Constraints on the double-parton scattering cross section from same-sign W boson pair production in proton-proton collisions at \( \sqrt{s} = 8 \text{ TeV} \)

The CMS Collaboration

Abstract

A first search for same-sign WW production via double-parton scattering is performed based on proton-proton collision data at a center-of-mass energy of 8 TeV using dimuon and electron-muon final states. The search is based on the analysis of data corresponding to an integrated luminosity of 19.7 fb\(^{-1}\). No significant excess of events is observed above the expected single-parton scattering yields. A 95% confidence level upper limit of 0.32 pb is set on the inclusive cross section for same-sign WW production via the double-parton scattering process. This upper limit is used to place a 95% confidence level lower limit of 12.2 mb on the effective double-parton cross section parameter, closely related to the transverse distribution of partons in the proton. This limit on the effective cross section is consistent with previous measurements as well as with Monte Carlo event generator predictions.

Submitted to the Journal of High Energy Physics
1 Introduction

In proton-proton (pp) collisions at the CERN LHC, the large density of partons inside the proton at small $x$, where $x$ is the momentum fraction of the proton carried by a parton, results in a significant probability for the simultaneous occurrence of two or more parton-parton interactions within a single pp collision [1]. These short-distance inelastic processes, called multiple-parton interactions (MPI), usually produce particles with relatively small transverse momenta ($p_T$) that predominantly constitute the so-called “underlying event”. With increased parton densities at high center-of-mass energies, there is a nonnegligible probability for the production of high-$p_T$ or high-mass particles even from the second-hardest parton-parton scattering, a process known as double-parton scattering (DPS). The production cross section for a DPS process, $\sigma_{\text{DPS}}^{AB}$, involving two independent processes “A” and “B” with respective individual production cross sections $\sigma_A$ and $\sigma_B$, can be factorized as:

$$\sigma_{\text{DPS}}^{AB} = \frac{m \sigma_A \sigma_B}{2} \sigma_{\text{eff}},$$

where $m$ is a combinatorial factor ($m = 1$ for identical and $m = 2$ for different processes) and $\sigma_{\text{eff}}$ is an effective cross section, mainly determined by the transverse profile of partons inside the colliding hadrons and their overlap in a collision. Such a simple geometric interpretation of $\sigma_{\text{eff}}$ assumes negligible parton-parton correlations (in momentum, space, colour, flavour, . . . ) [2], which is an assumption particularly well justified at low $x$ values where the parton densities are very large [3].

The measurement of the DPS cross section is important as it provides valuable information on the distribution of partons inside the proton in the transverse direction and on the correlations between them [2–7]. DPS also constitutes a background to searches for new physics, in rare final states with multiple heavy particles, as well as to measurements of standard model processes, such as the associated production of a Higgs and a W or Z boson [8–9]. Studies of DPS have been proposed using a variety of processes, including double Drell–Yan (DY) production [10], the production of same-sign W bosons [3], W or Z boson production in association with jets [11–12], and four-jet production [13–14]. A number of experiments have previously measured DPS cross sections, using various final states at different collision energies [15–22]. The magnitude of the cross section for a given DPS process depends on the value of $\sigma_{\text{eff}}$ and on the cross sections for the individual single-parton scattering (SPS) processes involved, according to Eq. (1). In the simplest approaches, $\sigma_{\text{eff}}$ is expected to be independent of collision energy and of the processes involved [2–4]. Values of $\sigma_{\text{eff}} \approx 20 \text{ mb}$ are predicted by Monte Carlo (MC) event generators, tuned to reproduce low-$p_T$ MPI measurements [25], that assume the independence of $\sigma_{\text{eff}}$ with respect to the scale of MPI, as defined by the momentum transfer in a given parton-parton interaction. However, the existing measurements of $\sigma_{\text{eff}}$ have large systematic uncertainties [21] and hence it is not possible to draw a firm conclusion about the dependence of $\sigma_{\text{eff}}$ on either the process or the collision energy. It is therefore important to perform further DPS cross section measurements using a variety of processes at different center-of-mass energies.

