

MIT Open Access Articles

Search for Anomalous Couplings in boosted $WW/WZ \rightarrow ##qq##$ production in Proton-proton Collisions At $\sqrt{s} = 8$ TeV

The MIT Faculty has made this article openly available. **Please share** how this access benefits you. Your story matters.

Citation: Sirunyan, A.M. et al. "Search for Anomalous Couplings in boosted $WW/WZ \rightarrow ##qq##$ production in Proton-proton Collisions At $\sqrt{s} = 8$ TeV." Physics Letters B 772 (September 2017): 21-42 © 2017 The Author

As Published: <http://dx.doi.org/10.1016/J.PHYSLETB.2017.06.009>

Publisher: Elsevier

Persistent URL: <http://hdl.handle.net/1721.1/119229>

Version: Final published version: final published article, as it appeared in a journal, conference proceedings, or other formally published context

Terms of use: Creative Commons Attribution 4.0 International License





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



The CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:

Received 17 March 2017
 Received in revised form 20 May 2017
 Accepted 5 June 2017
 Available online 12 June 2017
 Editor: M. Doser

Keywords:

CMS
 Physics
 aTGC

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 $\sqrt{s} = 8$ TeV with the CMS detector at the LHC, correspond to an integrated luminosity of 19 fb^{-1} . No evidence for anomalous triple gauge couplings is found and the following 95% confidence level limits are set on their values: λ ($[-0.011, 0.011]$), $\Delta\kappa_\gamma$ ($[-0.044, 0.063]$), and Δg_1^Z ($[-0.0087, 0.024]$). These limits are also translated into their effective field theory equivalents: c_{WWW}/Λ^2 ($[-2.7, 2.7] \text{ TeV}^{-2}$), c_B/Λ^2 ($[-14, 17] \text{ TeV}^{-2}$), and c_W/Λ^2 ($[-2.0, 5.7] \text{ TeV}^{-2}$).

© 2017 The Author. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP³.

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 $q\bar{q}$ annihilation diagrams have a triple-boson vertex. In WW production, the $WW\gamma$ 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 ($\lambda_{\text{SM}} = 0$). 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 ($W_{\text{lep}} \rightarrow \ell\nu$, with $\ell = e, \mu$), while the other vector boson V_{had} de-

cays 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 $\ell\nu q\bar{q}$ 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 $\ell\nu q\bar{q}$ channel, arising mainly from W +jets production. The sensitivity of WW production to the $WW\gamma$ 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 out-

* E-mail address: cms-publication-committee-chair@cern.ch.

side 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 $W \rightarrow \tau\nu$ 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 $\Delta R(\ell, J) > \pi/2$, $\Delta\phi(E_T^{\text{miss}}, J) > 2.0$, and $\Delta\phi(W_{\text{lep}}, J) > 2.0$. We veto events based on the presence of any b-tagged AK5 jets with $p_T > 20$ GeV and outside the CA8 jet cone to reduce the $t\bar{t}$ 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 ($t\bar{t}$ and single top quark), and SM diboson production. Multijets, Z+jets, ZZ, $Z\gamma$, $H(125) \rightarrow WW^*$, 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 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 $40 < m_J < 140$ 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 $70 < m_J < 100$ 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

