructed particles in an event. A two-tier trigger system selects the events of interest. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [8].

3 Data and simulation samples

The data were collected using single-lepton triggers with p_T thresholds of 24 (27) GeV for muons (electrons). The overall trigger efficiency is about 94% (90%) for the muon (electron) data, with a small dependence (a few percent) on p_T and pseudorapidity η. The total integrated luminosity collected and processed is 19.3 (19.2) fb^{-1} for muon (electron) triggers.

We use the MADGRAPH5 1.3.30 [9] event generator to produce both the W+jets and Drell–Yan samples, with up to four additional partons in the matrix element calculation. Single top quark and top quark-antiquark pair ($t\bar{t}$) samples are generated with POWHEG 1.0 [10–14]. The diboson samples (WW, WZ) are generated on-shell at next-to-LO (NLO) with MADGRAPH5_aMC@NLO version 2.0.0 [15] and MADSPIN version 3.2 [16]. The decays $W \to \tau\nu$ are included for all processes. The τ lepton decays are simulated with TAUOLA [17]. The PYTHIA 6.422 generator [18] provides the fragmentation and parton shower simulation, with the parameters of the underlying event set to the Z2* tune [19, 20]. The k_T-MLM matching scheme is used to interface PYTHIA6 with MADGRAPH5 at LO [21]. The set of parton distribution functions (PDFs) used is CTEQ6L1 [22] for LO generators and CT10 [23] for NLO generators. A GEANT4-based simulation [24] of the CMS detector is used in the production of all Monte Carlo (MC) samples. The simulation also includes multiple proton-proton collisions within a bunch crossing (pileup). Simulated events are reconstructed and analyzed in the same way as measured collision events, subject to additional corrections that account for differences between data and simulation in trigger and selection efficiencies, and in the vertex multiplicity distribution.

4 Event reconstruction

All observable objects, namely leptons, jets, and E_T^{miss}, are reconstructed with a particle-flow technique [25, 26] that combines information from several subdetectors. Muons are reconstructed within $|\eta| < 2.4$ with the inner tracker and the muon system [27]. Electrons are reconstructed within $|\eta| < 2.5$ from tracks in the tracker pointing to energy clusters in the ECAL, and identified using a multivariate discriminator [28]. The selections applied to this discriminator are tuned to match the η-binned efficiencies used for Ref. [4]. Muons (electrons) are required to have p_T greater than 25 (30) GeV. The lepton candidates are required to be consistent with originating from the event's primary vertex, and to be isolated from other activity in the event. The isolation requirements for muons (electrons) are based on the particle-flow technique with an isolation cone of $\Delta R = 0.4\,(0.3)$, and are designed to reduce the effects of pileup and neutral particles. Events with additional loosely identified leptons are vetoed to reduce the backgrounds from fully leptonic decays, such as those originating from the Drell–Yan process and diboson production. Decays of the tau lepton to electrons or muons that pass these criteria are included as potential signal events.

The anti-k_T (AK) [29, 30] and Cambridge–Aachen (CA) [29–31] clustering algorithms are used to reconstruct jets in the event. The AK algorithm uses a distance parameter of $R = 0.5$ (AK5). The CA jets are clustered with $R = 0.8$ (CA8) and are used for reconstructing V_{had}, where the V boson decay products are merged into a single jet. The combined secondary vertex algorithm at the medium operating point is used to tag AK5 jets as b jets [32]. We assign the E_T^{miss} measured in the event to the neutrino candidate and combine this with the identified lepton to reconstruct W_{lep}. Boosted W events are selected by requiring $p_T > 200$ GeV for W_{lep}.

We require one CA8 jet with $p_T > 200$ GeV, and no additional CA8 jets with $p_T > 80$ GeV, in the region $|\eta| < 2.4$. The E_T^{miss} is required to be above 50 (70) GeV for the muon (electron) channel to suppress multijet backgrounds. We ensure that the two bosons are back-to-back by requiring $\Delta R(\ell, J) > \pi/2$, $\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, J) > 2.0$, and $\Delta\phi(\mathrm{W_{lep}}, J) > 2.0$. We veto events based on the presence of any b-tagged AK5 jets with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ and outside the CA8 jet cone to reduce the $\mathrm{t\bar{t}}$ background. After the kinematic selections, we apply jet substructure techniques. Improved separation between the signal and the multijet background is obtained in the jet mass observable by means of a "pruning" algorithm [33, 34] designed to remove soft gluon radiation and pileup contributions from jets. The "N-subjettiness" variable [35] is a jet substructure observable that defines a measure, τ_N, for a jet to have N subjets. We require τ_2/τ_1, which is the ratio of 2-subjettiness to 1-subjettiness, of the leading CA8 jet to be less than 0.55 to discriminate against W+jets backgrounds.

5 Background and signal modeling

After all selections the background comprises three main components: W+jets, top quark ($\mathrm{t\bar{t}}$ and single top quark), and SM diboson production. Multijets, Z+jets, ZZ, Zγ, H(125)$\rightarrow$ WW*, and fully hadronic and leptonic WW decay mode backgrounds were estimated and determined to be negligible.

For the aTGC search we select the merged jet p_{T}, p_{T}^{J}, as the observable, which for diboson pairs is the p_{T} of $\mathrm{V_{had}}$. We take the binned shape of the p_{T}^{J} distribution for each contributing process from MC samples. However, since the LO W+jets prediction falls below the data, we choose to extract the normalizations of the largest background components first from an unbinned maximum-likelihood fit to the data distribution of the merged jet mass, m_J. The diboson m_J shape in the fit region is unaffected by the aTGC signal at the level of sensitivity of this analysis.

5.1 Normalization extractions from the m_J fit

For this part of the analysis we employ a two-stage procedure: first we fit the distribution in simulation for each process individually. The MC templates used in the 7 TeV analysis are replaced by analytical functions, which provide additional flexibility to model the data accurately. Second, we utilize the results from the first set of fits to perform an unbinned maximum-likelihood fit to data that includes all components. Due to the differences in background compositions and shapes, the fit to data is performed separately for the muon and electron channels. All fits are performed over the mass range $40 < m_J < 140\,\mathrm{GeV}$. Within each fit to data, the normalization for each background process is either free to float or allowed to vary around a central value subject to a Gaussian constraint. Some components have been combined because of similarity in shape, or because the W and Z bosons are not well-resolved in m_J. Finally, the yields used to normalize background p_{T}^{J} components are extracted from the signal region of $70 < m_J < 100\,\mathrm{GeV}$.

To assist in the background determination, we define a control sample intended to isolate pure top quark events for comparison with simulation [36]. The sample is constructed by inverting the selection on the number of b-tagged AK5 jets outside the CA8 jet, thus requiring that there be at least one AK5 b-tagged jet. This control sample is subsequently referred to as the top control sample.