This paper presents the first measurement of the DPS process for same-sign WW events in the dilepton final state using pp collision data collected by the CMS experiment at a center-of-mass energy of $\sqrt{s} = 8 \text{ TeV}$. In the case of WW production via DPS, the scale of the second hard interaction is comparable to the mass of the W boson, which is the largest scale explored experimentally so far in DPS cross section measurements. Only same-sign WW events are considered in order to suppress the contribution from the DY and SPS processes. Leptonic decays of the two W bosons into either a pair of muons or an electron-muon pair are considered, as
only these $W$ decay channels result in a properly-reconstructed final state that is not completely overwhelmed by background. Figure 1 illustrates the production of a same-sign $W$ boson pair via the DPS process (left) and via a selection of leading order SPS processes (right). A set of DPS-sensitive observables is used in a multivariate analysis based on boosted decision trees (BDT) to enhance the signal sensitivity. The shape of the BDT discriminant is then used to set a limit on the cross section for same-sign $WW$ production via DPS, and subsequently on $\sigma_{\text{eff}}$.

Figure 1: Schematic diagrams corresponding to the production of a same-sign $W$ boson pair via the DPS process (left) and via SPS processes (right).

This paper is organized as follows: In Section 2, a brief description of the CMS detector is presented, followed by a description of the data and the simulated samples in Section 3. The event selection criteria, a description of the BDT, and the systematic uncertainties affecting the measurement are described in Section 4. The results are presented in Section 5, and Section 6 summarizes the studies presented here.

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 (HCAL), each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity ($\eta$) coverage provided by the barrel and endcap detectors. Muons are detected and measured using the gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid. The first level (L1) of the CMS trigger and data acquisition systems is designed to select potentially interesting events with high efficiency [26]. The L1 trigger uses information collected by the calorimeters and muon detectors to select the most interesting events in less than 4 $\mu$s. The detector data are pipelined to ensure negligible deadtime up to a L1 rate of 100 kHz. After L1 triggering, data are transferred from the readout electronics of all subdetectors to the high-level trigger processor farm, where a further reduction of event rate to few hundred Hz is achieved for the purpose of data storage. 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. [27].
3 Data and simulated samples

The analyzed data correspond to an integrated luminosity of 19.7 fb\(^{-1}\) recorded by the CMS detector during 2012 in pp collisions at \(\sqrt{s} = 8\) TeV. The decays of W bosons into a muon or an electron (plus the corresponding neutrinos) are considered, but only the same-sign dimuon and electron-muon final states are actually used in the current analysis. These final states also include the contributions from the leptonic decay of \(\tau\) leptons coming from the W bosons. The dielectron final state is not considered because of the relatively high probability of charge misidentification for electrons, which results in this final state being overwhelmed by background from the DY process. The trigger used to select dimuon events requires the presence of a pair of muons with the leading (subleading) muon having \(p_T > 17\) (8) GeV. The dilepton trigger, used for the online selection of the electron-muon final state, required one electron (muon) with \(p_T > 17\) GeV and one muon (electron) with \(p_T > 8\) GeV. The efficiencies of the dimuon and electron-muon triggers with respect to the offline selection are 90% and 94%, respectively.

The simulated signal events for DPS W boson pair production are generated using the PYTHIA8 event generator (version 8.165) with the 4C tune \([28, 29]\) to describe the underlying event processes. The contribution of W boson pair production via SPS is removed from the signal sample. In PYTHIA8, MPI are predominantly driven by the amount of overlap of the transverse matter distributions of the protons in impact parameter space \([1]\), and are interleaved with parton showering. For the tune used, the DPS cross section for (leading order) inclusive same-sign WW production (including all W boson decays) is 0.30 pb, and the corresponding effective DPS cross section amounts to \(\sigma_{\text{eff}} = 28\) mb.