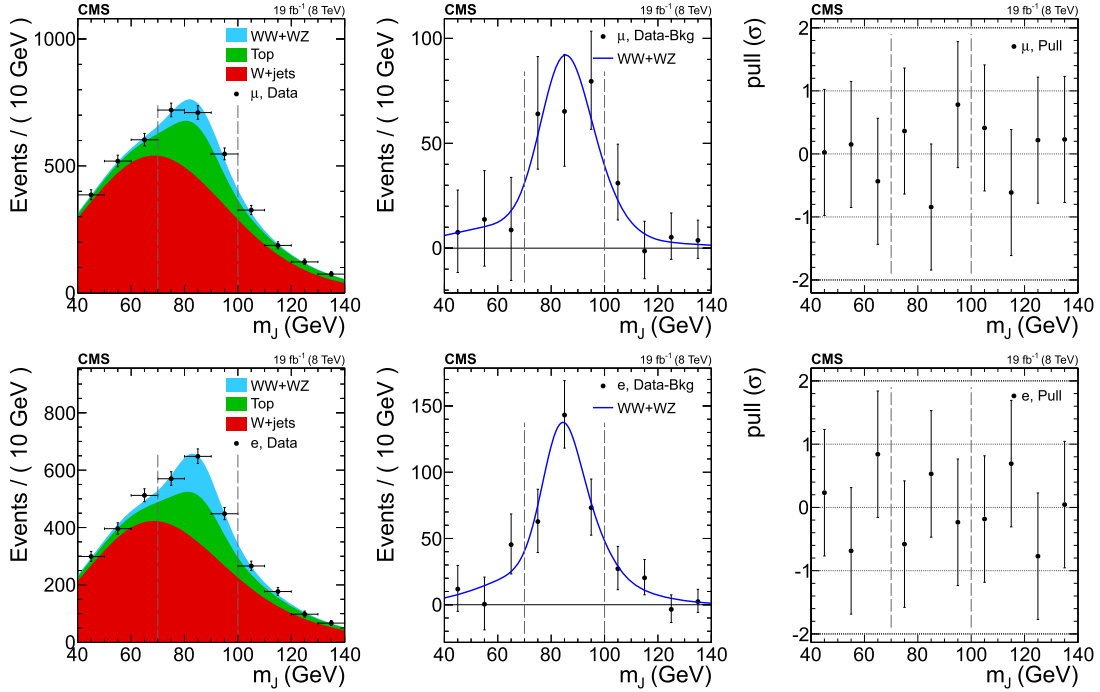


Fig. 1. Post-fit distributions of the merged jet invariant mass for muons (top) and electrons (bottom) with the estimates of the relevant backgrounds. The merged jet invariant mass is plotted for all events (left), after subtraction of all components except the diboson (center), and the subsequent normalized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

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 V_{had} is modeled by an error function times an exponential function. The W Gaussian parameters are subsequently corrected with MC-to-data 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 $\pm 50\%$ 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.

Fig. 1 shows the results of one of the fits to the data. The left plots show the observed 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 $(\text{data} - \text{fit})/(\text{fit uncertainty})$, 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 ($\mathcal{A}\epsilon$) is determined from the diboson MC. The electron channel has a smaller $\mathcal{A}\epsilon$ 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 prefit 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)).

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

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 $\mathcal{A}\epsilon$ (acceptance \times efficiency) includes W and Z branching fractions [37].

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

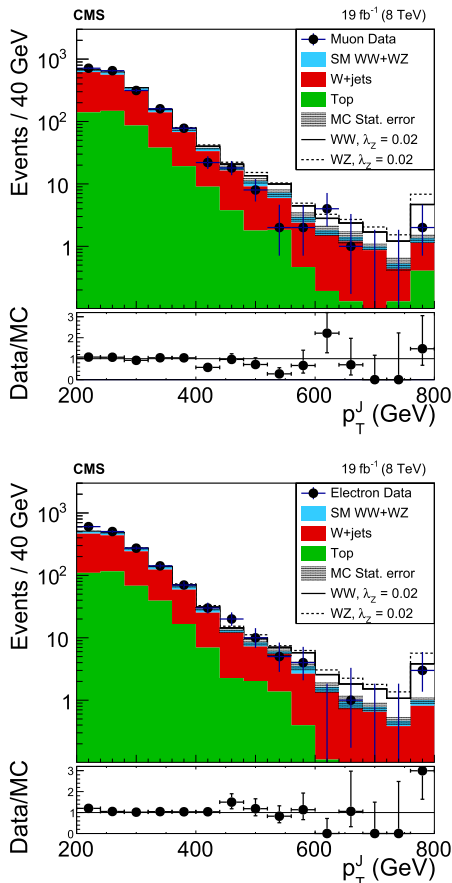


Fig. 2. $V_{\text{had}} p_T$ distributions for the muon (top) and electron (bottom) channels after full selection and with the requirement $70 < m_J < 100$ GeV. The MC errors are purely statistical. Examples of the effects of aTGCs are shown by the solid and dotted lines. Below we show the data/MC ratio.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

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., $|\mathcal{M}|^2/|\mathcal{M}|_{\text{SM}}^2$, where $|\mathcal{M}|^2$ is the squared matrix element in the presence of anomalous couplings and $|\mathcal{M}|_{\text{SM}}^2$ 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, $70 < m_J < 100$ 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 $p_T^W > 1$ TeV. For PDF uncertainties we compare aMC@NLO samples employing 41 alternative sets of CTQ6M 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%.