The diboson probability density function (pdf) in m_J is parametrized by a sum of two Gaussian functions corresponding to the W and Z resonances. The position and width of the Z Gaussian are fixed with respect to those of the W Gaussian, which is initially taken from simulation. The relative fractions of WW (84% of the total) and WZ (16%) are also taken from simulation. The broad background from jets misassigned to $\mathrm{V_{had}}$ is modeled by an error function times an exponential function. The W Gaussian parameters are subsequently corrected with MC-to-data

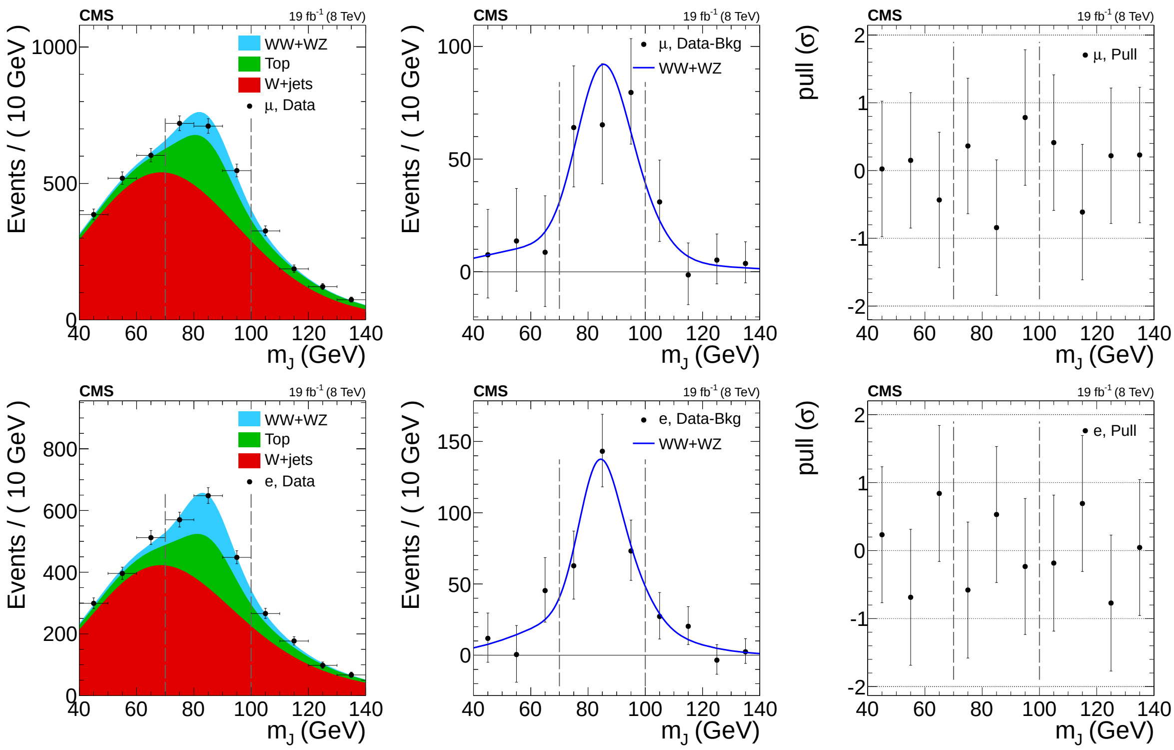

Figure 1: Post-fit distributions of the merged jet invariant mass for muons (top) and electrons (bottom) with the estimates of the relevant backgrounds. The merged jet invariant mass is plotted for all events (left), after subtraction of all components except the diboson (center), and the subsequent normalized residual or pull distributions: (data − fit)/(fit uncertainty) (right). The error bars represent statistical uncertainties. The dashed vertical lines mark the signal region of $70 < m_J < 100\,\text{GeV}$, from which the the p_T distribution normalizations are extracted.

scale factors determined from the top control sample, in order to account for mismodeling of the merged-jet mass in simulation. All diboson shape parameters are then fixed during the fits to the data, while the normalizations are free parameters to be measured.

For the W+jets process, the shape of the m_J distribution is described by a kinematic turn-on at lower masses (error function) followed by a rapidly falling tail (exponential). The pre-fit normalization is set to the LO MADGRAPH+PYTHIA6 cross section times an empirical factor of 1.3. This factor provides an initial estimate of the difference between data and simulation in the topologies, effectively accounting for the expected increase in the inclusive cross section from NNLO corrections, and given a loose ±50% constraint. The shape parameters of the function are allowed to vary in the fit to the data without constraint.

The top quark background is a combination of $t\bar{t}$ and single top quark production processes. The top quark model is parametrized by a sum of an error function times an exponential function and a double Gaussian function, corresponding to both merged and unmerged jets from hadronic W decays. The top control sample is used to correct the W resonance shape parameters, to estimate the expected yield and yield uncertainties by extrapolating to the signal region, and to adjust the top normalization uncertainty. All top shape parameters are fixed in the fit to the data, and the normalization is constrained to a Gaussian with a width of 8 (10)% for muons (electrons). These come from a combination of theory uncertainty and uncertainties associated with use of the top control sample.

Figure 1 shows the results of one of the fits to the data. The left plots show the observed

Table 1: Observed event yields and associated ratios (in parentheses) with respect to the pre-fit values extracted in the signal region ($70 < m_J < 100$ GeV). The term $\mathcal{A}\varepsilon$ (acceptance $\times$ efficiency) includes W and Z branching fractions [37].

Quantity	μ channel	e channel
Data	1977	1666
W+jets	1318 (1.22 ± 0.06)	1023 (1.17 ± 0.07)
Top quark	450 (1.00 ± 0.08)	364 (1.00 ± 0.10)
WV	204 (1.35 ± 0.77)	285 (2.23 ± 0.84)
$\mathcal{A}\varepsilon$	9.7×10^{-5}	8.3×10^{-5}

m_J distributions, together with the fitted contributions of the three largest SM processes. The central plots show the same distribution after subtracting all SM contributions from data except for diboson events. The right plots show the pull distribution, i.e., the normalized residual defined as (data − fit)/(fit uncertainty), where the fit uncertainty is computed at each data point by propagating the uncertainty in the normalization coefficients.

The individual process yields, as determined by the fit, are reported in Table 1. The acceptance times efficiency ($\mathcal{A}\varepsilon$) is determined from the diboson MC. The electron channel has a smaller $\mathcal{A}\varepsilon$ because of its higher kinematic threshold. The top quark results reflect the inability of the fit to further constrain this background. The W+jets yields are about 20% higher than the pre-fit value of 1.3 times the LO prediction, which exhibits our limited knowledge of this boosted regime. For the diboson process, 1.35 (2.23) times the expected event count is observed in the muon (electron) channel. This excess is statistically consistent with the SM NLO prediction [15]. Overall, the approach produces a high quality model of the data (Fig. 1(left)), with pull distributions consistent with zero (Fig. 1(right)), that allows us to extract the diboson contribution to the V_{had} resonance (Fig. 1(center)).