Several SPS processes share the same like-sign dilepton final state as our DPS signal. All backgrounds have been studied in detail with MC simulated events as well as with data-driven estimates. The production of same-sign W boson pairs, electroweak and strong production of W boson pairs in association with jets (WW+jets), fully leptonic decays of top quark-antiquark pairs (t\(\bar{t}\)), DY, W\(\gamma^*\), and W/Z\(\gamma\) events are simulated using the MADGRAPH5 (version 5.1.3.30) event generator \([30]\). The single top quark production processes in \(t\)- and \(s\)-channels are modeled using the POWHEG (version 1.0) event generator \([31]\). The WZ and ZZ production processes are generated with the PYTHIA6 event generator. All simulated samples use the CTEQ6L1 \([32]\) parton density functions (PDF) set, with parton showering and hadronization performed with PYTHIA6 (version 6.4.25) using the ZZ* tune for the modeling of underlying event activity \([33, 34]\). The generated MC simulations are scaled to their respective theoretical cross sections (at next-to-leading order or next-to-next-to-leading order (NNLO) accuracy, the highest order prediction available in each case) \([35-38]\), and multiplied by the integrated luminosity of the data sample. In addition, other background processes that result from jets being misidentified as leptons—such as single W boson production in association with jets (W+jets), t\(\bar{t}\) in lepton+jets, and quantum chromodynamics (QCD) multijet production—are directly estimated from the data, as discussed in Section 4.2.

The data sample analyzed in this work was collected with high instantaneous luminosities which lead to additional pp interactions (pileup) produced within the same bunch crossing. The simulated samples include the effect of pileup, with a multiplicity of pp interactions matching that from the data. The average number of measured pileup interactions per beam crossing in the 8 TeV data set is about 21. The detector response is simulated using the GEANT4 package \([39]\) and the resulting simulated events are reconstructed with the same algorithms used for the data.
4 Experimental methods

4.1 Event selection

A particle-flow (PF) algorithm [40] is used for event reconstruction. The information from all subdetectors of the CMS detector is combined to reconstruct individual candidates for muons, electrons, photons, as well as charged and neutral hadrons produced in an event.

The offline event selection criteria require the presence of at least two well reconstructed and isolated leptons with the same sign (either two muons or an electron and a muon). The leading (subleading) lepton is required to have $p_T > 20$ (10) GeV. The muon candidates are identified using charged-particle tracks reconstructed in the muon system that are compatible with the tracks reconstructed in the central tracking system [41]. The muon candidates are required to lie within a geometrical acceptance defined by $|\eta| < 2.4$. The electrons are identified using a multivariate approach based on shower shape variables, the energy sharing between the ECAL and HCAL, and the matching information provided by the tracker [42]. The electrons with $|\eta| < 2.5$, except those falling in the transition region between the barrel and endcap of the ECAL (1.44 < $|\eta|$ < 1.57), are considered for this analysis.

A lepton isolation variable ($R_{\text{iso}}$) [38], measured relative to the lepton $p_T$, is used to discriminate between the prompt leptons originating from a W/Z boson decay and those from quark and hadron decays. This variable is defined based on the sum of the transverse energies of all reconstructed particles, charged or neutral, within a cone of $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2} < 0.3$ around the lepton direction, after subtracting the contributions from pileup and underlying event activity [43, 44] on an event-by-event basis. The value of $R_{\text{iso}}$ is required to be smaller than 0.12 (0.15) for muon (electron) candidates. The two lepton candidates also need to be associated with the same primary vertex, through the requirement that the longitudinal (transverse) impact parameter of each lepton is smaller than 0.1 (0.02) cm.

The missing transverse momentum vector ($\vec{p}_T^{\text{miss}}$) is defined as the projection of the negative vector sum of the momenta of all reconstructed PF objects in an event onto the plane perpendicular to the beam axis. Its magnitude is referred to as $p_T^{\text{miss}}$, and is corrected for anisotropic detector responses, inactive calorimeter cells, and detector misalignment. To suppress $Z \rightarrow \ell^+ \ell^-$ contributions, $p_T^{\text{miss}}$ is required to be greater than 20 GeV.

The jets are reconstructed using the anti-$k_T$ clustering algorithm with the FastJet (version 2.1) package [45] with a distance parameter of 0.5. To eliminate the jets originating from or being seeded by noisy channels in the calorimeters, a jet quality requirement, primarily based on the energy ratio between the charged and neutral hadrons, is applied [46]. Jet energy scale corrections [47, 48] are used to account for the nonlinear energy response of the calorimeters and other instrumental effects. The effect of jet energy scale corrections is also propagated to $p_T^{\text{miss}}$.