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

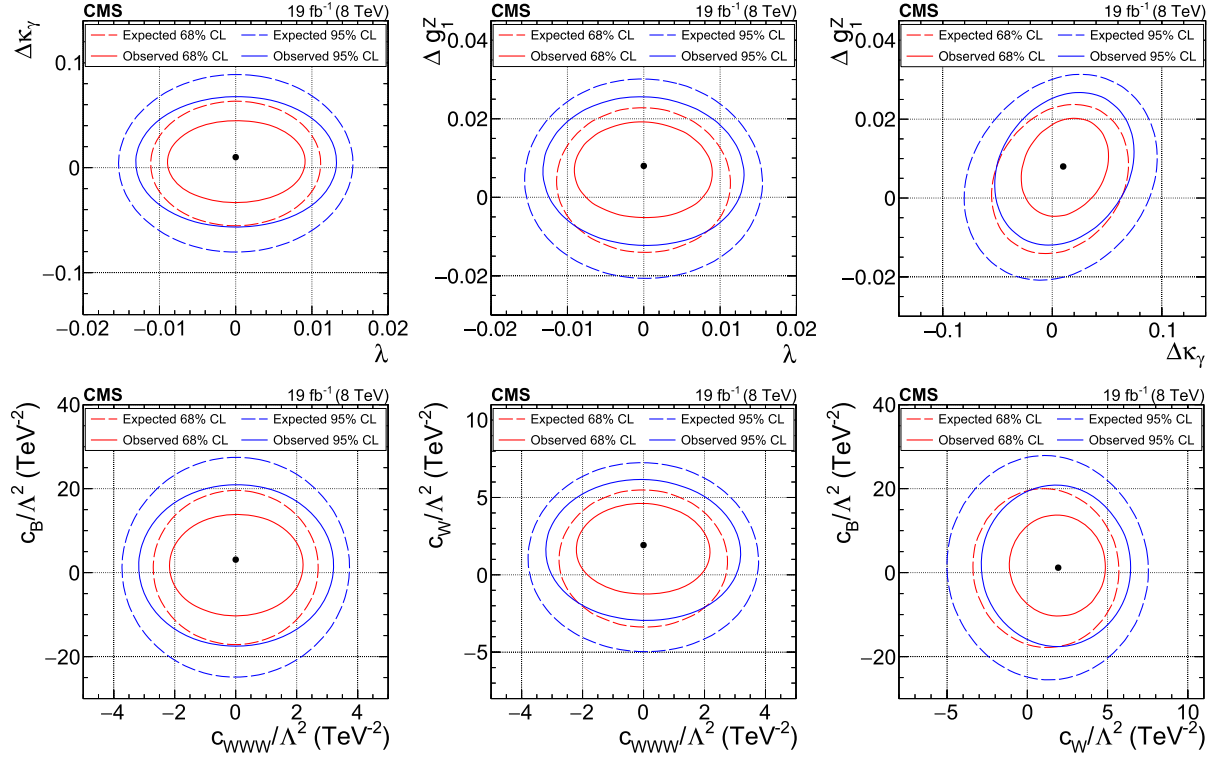


Fig. 3. The 68 and 95% CL observed and expected exclusion contours in ΔNLL are depicted for three pairwise combinations of the aTGC parameters in the LEP parametrization (top) and in the EFT formulation (bottom). The black dot represents the best fit point. The origin represents the SM prediction. The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

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 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].