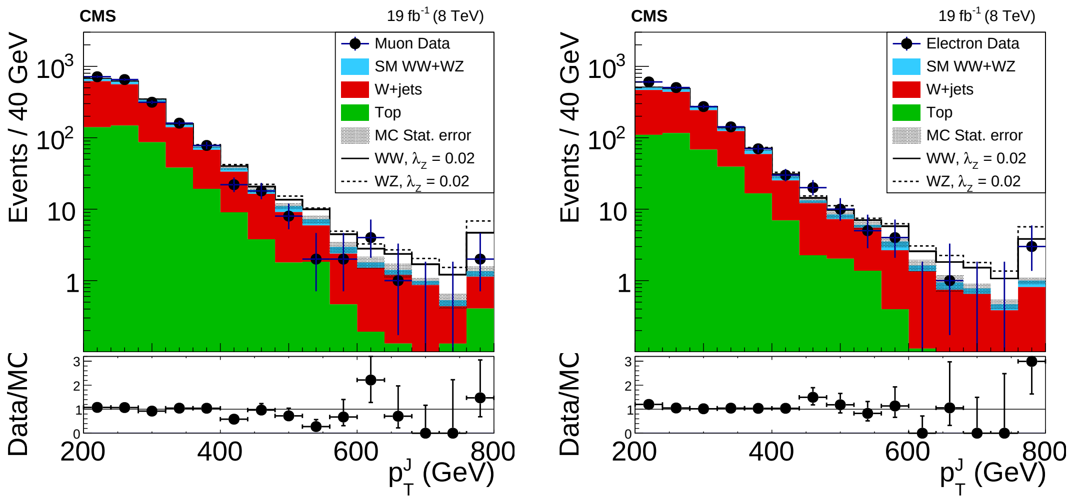

Figure 2: V_{had} p_T distributions for the muon (left) and electron (right) channels after full selection and with the requirement $70 < m_J < 100$ GeV. The MC errors are purely statistical. Examples of the effects of aTGCs are shown by the solid and dotted lines. Below we show the data/MC ratio. The last bin includes the overflow.

5.2 Fit validation

We validate the fit procedure by performing pseudo-experiments. For each experiment, we generate the m_J pseudo-data for the SM processes using the fitted pdf, taking into account the correlations between the yields, and then perform a fit to each pseudo-data m_J distribution as if it were the real data. Likewise, we ensure that the parametrization used is sufficiently general by generating pseudo-data with more general functional forms and fitting them with the default configuration. The results indicate that biases in all background yields and yield uncertainties are small.

5.3 Signal modeling

The dependence of the p_{T}^{J} distribution on specific aTGCs is modeled by reweighting the simulations of SM WW and WZ by the ratio of squared matrix elements with and without the anomalous coupling, i.e., $|\mathcal{M}|^2/|\mathcal{M}|^2_{\mathrm{SM}}$, where $|\mathcal{M}|^2$ is the squared matrix element in the presence of anomalous couplings and $|\mathcal{M}|^2_{\mathrm{SM}}$ is the squared matrix element in the SM, calculated with MCFM version 6.0 [38]. These ratios are calculated, parametrized with polynomials, and the polynomials encapsulated into a unified signal model in two-dimensional (2D) space for three pairwise combinations of the effective Lagrangian parameters being studied.

5.4 Preparing p_{T}^{J} distributions

Distributions of p_{T}^{J} in the form of histograms binned over the range 200–800 GeV (Fig. 2) are used to compute limits. All selections have been applied, including the signal window, $70 < m_J < 100\,\mathrm{GeV}$. The W+jets and top quark background normalizations are fixed according to the results from the m_J fits. The SM diboson components, however, are normalized to the NLO predictions, since a) we are searching for enhancements to the diboson production relative to those predictions, and b) given the excess of SM diboson events obtained from the fits in both channels, normalizing to theory predictions yields substantially more conservative, less sensitive expected limits. We treat the two lepton categories as separate channels in the limit setting process.

Since the W+jets shape is only calculated to LO, and we are exploring a new region of phase space, we adjust the shape and normalization from MC by comparing it to a distribution derived using an alternative method. This method involves extrapolating the W+jets p_{T}^{J} distribution from a m_J data sideband to the signal region by means of a transfer function. The transfer function is a ratio of curves fitted to the W+jets p_{T}^{J} distributions in the signal and sideband regions of W+jets simulation [36, 39]. The comparison shows that the ratio of the W+jets backgrounds derived using the two methods is statistically consistent with unity.

6 Systematic uncertainties

The main source of systematic uncertainty is the normalization uncertainty in the W+jets background estimate. From the alternative method described in Sec. 5.4, we extract a 20% uncertainty in the total background normalization by taking the precision of the ratio of the W+jets background distribution derived from the two methods and summing over the high p_{T} region (400–800 GeV), where the signal is expected.

The theoretical uncertainties in the signal normalization are associated with the renormalization and factorization scales, and with the choice of PDF, for $p_{\mathrm{T}}^{\mathrm{W}} > 1\,\mathrm{TeV}$. For PDF uncertainties we compare aMC@NLO samples employing 41 alternative sets of CTEQ6M PDFs following the prescription in Ref. [22]. Factorization and renormalization scale uncertainties are estimated by simultaneously varying them up or down by a factor of 2. Both scale and PDF uncertainties are estimated to be approximately 18–26%.

Table 2: Summary of expected and observed one-dimensional limits in the LEP parametrization. Each number pair represents the observed 95% confidence interval for that parameter.

Parameter	Expected Limits	Observed Limits
λ_Z	$[-0.014, 0.013]$	$[-0.011, 0.011]$
$\Delta\kappa_\gamma$	$[-0.068, 0.082]$	$[-0.044, 0.063]$
Δg_1^Z	$[-0.018, 0.028]$	$[-0.0087, 0.024]$

Table 3: Summary of one-dimensional limits in the EFT formulation for this analysis (*) compared to previous results.

	c_{WWW}/Λ^2 (TeV^{-2})	c_B/Λ^2 (TeV^{-2})	c_W/Λ^2 (TeV^{-2})
*	$[-2.7, 2.7]$	$[-14, 17]$	$[-2.0, 5.7]$
[6]	$[-5.7, 5.9]$	$[-29.2, 23.9]$	$[-11.4, 5.4]$
[7]	$[-4.61, 4.60]$	$[-20.9, 26.3]$	$[-5.87, 10.54]$
[43]	$[-4.6, 4.2]$	$[-260, 210]$	$[-4.2, 8.0]$
[44]	$[-3.9, 4.0]$	$[-320, 210]$	$[-4.3, 6.8]$

The uncertainty in the signal shape coming from the effects of reconstruction is estimated by comparing the aTGC/SM ratios at the generator level and the aTGC/SM ratios at the reconstruction level after all major selections are applied for both samples. The ratio is consistent with unity, and therefore only the statistical error on the ratio is propagated as an uncertainty in the modeling of different aTGC signal grid points.