To reduce the contributions from ZZ, WZ, and $W\gamma^*$ production processes, where the final state can have more than two leptons, events having three or more well reconstructed and isolated leptons with $p_T > 10$ GeV are rejected. Furthermore, to reduce events from low-mass resonances, the two selected leptons are required to have an invariant mass ($m_{\ell\ell}$) greater than 20 GeV. Additionally, for the dimuon final state, $m_{\ell\ell}$ is also required to be away from the Z boson mass peak ($m_{\ell\ell} \not\in [75, 105]$ GeV). A minimum threshold of 45 GeV on the scalar sum of the $p_T$ of the two muons is also applied to reduce the contributions from QCD multijet events.

The main background in the electron-muon final state comes from events in which a pair of top quarks are produced and subsequently decay via their semileptonic mode $t \rightarrow bW; W \rightarrow \ell\nu_\ell$, ...
4.2 Background evaluation

Table 1: Event selection criteria for same-sign W boson pair production in dimuon and electron-muon channels.

| Dimuon channel | Electron-muon channel |
|----------------|-----------------------|
| Pair of same-sign leptons | |
| Leading lepton $p_T > 20$ GeV | |
| Subleading lepton $p_T > 10$ GeV | |
| No third isolated and identified lepton with $p_T > 10$ GeV | |
| $p_T^{miss} > 20$ GeV | |
| $m_\ell \ell > 20$ GeV | |
| $m_\ell \ell / \in [75, 105]$ GeV | |
| $|p_T^{\mu_1}| + |p_T^{\mu_2}| > 45$ GeV | |
| — No b-tagged jet with $p_T > 30$ GeV and $|\eta| < 2.1$ | |

with $\ell = e, \mu, \tau$. The contribution from this background for the dimuon channel is found to be negligible. A b jet veto is applied in the electron-muon final state to reduce the contribution from this source. The combined secondary vertex b tagging algorithm [49] is used to identify jets that are likely to originate from the hadronization of b quarks. Events containing one or more b-tagged jets with $p_T > 30$ GeV and $|\eta| < 2.1$ are vetoed. The b tagging efficiency is 60–80%, while the mistag rate for light-flavored jets is about 2–3% after the same-sign WW selection criteria, given in Table 1, have been applied.

4.2 Background evaluation

The majority of background events originate from processes in which one or both of the leptons, coming from leptonic decays of heavy quarks or in-flight decays of light mesons, pass the event selection criteria. In the case of the electrons, overlaps of $\pi^0 \rightarrow \gamma\gamma$ decays with charged hadrons may also contaminate the sample. These lepton candidates are referred to as misidentified leptons. Events containing one prompt and one misidentified lepton, referred to as prompt-misid. events, mainly come from W+jets production and from semileptonic decays of top quarks. The QCD multijet events fall into the category of misid.-misid. events, as both leptons are misidentified. A method based on control samples in the data is used to estimate the contributions of misid.-misid. and prompt-misid. backgrounds [38]. The method relies on a lepton misidentification rate estimated from the efficiency for a lepton-like object, passing loose lepton selection criteria of $R_{Iso} < 1.0$ and $p_T > 10$ GeV, to also pass the complete set of lepton selection criteria described in Section 4.1. The lepton misidentification rates are measured using a control sample in the data that is enriched with misidentified leptons, and are parametrized as a function of the lepton $p_T$ and $\eta$.

Table 2 lists the selection criteria used to construct two regions (referred to as Region 1 and Region 2) in the data that are enriched with misidentified leptons. Region 1 is used for the dimuon final state while Region 2, which additionally requires the presence of at least one b-tagged jet, is used in the electron-muon final state, since it includes a major contribution from semileptonically decaying t events. Both regions require the presence of only one loosely identified (“loose”) lepton in order to suppress Z → $\ell^+\ell^-$ contributions. Also, to further reduce the contributions from W/Z boson decays in the regions enriched with misidentified leptons, the transverse mass of the lepton and $p_T^{miss}$, $m_T(\ell, p_T^{miss})$, is required to be less than 20 GeV and $p_T^{miss}$ to be less than 20 GeV. The backgrounds with one prompt and one misidentified lepton are estimated using the tight-fail control sample that is constructed by requiring that one of the leptons passes the loose selection criteria only, whilst the other passes the full lepton selection criteria. Similarly, another control sample with fail-fail lepton pairs is defined in which
both of the leptons pass only the loose selection criteria. Finally, the selection criteria, given in Table 1, are applied to these samples and the resulting numbers of events are scaled using the lepton misidentification rate to estimate the contributions from prompt-misid. and misid.-misid. backgrounds in the signal region.