Acknowledgements

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); ThEP-Center, 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 Alfred 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 Thalís 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, A. Signer, Vector boson pair production in hadronic collisions at order α_s : lepton correlations and anomalous couplings, *Phys. Rev. D* 60 (1999) 114037, <http://dx.doi.org/10.1103/PhysRevD.60.114037>, arXiv:hep-ph/9907305.
- [2] K. Hagiwara, S. Ishihara, R. Szalapski, D. Zeppenfeld, Low energy effects of new interactions in the electroweak boson sector, *Phys. Rev. D* 48 (1993) 2182, <http://dx.doi.org/10.1103/PhysRevD.48.2182>.
- [3] C. Degrande, N. Greiner, W. Kilian, O. Mattelaer, H. Mebane, T. Stelzer, S. Willenbrock, C. Zhang, Effective field theory: a modern approach to anomalous couplings, *Ann. Phys.* 335 (2013) 21, <http://dx.doi.org/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, <http://dx.doi.org/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, *J. High Energy Phys.* 01 (2015) 049, [http://dx.doi.org/10.1007/JHEP01\(2015\)049](http://dx.doi.org/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, <http://dx.doi.org/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, *J. High Energy Phys.* 09 (2016) 029, [http://dx.doi.org/10.1007/JHEP09\(2016\)029](http://dx.doi.org/10.1007/JHEP09(2016)029), arXiv:1603.01702.
- [8] CMS Collaboration, The CMS experiment at the CERN LHC, *J. Instrum.* 3 (2008) S08004, <http://dx.doi.org/10.1088/1748-0221/3/08/S08004>.
- [9] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer, MadGraph 5: going beyond, *J. High Energy Phys.* 06 (2011) 128, [http://dx.doi.org/10.1007/JHEP06\(2011\)128](http://dx.doi.org/10.1007/JHEP06(2011)128), arXiv:1106.0522.
- [10] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, *J. High Energy Phys.* 11 (2004) 040, <http://dx.doi.org/10.1088/1126-6708/2004/11/040>, arXiv:hep-ph/0409146.
- [11] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with Parton Shower simulations: the POWHEG method, *J. High Energy Phys.* 11 (2007) 070, <http://dx.doi.org/10.1088/1126-6708/2007/11/070>, arXiv:0709.2092.
- [12] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, *J. High Energy Phys.* 06 (2010) 043, [http://dx.doi.org/10.1007/JHEP06\(2010\)043](http://dx.doi.org/10.1007/JHEP06(2010)043), arXiv:1002.2581.
- [13] S. Frixione, P. Nason, G. Ridolfi, A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction, *J. High Energy Phys.* 09 (2007) 126, <http://dx.doi.org/10.1088/1126-6708/2007/09/126>, arXiv:0707.3088.
- [14] S. Alioli, P. Nason, C. Oleari, E. Re, NLO single-top production matched with shower in POWHEG: s- and t-channel contributions, *J. High Energy Phys.* 09 (2009) 111, <http://dx.doi.org/10.1088/1126-6708/2009/09/111>, arXiv:0907.4076.
- [15] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, et al., The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations, *J. High Energy Phys.* 07 (2014) 079, [http://dx.doi.org/10.1007/JHEP07\(2014\)079](http://dx.doi.org/10.1007/JHEP07(2014)079), arXiv:1405.0301.
- [16] P. Artoisenet, R. Frederix, O. Mattelaer, R. Rietkerk, Automatic spin-entangled decays of heavy resonances in Monte Carlo simulations, *J. High Energy Phys.* 03 (2013) 015, [http://dx.doi.org/10.1007/JHEP03\(2013\)015](http://dx.doi.org/10.1007/JHEP03(2013)015), arXiv:1212.3460.
- [17] S. Jadach, Z. Wař, R. Decker, J.H. Kühn, The tau decay library TAUOLA, version 2.4, *Comput. Phys. Commun.* 76 (1993) 361, [http://dx.doi.org/10.1016/0010-4655\(93\)90061-G](http://dx.doi.org/10.1016/0010-4655(93)90061-G).
- [18] T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual, *J. High Energy Phys.* 05 (2006) 026, <http://dx.doi.org/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, *J. High Energy Phys.* 04 (2013) 072, [http://dx.doi.org/10.1007/JHEP04\(2013\)072](http://dx.doi.org/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, <http://dx.doi.org/10.1140/epjc/s10052-016-3988-x>, arXiv:1512.00815.
- [21] J. Alwall, S. Höche, F. Krauss, N. Lavesson, L. Lönnblad, F. Maltoni, M.L. Mangano, M. Moretti, C.G. Papadopoulos, F. Piccinini, S. Schumann, M. Treccani, J. Winter, M. Worek, Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions, *Eur. Phys. J. C* 53 (2008) 473, <http://dx.doi.org/10.1140/epjc/s10052-007-0490-5>, arXiv:0706.2569.
- [22] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P.M. Nadolsky, W.K. Tung, New generation of parton distributions with uncertainties from global QCD analysis, *J. High Energy Phys.* 07 (2002) 012, <http://dx.doi.org/10.1088/1126-6708/2002/07/012>, arXiv:hep-ph/0201195.
- [23] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P.M. Nadolsky, J. Pumplin, C.-P. Yuan, New parton distributions for collider physics, *Phys. Rev. D* 82 (2010) 074024, <http://dx.doi.org/10.1103/PhysRevD.82.074024>, arXiv:1007.2241.
- [24] S. Agostinelli, et al., GEANT4 Collaboration, GEANT4 – a simulation toolkit, *Nucl. Instrum. Methods Phys. Res., Sect. A, Accel. Spectrom. Detect. Assoc. Equip.* 506 (2003) 250, [http://dx.doi.org/10.1016/S0168-9002\(03\)01368-8](http://dx.doi.org/10.1016/S0168-9002(03)01368-8).
- [25] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and E_T^{miss} , CMS Physics Analysis Summary CMS-PAS-PFT-09-001, 2009, <http://cdsweb.cern.ch/record/1194487>.
- [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, <http://cdsweb.cern.ch/record/1247373>.
- [27] CMS Collaboration, The performance of the CMS muon detector in proton–proton collisions at $\sqrt{s} = 7$ TeV at the LHC, *J. Instrum.* 8 (2013) P11002, <http://dx.doi.org/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, *J. Instrum.* 10 (2015) P06005, <http://dx.doi.org/10.1088/1748-0221/10/06/P06005>, arXiv:1502.02701.
- [29] M. Cacciari, G.P. Salam, G. Soyez, The anti- k_r jet clustering algorithm, *J. High Energy Phys.* 04 (2008) 063, <http://dx.doi.org/10.1088/1126-6708/2008/04/063>, arXiv:0802.1189.
- [30] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, *Eur. Phys. J. C* 72 (2012) 1896, <http://dx.doi.org/10.1140/epjc/s10052-012-1896-2>, arXiv:1111.6097.
- [31] Y.L. Dokshitzer, G.D. Leder, S. Moretti, B.R. Webber, Better jet clustering algorithms, *J. High Energy Phys.* 08 (1997) 001, <http://dx.doi.org/10.1088/1126-6708/1997/08/001>, arXiv:hep-ph/9707323.
- [32] CMS Collaboration, Identification of b-quark jets with the CMS experiment, *J. Instrum.* 8 (2013) P04013, <http://dx.doi.org/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, [http://dx.doi.org/10.1007/JHEP05\(2013\)090](http://dx.doi.org/10.1007/JHEP05(2013)090).
- [34] S.D. Ellis, C.K. Vermilion, J.R. Walsh, Recombination algorithms and jet substructure: pruning as a tool for heavy particle searches, *Phys. Rev. D* 81 (2010) 094023, <http://dx.doi.org/10.1103/PhysRevD.81.094023>, arXiv:0912.0033.
- [35] J. Thaler, K. Van Tilburg, Identifying boosted objects with N-subjettiness, *J. High Energy Phys.* 03 (2011) 015, [http://dx.doi.org/10.1007/JHEP03\(2011\)015](http://dx.doi.org/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, *J. High Energy Phys.* 08 (2014) 174, [http://dx.doi.org/10.1007/JHEP08\(2014\)174](http://dx.doi.org/10.1007/JHEP08(2014)174), arXiv:1405.3447.
- [37] C. Patrignani, et al., Particle Data Group, Review of particle physics, *Chin. Phys. C* 40 (2016) 100001, <http://dx.doi.org/10.1088/1674-1137/40/10/100001>.
- [38] J.M. Campbell, R.K. Ellis, MCFM for the Tevatron and the LHC, *Nucl. Phys. B, Proc. Suppl.* 205–206 (2010) 10, <http://dx.doi.org/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, *J. High Energy Phys.* 10 (2015) 144, [http://dx.doi.org/10.1007/JHEP10\(2015\)144](http://dx.doi.org/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, <http://cdsweb.cern.ch/record/1598864>.
- [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, <http://cdsweb.cern.ch/record/1379837>.