The uncertainty in the luminosity measurement is 2.6% [40]. Additional sources of uncertainty from limited MC sample size, jet energy scale and resolution, E_T^{miss} resolution, trigger efficiency, lepton reconstruction and selection efficiency, additional jet veto, pileup, and b-tag efficiency are negligible in comparison to the primary sources. These uncertainties are treated as nuisance parameters in the model and profiled according to Ref. [41], Appendix A. Luminosity and theory uncertainties are treated as 100% correlated between the two channels.

7 Coupling limits and summary

Two-dimensional likelihood fits are performed in the three planes described in Sec. 5.3. Each time the third parameter is profiled. The electron and muon channels are fitted simultaneously in the limit setting procedure. No evidence for anomalous couplings is found, and we calculate the 68 and 95% confidence level (CL) exclusion contours, using the differences of the negative log likelihood (ΔNLL) relative to the best fit point. No form factors are used. The limits are subsequently translated [3] into equivalent limits on the parameters within the EFT approach, namely c_{WWW}/Λ^2, c_W/Λ^2, and c_B/Λ^2, shown in Fig. 3. We also set 1D 95% CL limits on all six parameters, with the second parameter profiled and the third parameter fixed to zero. These are shown in Tables 2 and 3. The latter also shows other recent 8 TeV results for comparison.

In summary, our limits are consistent with the SM prediction and improve upon the sensitivity of the fully leptonic 8 TeV results [6, 7] and the combined LEP experiments [37, 42].

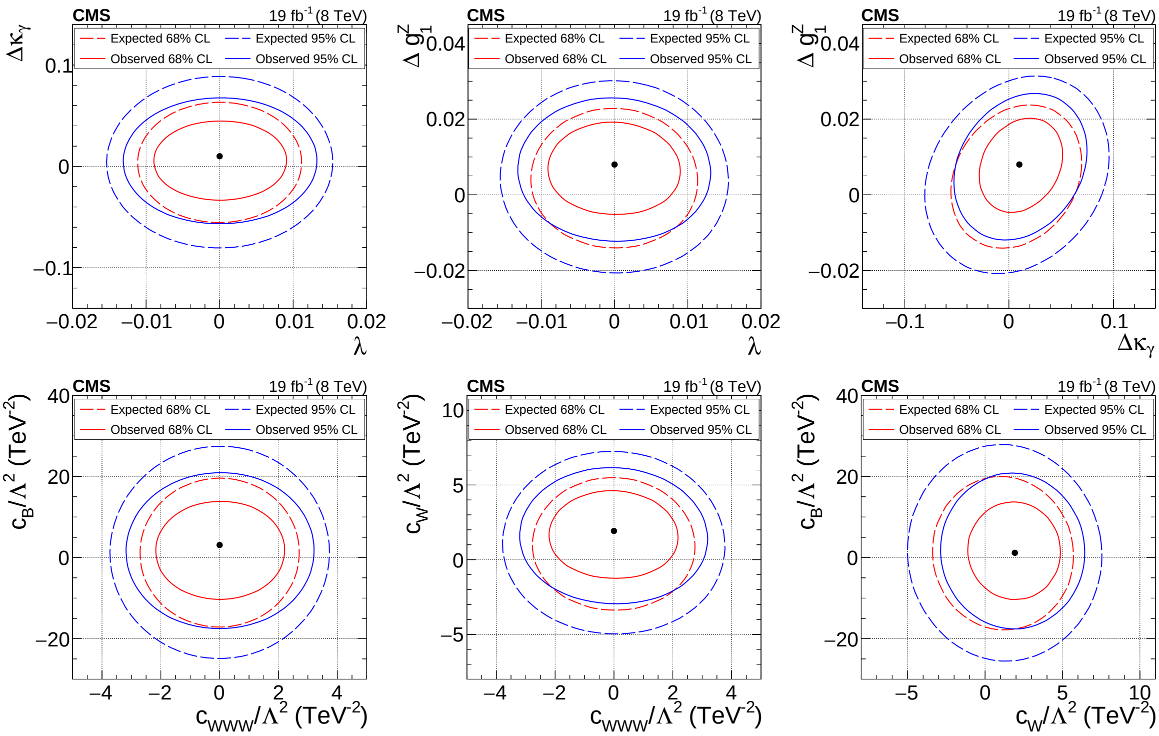

Figure 3: The 68 and 95% CL observed and expected exclusion contours in ΔNLL are depicted for three pairwise combinations of the aTGC parameters in the LEP parametrization (top) and in the EFT formulation (bottom). The black dot represents the best fit point. The origin represents the SM prediction. The asymmetry of expected limits around the SM is allowed by the theoretical parametrization.

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).

Individuals have received support from the Marie-Curie program and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of the Czech Republic; the Council of Science and Industrial Research, India; the HOMING PLUS program of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus program of the Ministry of Science and Higher Education, the National Science Center (Poland), contracts Harmonia 2014/14/M/ST2/00428, Opus 2014/13/B/ST2/02543, 2014/15/B/ST2/03998, and 2015/19/B/ST2/02861, Sonata-bis 2012/07/E/ST2/01406; the National Priorities Research Program by Qatar National Research Fund; the Programa Clarín-COFUND del Principado de Asturias; the Thalis and Aristeia programs cofinanced by EU-ESF and the Greek NSRF; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University and the Chulalongkorn Academic into Its 2nd Century Project Advancement Project (Thailand); and the Welch Foundation, contract C-1845.

References

[1] L. J. Dixon, Z. Kunszt, and A. Signer, "Vector boson pair production in hadronic collisions at order α_s : lepton correlations and anomalous couplings", *Phys. Rev. D* **60** (1999) 114037, doi:10.1103/PhysRevD.60.114037, arXiv:hep-ph/9907305.

[2] K. Hagiwara, S. Ishihara, R. Szalapski, and D. Zeppenfeld, "Low energy effects of new interactions in the electroweak boson sector", *Phys. Rev. D* **48** (1993) 2182, doi:10.1103/PhysRevD.48.2182.

[3] C. Degrande et al., "Effective Field Theory: A Modern Approach to Anomalous Couplings", *Annals Phys.* **335** (2013) 21, doi:10.1016/j.aop.2013.04.016, arXiv:1205.4231.

[4] CMS Collaboration, "Measurement of the sum of WW and WZ production with W+dijet events in pp collisions at $\sqrt{s} = 7$ TeV", *Eur. Phys. J. C* **73** (2013) 2283, doi:10.1140/epjc/s10052-013-2283-3, arXiv:1210.7544.

[5] ATLAS Collaboration, "Measurement of the WW+WZ cross section and limits on anomalous triple gauge couplings using final states with one lepton, missing transverse momentum, and two jets with the ATLAS detector at $\sqrt{s} = 7$ TeV", *JHEP* **01** (2015) 049, doi:10.1007/JHEP01(2015)049, arXiv:1410.7238.