Table 2: Control regions enriched with misidentified leptons used to extract the lepton misidentification rate. Region 1 is used for the dimuon channel. Region 2, with the additional requirement of at least one b-tagged jet, is used in the electron-muon channel to reduce semileptonically decaying tt̄ events.

| Region 1 | Region 2 |
|----------|----------|
| Only one loose lepton with $p_T > 10\text{ GeV}$ | Only one loose lepton with $p_T > 10\text{ GeV}$ |
| $m_T(\ell, p_T^{\text{miss}}) < 20\text{ GeV}$ | $m_T(\ell, p_T^{\text{miss}}) < 20\text{ GeV}$ |
| $p_T^{\text{miss}} < 20\text{ GeV}$ | $p_T^{\text{miss}} < 20\text{ GeV}$ |
| — | At least one b-tagged jet with $p_T > 30\text{ GeV}$ and $|\eta| < 2.1$ |

For the $W\gamma^*$ background contribution, a correction factor for the simulated events is obtained from a high-purity data sample enriched with $W\gamma^*$ events, identified by the presence of three reconstructed leptons, as described in Ref. [38]. A factor of 1.5±0.3 with respect to the predicted leading-order cross section is determined. Charged dilepton final-states from DY and tt̄ decays contribute to the background when the charge of one of the leptons is misidentified. These processes also contribute to the background if a hadronically decaying $\tau$ lepton is misidentified as an electron or a muon and combines with a prompt lepton to form a same-sign electron-muon pair. The charge misidentification probability for electrons in the data is found to be compatible with that from the simulation; these backgrounds can therefore be estimated using the simulated samples. However, due to the limited statistical precision of the MC simulated samples, the shapes of the kinematic observables are obtained with opposite-sign electron-muon pairs in order to increase the sample sizes; all the other selection criteria given in Table 1 are applied unchanged. The resulting distributions are then normalized to the corresponding same-sign yields. The normalizations of these two backgrounds are cross-checked by constructing control regions enriched with these backgrounds. To construct a DY-enriched control region, opposite-sign pairs of electrons and muons are required to have a dilepton invariant mass that satisfies $40 < m_{\ell\ell} < 80\text{ GeV}$, and a dilepton transverse mass that satisfies $m_T < 60\text{ GeV}$. For the dileptonic tt̄ decays, a control region enriched with top quark events is constructed by inverting the b jet veto criteria in the opposite-sign WW selection requirements.

The background contributions arising from lepton misidentification constitute the dominant fraction (72%) of the total event yield after the same-sign WW selection criteria have been applied for both final states.

### 4.3 Multivariate analysis

The BDT-based framework [50] is used to discriminate between the signal and the background events, combining information from a set of kinematic variables that are sensitive to the differences between DPS WW production and the background processes. The BDT is trained using the DPS signal and the major background processes, including those originating from misidentification of leptons and diboson processes. The variables used as input for the BDT are based on energy-momentum conservation and are sensitive to the energy imbalance in the reference system of the W boson pair.

For the dimuon channel, the following set of variables has been used for the training and testing of the BDT:
4.4 Systematic uncertainties

The systematic uncertainties in this analysis arise from the background estimation techniques, experimental measurements, and theoretical predictions.

The dominant source of systematic uncertainty is associated with the method adopted for the estimation of misid.-misid. and prompt-misid. backgrounds, and with the definition of the control sample used to obtain the lepton misidentification rate.

To estimate the effects of the jet $p_T$ spectra and jet flavor on the lepton misidentification rate, these backgrounds are estimated by changing the definition of the misidentified lepton-enriched region. The observed differences in the estimated event yields and in the shapes of the kinematic observables, for the different definitions of the control samples, are taken as the systematic uncertainty. For the dimuon channel, the lepton misidentification rate is recalculated by requiring the presence of a jet with $p_T > 25$ GeV in addition to the nominal selection criteria for Region 1. To estimate the effect of jet flavor, the lepton misidentification rate is measured using the QCD multijet simulated sample and applied to the W+jets simulated sample.