- [42] S. Schael, et al., ALEPH, DELPHI, L3, OPAL, LEP Electroweak, Electroweak measurements in electron-positron collisions at W-boson-pair energies at LEP, Phys. Rep. 532 (2013) 119, <http://dx.doi.org/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) 236, <http://dx.doi.org/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, <http://dx.doi.org/10.1103/PhysRevD.93.092004>, arXiv:1603.02151.

The CMS Collaboration

A.M. Sirunyan, A. Tumasyan

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, A. König, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady, N. Rad, B. Rahbaran, H. Rohringer, J. Schieck¹, J. Strauss, W. Waltenberger, C.-E. Wulz¹

Institut für Hochenergiephysik, Wien, Austria

O. Dvornikov, V. Makarenko, V. Mossolov, J. Suarez Gonzalez, V. Zykunov

Institute for Nuclear Problems, Minsk, Belarus

N. Shumeiko

National Centre for Particle and High Energy Physics, Minsk, Belarus

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

Universiteit Antwerpen, Antwerpen, 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

Vrije Universiteit Brussel, Brussel, 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. Zhang²

Université Libre de Bruxelles, Bruxelles, 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

Ghent University, Ghent, Belgium

H. Bakhshiansohi, C. Beluffi³, 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. Piotrkowski, L. Quertenmont, M. Selvaggi, M. Vidal Marono, S. Wertz

Université Catholique de Louvain, Louvain-la-Neuve, Belgium

N. Belyi

Université de Mons, Mons, Belgium

W.L. Aldá Júnior, F.L. Alves, G.A. Alves, L. Brito, C. Hensel, A. Moraes, M.E. Pol, P. Rebello Teles

Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁴, A. Custódio, E.M. Da Costa, G.G. Da Silveira⁵, 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 Manganote⁴, F. Torres Da Silva De Araujo, A. Vilela Pereira

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 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

^a *Universidade Estadual Paulista, São Paulo, Brazil*

^b *Universidade Federal do ABC, São Paulo, Brazil*

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

University of Sofia, Sofia, Bulgaria

W. Fang⁶

Beihang University, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, Y. Chen⁷, 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

Institute of High Energy Physics, Beijing, China

Y. Ban, G. Chen, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, C.F. González Hernández, J.D. Ruiz Alvarez⁸, J.C. Sanabria

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, I. Puljak, P.M. Ribeiro Cipriano, T. Sculac

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia

Z. Antunovic, M. Kovac

University of Split, Faculty of Science, Split, Croatia

V. Brigljevic, D. Ferencek, K. Kadija, B. Mesic, T. Susa

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

M. Finger⁹, M. Finger Jr.⁹

Charles University, Prague, Czech Republic

E. Carrera Jarrin

Universidad San Francisco de Quito, Quito, Ecuador

A.A. Abdelalim^{10,11}, E. El-khateeb¹², E. Salama^{13,12}

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

M. Kadastik, L. Perrini, M. Raidal, A. Tiko, C. Veelken

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, J. Pekkanen, M. Voutilainen

Department of Physics, University of Helsinki, 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

Helsinki Institute of Physics, Helsinki, Finland

J. Talvitie, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

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. Mached, J. Malcles, J. Rander, A. Rosowsky, M. Titov

IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, 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

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

J.-L. Agram¹⁴, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte¹⁴, X. Coubez, J.-C. Fontaine¹⁴, D. Gelé, U. Goerlach, A.-C. Le Bihan, P. Van Hove

Institut Pluridisciplinaire Hubert Curien (IPHC), Université de Strasbourg, CNRS-IN2P3, France

S. Gadrat

Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules, CNRS/IN2P3, 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. Popov¹⁵, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France

T. Toriashvili¹⁶

Georgian Technical University, Tbilisi, Georgia

Z. Tsamalaidze⁹

Tbilisi State University, Tbilisi, Georgia

C. Autermann, S. Beranek, L. Feld, M.K. Kiesel, K. Klein, M. Lipinski, M. Preuten, C. Schomakers, J. Schulz, T. Verlage

RWTH Aachen University, I. Physikalisches Institut, 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. Teysier, S. Thüer

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany

V. Cherepanov, G. Flügge, B. Kargoll, T. Kress, A. Künsken, J. Lingemann, T. Müller, A. Nehr Korn, A. Nowack, C. Pistone, O. Pooth, A. Stahl¹⁷