[6] CMS Collaboration, "Measurement of the W^+W^- cross section in pp collisions at $\sqrt{s} = 8$ TeV and limits on anomalous gauge couplings", *Eur. Phys. J. C* **76** (2016) 401, doi:10.1140/epjc/s10052-016-4219-1, arXiv:1507.03268.

[7] ATLAS Collaboration, "Measurement of total and differential W^+W^- production cross sections in proton-proton collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector and limits on anomalous triple-gauge-boson couplings", *JHEP* **09** (2016) 029, doi:10.1007/JHEP09(2016)029, arXiv:1603.01702.

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

[9] J. Alwall et al., "MadGraph 5: going beyond", *JHEP* **06** (2011) 128, doi:10.1007/JHEP06(2011)128, arXiv:1106.0522.

[10] P. Nason, "A New method for combining NLO QCD with shower Monte Carlo algorithms", *JHEP* **11** (2004) 040, doi:10.1088/1126-6708/2004/11/040, arXiv:hep-ph/0409146.

[11] S. Frixione, P. Nason, and C. Oleari, "Matching NLO QCD computations with Parton Shower simulations: the POWHEG method", *JHEP* **11** (2007) 070, doi:10.1088/1126-6708/2007/11/070, arXiv:0709.2092.

[12] S. Alioli, P. Nason, C. Oleari, and E. Re, "A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX", *JHEP* **06** (2010) 043, doi:10.1007/JHEP06(2010)043, arXiv:1002.2581.

[13] S. Frixione, P. Nason, and G. Ridolfi, "A Positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction", *JHEP* **09** (2007) 126, doi:10.1088/1126-6708/2007/09/126, arXiv:0707.3088.

[14] S. Alioli, P. Nason, C. Oleari, and E. Re, "NLO single-top production matched with shower in POWHEG: *s*- and *t*-channel contributions", *JHEP* **09** (2009) 111, doi:10.1088/1126-6708/2009/09/111, arXiv:0907.4076. [Erratum: doi:10.1007/JHEP02(2010)011].

[15] 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.

[16] P. Artoisenet, R. Frederix, O. Mattelaer, and R. Rietkerk, "Automatic spin-entangled decays of heavy resonances in Monte Carlo simulations", *JHEP* **03** (2013) 015, doi:10.1007/JHEP03(2013)015, arXiv:1212.3460.

[17] S. Jadach, Z. Wąs, R. Decker, and J. H. Kühn, "The tau decay library TAUOLA, version 2.4", *Comput. Phys. Commun.* **76** (1993) 361, doi:10.1016/0010-4655(93)90061-G.

[18] 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.

[19] CMS Collaboration, "Study of the underlying event at forward rapidity in pp collisions at $\sqrt{s}$ = 0.9, 2.76, and 7 TeV", *JHEP* **04** (2013) 072, doi:10.1007/JHEP04(2013)072, arXiv:1302.2394.

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

[21] J. Alwall et al., "Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions", *Eur. Phys. J. C* **53** (2008) 473, doi:10.1140/epjc/s10052-007-0490-5, arXiv:0706.2569.

[22] J. Pumplin et al., "New generation of parton distributions with uncertainties from global QCD analysis", *JHEP* **07** (2002) 012, doi:10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.

[23] H.-L. Lai et al., "New parton distributions for collider physics", *Phys. Rev. D* **82** (2010) 074024, doi:10.1103/PhysRevD.82.074024, arXiv:1007.2241.

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

[25] CMS Collaboration, "Particle–Flow Event Reconstruction in CMS and Performance for Jets, Taus, and $E_{\mathrm{T}}^{\text{miss}}$", CMS Physics Analysis Summary CMS-PAS-PFT-09-001, 2009.

[26] 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.

[27] CMS Collaboration, "The performance of the CMS muon detector in proton-proton collisions at $\sqrt{s} = 7$ TeV at the LHC", *JINST* **8** (2013) P11002, doi:10.1088/1748-0221/8/11/P11002, arXiv:1306.6905.

[28] CMS Collaboration, "Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV", *JINST* **10** (2015) P06005, doi:10.1088/1748-0221/10/06/P06005, arXiv:1502.02701.

[29] 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.

[30] M. Cacciari, G. P. Salam, and G. Soyez, "FastJet user manual", *Eur. Phys. J. C* **72** (2012) 1896, doi:10.1140/epjc/s10052-012-1896-2, arXiv:1111.6097.

[31] Y. L. Dokshitzer, G. D. Leder, S. Moretti, and B. R. Webber, "Better jet clustering algorithms", *JHEP* **08** (1997) 001, doi:10.1088/1126-6708/1997/08/001, arXiv:hep-ph/9707323.

[32] CMS Collaboration, "Identification of b-quark jets with the CMS experiment", *JINST* **8** (2013) P04013, doi:10.1088/1748-0221/8/04/P04013, arXiv:1211.4462.

[33] CMS Collaboration, "Studies of jet mass in dijet and W/Z+jet events", *J. High Energy Phys.* **05** (2013) 090, doi:10.1007/JHEP05(2013)090.

[34] S. D. Ellis, C. K. Vermilion, and J. R. Walsh, "Recombination algorithms and jet substructure: pruning as a tool for heavy particle searches", *Phys. Rev. D* **81** (2010) 094023, doi:10.1103/PhysRevD.81.094023, arXiv:0912.0033.

[35] 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.

[36] 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.

[37] Particle Data Group, C. Patrignani et al., "Review of Particle Physics", *Chin. Phys. C* **40** (2016) 100001, doi:10.1088/1674-1137/40/10/100001.

[38] J. M. Campbell and R. K. Ellis, "MCFM for the Tevatron and the LHC", *Nucl. Phys. Proc. Suppl.* **205–206** (2010) 10, doi:10.1016/j.nuclphysbps.2010.08.011, arXiv:1007.3492.

[39] CMS Collaboration, "Search for a Higgs boson in the mass range from 145 to 1000 GeV decaying to a pair of W or Z bosons", *JHEP* **10** (2015) 144, doi:10.1007/JHEP10(2015)144, arXiv:1504.00936.

[40] CMS Collaboration, “CMS Luminosity Based on Pixel Cluster Counting - Summer 2013 Update”, CMS Physics Analysis Summary CMS-PAS-LUM-13-001, 2013.

[41] ATLAS and CMS Collaborations, LHC Higgs Combination Group, “Procedure for the LHC Higgs boson search combination in Summer 2011”, Technical Report ATL-PHYS-PUB 2011-11, CMS-NOTE 2011-005, 2011.

[42] ALEPH, DELPHI, L3, OPAL, LEP Electroweak Collaboration, “Electroweak measurements in electron-positron collisions at W-boson-pair energies at LEP”, *Phys. Rept.* **532** (2013) 119, doi:10.1016/j.physrep.2013.07.004, arXiv:1302.3415.