For the electron-muon channel, these backgrounds are recalculated after removing the requirement of the presence of a b-tagged jet in the definition of the misidentified lepton-enriched region. The effect of statistical fluctuations on the lepton misidentification rate is also considered when calculating the final background yields. The systematic uncertainty arising from this
in quadrature. The hatched bands in all cases represent the sum of the systematic and statistical uncertainties of the simulated samples, added in quadrature.

Figure 2: Distributions of the $p_T$ (top-left), $m_T(\mu_2, p_T^{miss})$ (top-right), $\Delta\phi(p_T^1, p_T^{miss})$ (bottom-left), and $\Delta\phi(p_T^1, p_T^{miss})$ (bottom-right) variables for the dimuon channel, after the same-sign WW selection criteria have been applied. The data are represented by the black dots and the shaded histograms represent the predicted signal and background processes normalized according to the estimated cross sections and the luminosity. For each individual distribution, the bottom panels show the ratio of the number of events observed in the data to that predicted by the simulation, along with the associated statistical uncertainty. The hatched bands in all cases represent the sum of the systematic and statistical uncertainties of the simulated samples, added in quadrature.
4.4 Systematic uncertainties

The trigger and lepton identification efficiencies in the data and simulation are measured using the “tag-and-probe” method [38]. The ratio of the efficiencies obtained from the data and simulation is used to scale the selection efficiency in the simulated samples. The uncertainty on this scale factor for the trigger efficiency is of the order of 1% and is also applied to all the simulated samples. The systematic uncertainty associated with the lepton identification efficiency
Results

The expected and observed upper limits at 95% confidence level (CL) on the cross section for inclusive same-sign WW production via DPS have been extracted. The statistical interpretation of the results is performed using an asymptotic approximation of the CLs method. These limits are estimated by fitting the shape of the BDT discriminant, using the methodology developed by the ATLAS and CMS Collaborations. A log-normal probability distribution function is assumed for the nuisance parameters that affect the event yields of the signal and various background contributions. Systematic uncertainties affecting the shape of the BDT discriminant are assumed to have a Gaussian probability distribution function. A binned maximum likelihood fit is performed on the selected events while the systematic uncertainties are included in the fit as nuisance parameters and are profiled during the minimization.

While performing the combination of the results from the two final states, the systematic uncertainties arising from theoretical predictions or from the background estimation techniques are taken to be fully correlated across the two final states, while no correlation is assumed for uncertainties of statistical origin. The uncertainty associated with the absolute scale of the integrated luminosity and the effects of pileup are correlated across the two final states. Experimental uncertainties on the lepton selection and trigger efficiencies for the same kind of physics objects are assumed to be correlated. Theoretical uncertainties on the production cross sections for each process are correlated across the two final states. However, the uncertainties on different processes are assumed to be independent.

Figure 4 shows the distributions of the BDT discriminant having post-fit contributions for the backgrounds and pre-fit ones for the signal, for the dimuon and electron-muon final states with (1% for muons and 4% for electrons) is applied to all simulated samples. The lepton momentum scale has uncertainties due to detector misalignment. For the muons, a momentum scale uncertainty of 1%, independent of its $\eta$, is assigned. A momentum scale uncertainty of 2% is assigned for electrons in the barrel, and 4% for electrons in the endcaps of the ECAL. The lepton momentum scale affects the final predicted yields by 1–2% in each channel. The effects of the jet energy scale uncertainty and the jet energy resolution are evaluated by shifting the $p_T$ of the leptons and the jets by their respective uncertainties, with the effect being propagated to $p_T^{\text{miss}}$. These uncertainties cause the predicted event yields to vary by 2–4% for the dimuon and by 5% for the electron-muon channels, respectively.

A scale factor is applied to the simulation to correct for different $b$ jet tagging efficiencies and mistag rates measured in the data. This correction is applied by reweighting all the simulated samples on an event-by-event basis, where the weight depends on the flavor and kinematics of the jets. This results in an uncertainty of 4% on the $b$ jet dominated background and less than 1% for other background processes. It should be noted that this particular source of systematic uncertainty affects the electron-muon channel only.