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany

M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, K. Beernaert, O. Behnke, U. Behrens, A.A. Bin Anuar, K. Borras¹⁸, A. Campbell, P. Connor, C. Contreras-Campana, F. Costanza, C. Diez Pardos, G. Dolinska, G. Eckerlin, D. Eckstein, T. Eichhorn, E. Eren, E. Gallo¹⁹, J. Garay Garcia, A. Geiser, A. Gizhko, J.M. Grados Luyando, A. Grohsjean, P. Gunnellini, A. Harb, J. Hauk, M. Hempel²⁰, H. Jung, A. Kalogeropoulos, O. Karacheban²⁰, M. Kasemann, J. Keaveney, C. Kleinwort, I. Korol, D. Krücker, W. Lange, A. Lelek, T. Lenz, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann²⁰, 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

Deutsches Elektronen-Synchrotron, 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. Pantaleo¹⁷, 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. Vanelderden, A. Vanhoefer, B. Vormwald

University of Hamburg, Hamburg, 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. Hartmann¹⁷, S.M. Heindl, U. Husemann, F. Kassel¹⁷, I. Katkov¹⁵, 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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

G. Anagnostou, G. Daskalakis, T. Geralis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, I. Topsis-Giotis

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Tziaferi

National and Kapodistrian University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

N. Filipovic, G. Pasztor

MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary

G. Bencze, C. Hajdu, D. Horvath²¹, F. Sikler, V. Veszpremi, G. Vesztergombi²², A.J. Zsigmond

Wigner Research Centre for Physics, Budapest, Hungary

N. Beni, S. Czellar, J. Karacsi²³, A. Makovec, J. Molnar, Z. Szillasi

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

M. Bartók²², P. Raics, Z.L. Trocsanyi, B. Ujvari

Institute of Physics, University of Debrecen, Hungary

J.R. Komaragiri

Indian Institute of Science (IISc), India

S. Bahinipati²⁴, S. Bhowmik²⁵, S. Choudhury²⁶, P. Mal, K. Mandal, A. Nayak²⁷, D.K. Sahoo²⁴, N. Sahoo, S.K. Swain

National Institute of Science Education and Research, Bhubaneswar, 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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, 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

Saha Institute of Nuclear Physics, Kolkata, India

P.K. Behera

Indian Institute of Technology Madras, Madras, India

R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty¹⁷, P.K. Netrakanti, L.M. Pant, P. Shukla, A. Topkar

Bhabha Atomic Research Centre, 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-A, Mumbai, India

S. Banerjee, R.K. Dewanjee, S. Ganguly, M. Guchait, Sa. Jain, S. Kumar, M. Maity²⁵, G. Majumder, K. Mazumdar, T. Sarkar²⁵, N. Wickramage²⁸

Tata Institute of Fundamental Research-B, Mumbai, India

S. Chauhan, S. Dube, V. Hegde, A. Kapoor, K. Kothekar, S. Pandey, A. Rane, S. Sharma

Indian Institute of Science Education and Research (IISER), Pune, India

S. Chenarani²⁹, E. Eskandari Tadavani, S.M. Etesami²⁹, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi³⁰, F. Rezaei Hosseinabadi, B. Safarzadeh³¹, M. Zeinali

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

M. Felcini, M. Grunewald

University College Dublin, Dublin, Ireland

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

^a INFN Sezione di Bari, Bari, Italy

^b Università di Bari, Bari, Italy

^c Politecnico di Bari, Bari, 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}

^a INFN Sezione di Bologna, Bologna, Italy

^b Università di Bologna, Bologna, 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}

^a INFN Sezione di Catania, Catania, Italy

^b Università di Catania, Catania, 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}

^a INFN Sezione di Firenze, Firenze, Italy

^b Università di Firenze, Firenze, Italy

L. Benussi, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera ¹⁷

INFN Laboratori Nazionali di Frascati, Frascati, Italy

V. Calvelli ^{a,b}, F. Ferro ^a, M.R. Monge ^{a,b}, E. Robutti ^a, S. Tosi ^{a,b}

^a INFN Sezione di Genova, Genova, Italy

^b Università di Genova, Genova, 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}

^a INFN Sezione di Milano-Bicocca, Milano, Italy

^b Università di Milano-Bicocca, Milano, 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

^a INFN Sezione di Napoli, Napoli, Italy

^b Università di Napoli 'Federico II', Napoli, Italy

^c Università della Basilicata, Potenza, Italy

^d Università G. Marconi, Roma, 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}

^a INFN Sezione di Padova, Padova, Italy

^b Università di Padova, Padova, Italy

^c Università di Trento, Trento, 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}

^a INFN Sezione di Pavia, Pavia, Italy

^b Università di Pavia, Pavia, 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}

^a INFN Sezione di Perugia, Perugia, Italy

^b Università di Perugia, Perugia, Italy

K. Androso ^{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

^a INFN Sezione di Pisa, Pisa, Italy

^b Università di Pisa, Pisa, Italy

^c Scuola Normale Superiore di Pisa, Pisa, 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}

^a INFN Sezione di Roma, Roma, Italy

^b Università di Roma, Roma, 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}