[43] CMS Collaboration, “Measurement of the WZ production cross section in pp collisions at $\sqrt{s} = 7$ and 8 TeV and search for anomalous triple gauge couplings at $\sqrt{s} = 8$ TeV”, *Eur. Phys. J. C* **77** (2017), no. 4, 236, doi:10.1140/epjc/s10052-017-4730-z, arXiv:1609.05721.

[44] ATLAS Collaboration, “Measurements of $W^{\pm}Z$ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector and limits on anomalous gauge boson self-couplings”, *Phys. Rev. D* **93** (2016) 092004, doi:10.1103/PhysRevD.93.092004, arXiv:1603.02151.

A The CMS Collaboration

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

Institut für Hochenergiephysik, Wien, Austria
W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth[1], V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler[1], A. König, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady, N. Rad, B. Rahbaran, H. Rohringer, J. Schieck[1], J. Strauss, W. Waltenberger, C.-E. Wulz[1]

Institute for Nuclear Problems, Minsk, Belarus
O. Dvornikov, V. Makarenko, V. Mossolov, J. Suarez Gonzalez, V. Zykunov

National Centre for Particle and High Energy Physics, Minsk, Belarus
N. Shumeiko

Universiteit Antwerpen, Antwerpen, Belgium
S. Alderweireldt, E.A. De Wolf, X. Janssen, J. Lauwers, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium
S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, 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, A. Léonard, 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, S. Salva, R. Schöfbeck, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
H. Bakhshiansohi, C. Beluffi[3], 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. Selvaggi, 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, 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[4], A. Custódio, E.M. Da Costa, G.G. Da Silveira[5], D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, C. Mora Herrera, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote[4], 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], S. Dogra[a], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], P.G. Mercadante[b], C.S. Moon[a], S.F. Novaes[a], Sandra S. Padula[a], D. Romero Abad[b], J.C. Ruiz Vargas[a]

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

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

Beihang University, Beijing, China
W. Fang[6]

Institute of High Energy Physics, Beijing, China
M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, Y. Chen[7], T. Cheng, C.H. Jiang, D. Leggat, Z. Liu, F. Romeo, M. Ruan, S.M. Shaheen, A. Spiezia, J. Tao, C. Wang, Z. Wang, 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, J.P. Gomez, C.F. González Hernández, J.D. Ruiz Alvarez[8], J.C. Sanabria

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia
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[9], M. Finger Jr.[9]

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[10,11], E. El-khateeb[12], E. Salama[13,12]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
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, J. Tuominiemi, E. Tuovinen, L. Wendland

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, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri, S. Ganjour, S. Ghosh, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, I. Kucher, E. Locci, M. Machet, J. Malcles, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
A. Abdulsalam, I. Antropov, S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, O. Davignon, R. Granier de Cassagnac, M. Jo, S. Lisniak, P. Miné, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, P. Pigard, S. Regnard, R. Salerno, Y. Sirois, A.G. Stahl Leiton, T. Strebler, Y. Yilmaz, A. Zabi, A. Zghiche

Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3
J.-L. Agram[14], J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte[14], X. Coubez, J.-C. Fontaine[14], D. Gelé, U. Goerlach, A.-C. Le Bihan, 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, C.A. Carrillo Montoya, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, G. Grenier, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, A. Popov[15], V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

Georgian Technical University, Tbilisi, Georgia
T. Toriashvili[16]

Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[9]

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, L. Sonnenschein, D. Teyssier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
V. Cherepanov, G. Flügge, B. Kargoll, T. Kress, A. Künsken, J. Lingemann, T. Müller, A. Nehrkorn, A. Nowack, C. Pistone, O. Pooth, A. Stahl[17]

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, K. Beernaert, O. Behnke, U. Behrens, A.A. Bin Anuar, K. Borras[18], A. Campbell, P. Connor, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Dolinska, G. Eckerlin, D. Eckstein, T. Eichhorn, E. Eren, E. Gallo[19], J. Garay Garcia, A. Geiser, A. Gizhko, J.M. Grados Luyando, A. Grohsjean, P. Gunnellini, A. Harb, J. Hauk, M. Hempel[20], H. Jung, A. Kalogeropoulos, O. Karacheban[20], M. Kasemann, J. Keaveney, C. Kleinwort, I. Korol, D. Krücker, W. Lange, A. Lelek, T. Lenz, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann[20], R. Mankel, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, S. Spannagel, N. Stefaniuk, G.P. Van Onsem, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
V. Blobel, M. Centis Vignali, A.R. Draeger, T. Dreyer, E. Garutti, D. Gonzalez, J. Haller, M. Hoffmann, A. Junkes, R. Klanner, R. Kogler, N. Kovalchuk, T. Lapsien, I. Marchesini, D. Marconi, M. Meyer, M. Niedziela, D. Nowatschin, F. Pantaleo[17], T. Peiffer, A. Perieanu, C. Scharf, P. Schleper, A. Schmidt, S. Schumann, J. Schwandt, 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, C. Baus, J. Berger, E. Butz, R. Caspart, T. Chwalek, F. Colombo, W. De Boer, A. Dierlamm, S. Fink, B. Freund, R. Friese, M. Giffels, A. Gilbert, P. Goldenzweig, D. Haitz, F. Hartmann[17], S.M. Heindl, U. Husemann, F. Kassel[17], I. Katkov[15], S. Kudella, H. Mildner, M.U. Mozer, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, 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, E. Tziaferi

University of Ioánnina, Ioánnina, Greece
I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradas

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
N. Filipovic, G. Pasztor

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, D. Horvath[21], F. Sikler, V. Veszpremi, G. Vesztergombi[22], A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Karancsi[23], A. Makovec, J. Molnar, Z. Szillasi

Institute of Physics, University of Debrecen
M. Bartók[22], P. Raics, Z.L. Trocsanyi, B. Ujvari

Indian Institute of Science (IISc)
J.R. Komaragiri

National Institute of Science Education and Research, Bhubaneswar, India
S. Bahinipati[24], S. Bhowmik[25], S. Choudhury[26], P. Mal, K. Mandal, A. Nayak[27], D.K. Sahoo[24], N. Sahoo, S.K. Swain

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

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

Saha Institute of Nuclear Physics, Kolkata, India
R. Bhattacharya, S. Bhattacharya, K. Chatterjee, 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[17], P.K. Netrakanti, L.M. Pant, P. Shukla, A. Topkar

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

Tata Institute of Fundamental Research-B, Mumbai, India
S. Banerjee, R.K. Dewanjee, S. Ganguly, M. Guchait, Sa. Jain, S. Kumar, M. Maity[25], G. Majumder, K. Mazumdar, T. Sarkar[25], N. Wickramage[28]