^a INFN Sezione di Torino, Torino, Italy

^b Università di Torino, Torino, Italy

^c Università del Piemonte Orientale, Novara, Italy

S. Belforte^a, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, A. Zanetti^a

^a INFN Sezione di Trieste, Trieste, Italy

^b Università di Trieste, Trieste, Italy

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

Kyungpook National University, Daegu, Republic of Korea

A. Lee

Chonbuk National University, Jeonju, Republic of Korea

H. Kim

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Republic of Korea

J.A. Brochero Cifuentes, T.J. Kim

Hanyang University, Seoul, Republic of 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

Korea University, Seoul, Republic of 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

Seoul National University, Seoul, Republic of Korea

M. Choi, H. Kim, J.H. Kim, J.S.H. Lee, I.C. Park, G. Ryu, M.S. Ryu

University of Seoul, Seoul, Republic of Korea

Y. Choi, J. Goh, C. Hwang, J. Lee, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

V. Dudenas, A. Juodagalvis, J. Vaitkus

Vilnius University, Vilnius, Lithuania

I. Ahmed, Z.A. Ibrahim, M.A.B. Md Ali³⁴, F. Mohamad Idris³⁵, W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz³⁶, A. Hernandez-Almada, R. Lopez-Fernandez, R. Magaña Villalba, J. Mejia Guisao, A. Sanchez-Hernandez

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

S. Carrillo Moreno, C. Oropeza Barrera, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

S. Carpinteyro, I. Pedraza, H.A. Salazar Ibarquen, C. Uribe Estrada

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

A. Morelos Pineda

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

D. Krofcheck

University of Auckland, Auckland, New Zealand

P.H. Butler

University of Canterbury, Christchurch, New Zealand

A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, A. Saddique, M.A. Shah, M. Shoaib, M. Waqas

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

National Centre for Nuclear Research, Swierk, Poland

K. Bunkowski, A. Byszuk³⁷, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland

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. Vadrucio, J. Varela

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal

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

Joint Institute for Nuclear Research, Dubna, Russia

L. Chtchypounov, V. Golovtsov, Y. Ivanov, V. Kim⁴⁰, E. Kuznetsova⁴¹, V. Murzin, V. Oreshkin, V. Sulimov, A. Vorobyev

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyeu, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Nuclear Research, Moscow, Russia

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, M. Toms, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia

T. Aushev, A. Bylinkin³⁹

Moscow Institute of Physics and Technology, Moscow, Russia

M. Chadeeva⁴², O. Markin, V. Rusinov

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia

V. Andreev, M. Azarkin³⁹, I. Dremin³⁹, M. Kirakosyan, A. Leonidov³⁹, A. Terkulov

P.N. Lebedev Physical Institute, Moscow, Russia

A. Baskakov, A. Belyaev, E. Boos, M. Dubinin⁴³, L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Miagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

Skobel'syn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

V. Blinov⁴⁴, Y. Skovpen⁴⁴, D. Shtol⁴⁴

Novosibirsk State University (NSU), Novosibirsk, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, D. Elumakhov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkin, V. Petrov, R. Ryutin, A. Sobol, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia

P. Adzic⁴⁵, P. Cirkovic, D. Devetak, M. Dordevic, J. Milosevic, V. Rekovic

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

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

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

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

Universidad Autónoma de Madrid, Madrid, 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

Universidad de Oviedo, Oviedo, 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

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain

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 Marco⁴⁶, 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. Kornmayer¹⁷, M.J. Kortelainen, K. Kousouris,

M. Krammer¹, 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. Milenovic⁴⁷, 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. Rolandi⁴⁸, M. Rovere, H. Sakulin, J.B. Sauvan, C. Schäfer, C. Schwick, M. Seidel, A. Sharma, P. Silva, P. Sphicas⁴⁹, J. Steggemann, M. Stoye, Y. Takahashi, M. Tosi, D. Treille, A. Triossi, A. Tsirou, V. Veckalns⁵⁰, G.I. Veres²², M. Verweij, N. Wardle, H.K. Wöhri, A. Zagodzinska³⁷, W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, T. Rohe, S.A. Wiederkehr

Paul Scherrer Institut, Villigen, 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. Starodumov⁵¹, V.R. Tavolaro, K. Theofilatos, R. Wallny

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

T.K. Aarrestad, C. AMSler⁵², 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

Universität Zürich, Zurich, Switzerland

V. Candelise, T.H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, A. Pozdnyakov, S.S. Yu

National Central University, Chung-Li, 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

National Taiwan University (NTU), Taipei, Taiwan

B. Asavapibhop, G. Singh, N. Srimanobhas, N. Suwonjandee

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand

A. Adiguzel, M.N. Bakirci⁵³, S. Damarseckin, Z.S. Demiroglu, C. Dozen, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, I. Hos⁵⁴, E.E. Kangal⁵⁵, O. Kara, U. Kiminsu, M. Oglakci, G. Onengut⁵⁶, K. Ozdemir⁵⁷, S. Ozturk⁵³, A. Polatoz, D. Sunar Cerci⁵⁸, S. Turkcapar, I.S. Zorbakir, C. Zorbilmez