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[29], E. Eskandari Tadavani, S.M. Etesami[29], M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi[30], F. Rezaei Hosseinabadi, B. Safarzadeh[31], 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], L. Fiore[a], G. Iaselli[a,c], 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,17], R. Venditti[a,b], P. Verwilligen[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], C. Battilana, 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,b], 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,b,17]

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], 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,32], G. Sguazzoni[a], D. Strom[a], L. Viliani[a,b,17]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera[17]

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

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
L. Brianza[a,b,17], F. Brivio[a,b], V. Ciriolo, M.E. Dinardo[a,b], S. Fiorendi[a,b,17], 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], D. Pedrini[a], S. Pigazzini[a,b], 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], G. De Nardo, S. Di Guida[a,d,17], M. Esposito[a,b], F. Fabozzi[a,c], F. Fienga[a,b], A.O.M. Iorio[a,b], G. Lanza[a], L. Lista[a], S. Meola[a,d,17], P. Paolucci[a,17], 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,17], 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], M. Dall'Osso[a,b], 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], J. Pazzini[a,b], N. Pozzobon[a,b], P. Ronchese[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], 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], G.M. Bilei[a], D. Ciangottini[a,b], L. Fanò[a,b], P. Lariccia[a,b], R. Leonardi[a,b], G. Mantovani[a,b], V. Mariani[a,b], M. Menichelli[a], A. Saha[a], A. Santocchia[a,b]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
K. Androsov[a,32], P. Azzurri[a,17], G. Bagliesi[a], J. Bernardini[a], T. Boccali[a], R. Castaldi[a], M.A. Ciocci[a,32], R. Dell'Orso[a], S. Donato[a,c], G. Fedi, A. Giassi[a], M.T. Grippo[a,32], F. Ligabue[a,c], T. Lomtadze[a], L. Martini[a,b], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], A. Savoy-Navarro[a,33], P. Spagnolo[a], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Università di Roma [b], Roma, Italy
L. Barone[a,b], F. Cavallari[a], M. Cipriani[a,b], D. Del Re[a,b,17], 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,17], 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],

L. Finco[a,b], 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, S. Lee, S.W. Lee, 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

Hanyang University, Seoul, Korea
J.A. Brochero Cifuentes, 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, H. Lee, 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, M.S. Ryu

Sungkyunkwan University, Suwon, Korea
Y. Choi, J. Goh, 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[34], F. Mohamad Idris[35], 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[36], A. Hernandez-Almada, R. Lopez-Fernandez, R. Magaña Villalba, 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
S. Carpinteyro, 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, W.A. Khan, 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[37], K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, 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, P.G. Ferreira Parracho, M. Gallinaro, J. Hollar, N. Leonardo, L. Lloret Iglesias, M.V. Nemallapudi, J. Rodrigues Antunes, 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[38,39], V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, N. Voytishin, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
L. Chtchipounov, V. Golovtsov, Y. Ivanov, V. Kim[40], E. Kuznetsova[41], V. Murzin, V. Oreshkin, V. Sulimov, 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, M. Toms, E. Vlasov, A. Zhokin

Moscow Institute of Physics and Technology, Moscow, Russia
T. Aushev, A. Bylinkin[39]

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
M. Chadeeva[42], O. Markin, V. Rusinov

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin[39], I. Dremin[39], M. Kirakosyan, A. Leonidov[39], A. Terkulov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Baskakov, A. Belyaev, E. Boos, M. Dubinin[43], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

Novosibirsk State University (NSU), Novosibirsk, Russia
V. Blinov[44], Y.Skovpen[44], D. Shtol[44]

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[45], 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, E. Calvo, M. Cerrada, M. Chamizo Llatas, 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, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, M.S. Soares

Universidad Autónoma de Madrid, Madrid, Spain
J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad de Oviedo, Oviedo, Spain
J. Cuevas, 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, E. Curras, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, C. Martinez Rivero, 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, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, P. Bloch, A. Bocci, C. Botta, T. Camporesi, R. Castello, M. Cepeda, G. Cerminara, Y. Chen, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, A. De Roeck, E. Di Marco[46], M. Dobson, B. Dorney, T. du Pree, D. Duggan, M. Dünser, N. Dupont, A. Elliott-Peisert, P. Everaerts, S. Fartoukh, G. Franzoni, J. Fulcher, W. Funk, D. Gigi, K. Gill, M. Girone, F. Glege, D. Gulhan, S. Gundacker, M. Guthoff, P. Harris, J. Hegeman, V. Innocente, P. Janot, J. Kieseler, H. Kirschenmann, V. Knünz, A. Kornmayer[17], M.J. Kortelainen, K. Kousouris, M. Krammer[1], 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[47], F. Moortgat, S. Morovic, 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[48], M. Rovere, H. Sakulin, J.B. Sauvan, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, P. Sphicas[49], J. Steggemann, M. Stoye, Y. Takahashi, M. Tosi, D. Treille, A. Triossi, A. Tsirou, V. Veckalns[50], G.I. Veres[22], M. Verweij, N. Wardle, H.K. Wöhri, A. Zagozdzinska[37], 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, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Lustermann, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, 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. Rossini, M. Schönenberger, A. Starodumov[51], V.R. Tavolaro, K. Theofilatos, R. Wallny

Universität Zürich, Zurich, Switzerland
T.K. Aarrestad, C. Amsler[52], L. Caminada, M.F. Canelli, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, J. Ngadiuba, D. Pinna, G. Rauco, P. Robmann, D. Salerno, C. Seitz, Y. Yang, A. Zucchetta

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

National Taiwan University (NTU), Taipei, Taiwan
Arun Kumar, P. Chang, Y.H. 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, G. Singh, N. Srimanobhas, N. Suwonjandee

Cukurova University - Physics Department, Science and Art Faculty
A. Adiguzel, M.N. Bakirci[53], S. Damarseckin, Z.S. Demiroglu, C. Dozen, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, I. Hos[54], E.E. Kangal[55], O. Kara, U. Kiminsu, M. Oglakci, G. Onengut[56], K. Ozdemir[57], S. Ozturk[53], A. Polatoz, D. Sunar Cerci[58], S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey
B. Bilin, S. Bilmis, B. Isildak[59], G. Karapinar[60], M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, M. Kaya[61], O. Kaya[62], E.A. Yetkin[63], T. Yetkin[64]

Istanbul Technical University, Istanbul, Turkey
A. Cakir, K. Cankocak, S. Sen[65]

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, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, D.M. Newbold[66], 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[67], 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
M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, R. Di Maria, P. Dunne, A. Elwood, D. Futyan, Y. Haddad, G. Hall, G. Iles, T. James, R. Lane, C. Laner, R. Lucas[66], L. Lyons, A.-M. Magnan, S. Malik, L. Mastrolorenzo, J. Nash, A. Nikitenko[51], J. Pela, B. Penning,