Cukurova University - Physics Department, Science and Art Faculty, Turkey

B. Bilin, S. Bilmis, B. Isildak⁵⁹, G. Karapinar⁶⁰, M. Yalvac, M. Zeyrek

Middle East Technical University, Physics Department, Ankara, Turkey

E. Gülmez, M. Kaya⁶¹, O. Kaya⁶², E.A. Yetkin⁶³, T. Yetkin⁶⁴

Bogazici University, Istanbul, Turkey

A. Cakir, K. Cankocak, S. Sen⁶⁵

Istanbul Technical University, Istanbul, Turkey

B. Grynyov

Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine

L. Levchuk, P. Sorokin

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine

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. Newbold⁶⁶, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, D. Smith, V.J. Smith

University of Bristol, Bristol, United Kingdom

K.W. Bell, A. Belyaev⁶⁷, 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

Rutherford Appleton Laboratory, Didcot, 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. Lucas⁶⁶, L. Lyons, A.-M. Magnan, S. Malik, L. Mastrolorenzo, J. Nash, A. Nikitenko⁵¹, 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 Acosta⁶⁸, T. Virdee¹⁷, J. Wright, S.C. Zenz

Imperial College, London, United Kingdom

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Brunel University, Uxbridge, United Kingdom

A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, H. Liu, N. Pastika

Baylor University, Waco, USA

R. Bartek, A. Dominguez

Catholic University of America, Washington, DC, USA

A. Buccilli, S.I. Cooper, C. Henderson, P. Rumerio, C. West

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, 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

Brown University, Providence, 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, Davis, Davis, 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, Los Angeles, 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, Riverside, Riverside, 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. Wasserbaech⁶⁹, C. Welke, J. Wood, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, San Diego, La Jolla, 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

University of California, Santa Barbara - Department of Physics, Santa Barbara, 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

California Institute of Technology, Pasadena, USA

M.B. Andrews, T. Ferguson, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev, M. Weinberg

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado Boulder, Boulder, 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

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, 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

Fermi National Accelerator Laboratory, Batavia, 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

University of Florida, Gainesville, USA

S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida International University, Miami, 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 State University, Tallahassee, USA

M.M. Baarmand, V. Bhopatkar, S. Colafranceschi, M. Hohlmann, D. Noonan, T. Roy, F. Yumiceva

Florida Institute of Technology, Melbourne, 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

University of Illinois at Chicago (UIC), Chicago, USA

B. Bilki⁷⁰, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁷¹, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁷², A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

The University of Iowa, Iowa City, 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

Johns Hopkins University, Baltimore, 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

The University of Kansas, Lawrence, USA

A. Ivanov, K. Kaadze, Y. Maravin, A. Mohammadi, L.K. Saini, N. Skhirtladze, S. Toda

Kansas State University, Manhattan, USA

F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, 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

University of Maryland, College Park, 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. Stephens, K. Tatar, D. Velicanu, J. Wang, T.W. Wang, B. Wyslouch

Massachusetts Institute of Technology, Cambridge, 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 Minnesota, Minneapolis, USA

J.G. Acosta, S. Oliveros

University of Mississippi, Oxford, 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

University of Nebraska-Lincoln, Lincoln, USA

M. Alyari, J. Dolen, A. Godshalk, C. Harrington, I. Iashvili, J. Kaisen, D. Nguyen, A. Parker, S. Rappoccio, B. Roozbahani

State University of New York at Buffalo, Buffalo, 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

Northeastern University, Boston, 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

Northwestern University, Evanston, USA

N. Dev, M. Hildreth, K. Hurtado Anampa, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁸, M. Planer, A. Reinsvold, R. Ruchti, N. Rupprecht, G. Smith, S. Taroni, M. Wayne, M. Wolf, A. Woodard

University of Notre Dame, Notre Dame, 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

The Ohio State University, Columbus, 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

Princeton University, Princeton, USA

S. Malik

University of Puerto Rico, Mayaguez, 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, West Lafayette, USA

N. Parashar, J. Stupak

Purdue University Northwest, Hammond, 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

Rice University, Houston, 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

University of Rochester, Rochester, 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

Rutgers, The State University of New Jersey, Piscataway, USA

A.G. Delannoy, M. Foerster, J. Heideman, G. Riley, K. Rose, S. Spanier, K. Thapa

University of Tennessee, Knoxville, USA

O. Bouhali⁷³, A. Celik, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, J. Gilmore, T. Huang, E. Juska, T. Kamon⁷⁴, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, L. Perniè, D. Rathjens, A. Safonov, A. Tatarinov, K.A. Ulmer

Texas A&M University, College Station, USA

N. Akchurin, J. Damgov, F. De Guio, C. Dragoiu, P.R. Duerdo, J. Faulkner, E. Garpinar, S. Kunori, K. Lamichhane, S.W. Lee, T. Libeiro, T. Peltola, S. Undleeb, I. Volobouev, Z. Wang

Texas Tech University, Lubbock, USA

S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, A. Melo, H. Ni, P. Sheldon, S. Tuo, J. Velkovska, Q. Xu

Vanderbilt University, Nashville, 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

University of Virginia, Charlottesville, USA

C. Clarke, R. Harr, P.E. Karchin, J. Sturdy

Wayne State University, Detroit, 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

University of Wisconsin - Madison, Madison, WI, USA

† 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, Medellín, 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.