M. Pesaresi, D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, S. Summers, A. Tapper, K. Uchida, M. Vazquez Acosta[68], T. Virdee[17], 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
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, O. Jesus, K.H.M. Kwok, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, E. Spencer, R. Syarif

University of California, Davis, Davis, USA
R. Breedon, D. Burns, M. Calderon De La Barca Sanchez, S. Chauhan, 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

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, M. Weber

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, H. Wei, S. Wimpenny, B. R. Yates

University of California, San Diego, La Jolla, USA
J.G. Branson, G.B. Cerati, S. Cittolin, M. Derdzinski, R. Gerosa, A. Holzner, D. Klein, V. Krutelyov, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech[69], C. Welke, 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. Bunn, J. Duarte, J.M. Lawhorn, A. Mott, H.B. Newman, C. Pena, M. Spiropulu, J.R. Vlimant, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
M.B. Andrews, T. Ferguson, 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, G. Nicolas Kaufman, J.R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, S.M. Tan, Z. Tao, J. Thom, J. Tucker, P. Wittich, M. Zientek

Fairfield University, Fairfield, USA
D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, A. Apresyan, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir[†], M. Cremonesi, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, D. Hare, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, B. Jayatilaka, S. Jindariani, M. Johnson, U. Joshi, B. Klima, B. Kreis, S. Lammel, J. Linacre, 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, K. Mishra, S. Mrenna, S. Nahn, V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, L. Ristori, 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, Y. Wu, F. Yang

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, J.F. Low, P. Ma, K. Matchev, H. Mei, G. Mitselmakher, D. Rank, L. Shchutska, D. Sperka, L. Thomas, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, USA
S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA
A. Ackert, T. Adams, A. Askew, S. Bein, S. Hagopian, V. Hagopian, K.F. Johnson, T. Kolberg, 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, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, K. Jung, I.D. Sandoval Gonzalez, N. Varelas, H. Wang, Z. Wu, M. Zakaria, J. Zhang

The University of Iowa, Iowa City, USA
B. Bilki[70], W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya[71], A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok[72], 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, L. Forthomme, R.P. Kenny III, S. Khalil, A. Kropivnitskaya, D. Majumder, W. Mcbrayer, M. Murray, S. Sanders, J. Sekaric, 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, J.A. Gomez, N.J. Hadley, S. Jabeen, G.Y. Jeng, R.G. Kellogg, J. Kunkle, A.C. Mignerey, F. Ricci-Tam, Y.H. Shin, A. Skuja, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA
D. Abercrombie, B. Allen, A. Apyan, V. Azzolini, R. Barbieri, A. Baty, R. Bi, K. Bierwagen, 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, K. Krajczar, 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, S.C. Kao, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, 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, A. Malta Rodrigues, 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, J. Kaisen, 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, A. Kumar, 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. Marinelli, F. Meng, C. Mueller, Y. Musienko[38], M. Planer, A. Reinsvold, R. Ruchti, N. Rupprecht, 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, R. Hughes, 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, D. Lange, J. Luo, D. Marlow, T. Medvedeva, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, P. Piroué, D. Stickland, A. Svyatkovskiy, C. Tully

University of Puerto Rico, Mayaguez, USA
S. Malik

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, J.F. Schulte, X. Shi, J. Sun, F. Wang, W. Xie

Purdue University Northwest, Hammond, USA
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
B. Betchart, 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

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, 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[73], A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, E. Juska, T. Kamon[74], R. Mueller, I. Osipenkov, 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, C. Dragoiu, 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, J. Goodell, 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

University of Wisconsin - Madison, Madison, WI, USA
D.A. Belknap, J. Buchanan, C. Caillol, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, T. Perry, 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 Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS/IN2P3, Strasbourg, France
4: Also at Universidade Estadual de Campinas, Campinas, Brazil
5: Also at Universidade Federal de Pelotas, Pelotas, Brazil
6: Also at Université Libre de Bruxelles, Bruxelles, Belgium
7: Also at Deutsches Elektronen-Synchrotron, Hamburg, Germany
8: Also at Universidad de Antioquia, Medellin, Colombia
9: Also at Joint Institute for Nuclear Research, Dubna, Russia
10: Also at Helwan University, Cairo, Egypt
11: Now at Zewail City of Science and Technology, Zewail, Egypt
12: Now at Ain Shams University, Cairo, Egypt
13: Also at British University in Egypt, Cairo, Egypt
14: Also at Université de Haute Alsace, Mulhouse, France
15: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
16: Also at Tbilisi State University, Tbilisi, Georgia
17: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
18: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
19: Also at University of Hamburg, Hamburg, Germany
20: Also at Brandenburg University of Technology, Cottbus, Germany
21: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
22: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
23: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary
24: Also at Indian Institute of Technology Bhubaneswar, Bhubaneswar, India
25: Also at University of Visva-Bharati, Santiniketan, India
26: Also at Indian Institute of Science Education and Research, Bhopal, India
27: Also at Institute of Physics, Bhubaneswar, India
28: Also at University of Ruhuna, Matara, Sri Lanka
29: Also at Isfahan University of Technology, Isfahan, Iran
30: Also at Yazd University, Yazd, Iran
31: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
32: Also at Università degli Studi di Siena, Siena, Italy
33: Also at Purdue University, West Lafayette, USA
34: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
35: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
36: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
37: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
38: Also at Institute for Nuclear Research, Moscow, Russia
39: Now at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
40: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
41: Also at University of Florida, Gainesville, USA
42: Also at P.N. Lebedev Physical Institute, Moscow, Russia

43: Also at California Institute of Technology, Pasadena, USA
44: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
45: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
46: Also at INFN Sezione di Roma; Università di Roma, Roma, Italy
47: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
48: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
49: Also at National and Kapodistrian University of Athens, Athens, Greece
50: Also at Riga Technical University, Riga, Latvia
51: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
52: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
53: Also at Gaziosmanpasa University, Tokat, Turkey
54: Also at Istanbul Aydin University, Istanbul, Turkey
55: Also at Mersin University, Mersin, Turkey
56: Also at Cag University, Mersin, Turkey
57: Also at Piri Reis University, Istanbul, Turkey
58: Also at Adiyaman University, Adiyaman, Turkey
59: Also at Ozyegin University, Istanbul, Turkey
60: Also at Izmir Institute of Technology, Izmir, Turkey
61: Also at Marmara University, Istanbul, Turkey
62: Also at Kafkas University, Kars, Turkey
63: Also at Istanbul Bilgi University, Istanbul, Turkey
64: Also at Yildiz Technical University, Istanbul, Turkey
65: Also at Hacettepe University, Ankara, Turkey
66: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
67: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
68: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
69: Also at Utah Valley University, Orem, USA
70: Also at Argonne National Laboratory, Argonne, USA
71: Also at Erzincan University, Erzincan, Turkey
72: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
73: Also at Texas A&M University at Qatar, Doha, Qatar
74: Also at Kyungpook National University, Daegu, Korea