To check the normalization of the DY background for the electron-muon channel, a DY-enriched control region is constructed from the data, as defined in Section 4.2. A normalization uncertainty of 10% is derived for the DY background by looking at the ratio of the data to simulation in this control region.

For the $W\gamma$ and $W\gamma^*$ backgrounds, a 30% uncertainty is derived for the normalization factor for both of the final states. The effects of varying the PDFs and the value of $\alpha_s$ as well as the effect of higher-order corrections, are estimated using the PDF4LHC prescription.

5 Results
the corresponding uncertainty bands (shown as hatched bands). The expected and observed 95% CL limits on the cross section for same-sign WW production via DPS ($\sigma_{\text{DPS}}^{W^{\pm}W^{\pm}}$) are summarized in Table 3.

![Figure 4: Distribution of the BDT discriminant, for the dimuon channel (left) and for the electron-muon channel (right). The data are represented by the black dots and the shaded histograms represent the pre-fit signal and post-fit background processes. The bottom panels show the ratio of data to the sum of all signal and background contributions. The hatched bands represent the post-fit uncertainty, which includes both the statistical and systematic components.](image)

Table 3: Expected and observed 95% CL limits on the cross section for inclusive same-sign WW production via DPS for the dimuon and electron-muon channels along with their combination.

| 95% CL | Dimuon | Electron-muon | Combined |
|--------|--------|---------------|----------|
| Expected | 0.67 pb | 0.78 pb | 0.48 pb |
| Expected ±1$\sigma$ | [0.46, 1.00] pb | [0.52, 1.16] pb | [0.33, 0.72] pb |
| Expected ±2$\sigma$ | [0.34, 1.45] pb | [0.37, 1.71] pb | [0.24, 1.04] pb |
| Observed | 0.72 pb | 0.64 pb | 0.32 pb |

The expected value of the DPS cross section derived with the factorization formula given by Eq. (1) is $\sigma_{\text{DPS}}^{W^{\pm}W^{\pm}} = 0.18 \pm 0.06$ pb, as obtained for the effective cross section $\sigma_{\text{eff}} = 20.7 \pm 6.6$ mb measured in the W+2 jets final state at 7 TeV [21], and the single-parton NNLO cross sections of $\sigma_{W^{+}} = 72.1 \pm 2.5$ nb and $\sigma_{W^{-}} = 50.8 \pm 1.9$ nb [60] combined.

Figure 5 provides a summary of the sensitivity of the BDT-based analysis for the different final states. The expected value of same-sign $\sigma_{\text{DPS}}^{W^{\pm}W^{\pm}}$ taken from PYTHIA8 is shown as a red line, while that extracted using the factorization approach is represented by a blue line. The observed and expected limits are consistent within the statistical fluctuations since the observed limits are within the green (68%) or yellow (95%) bands of the expected limit values. The observed limits for the combined analysis are more stringent than the limits from the individual final states.

Assuming the two scatterings to be independent, a limit can be placed on $\sigma_{\text{eff}}$ using Eq. (1) together with the SPS $\sigma_{W^{+}}$ and $\sigma_{W^{-}}$ cross section values at NNLO. A lower 95% CL limit on $\sigma_{\text{eff}}$
can be calculated as:

$$\sigma_{\text{eff}} > \frac{\sigma_{W+}^2 + \sigma_{W-}^2}{2 \sigma_{W^\pm W^\mp}^{\text{DPS}}} = 12.2 \text{ mb.}$$

The obtained lower limit on \( \sigma_{\text{eff}} \) is compatible with the values of \( \sigma_{\text{eff}} \approx 10–20 \text{ mb} \) obtained from measurements at different center-of-mass energies using a variety of processes [21].

6 Summary

A first search for same-sign W boson pair production via double-parton scattering (DPS) in pp collisions at a center-of-mass energy of 8 TeV has been presented. The analyzed data were collected by the CMS detector at the LHC during 2012 and correspond to an integrated luminosity of 19.7 fb\(^{-1}\). The results presented here are based on the analysis of events containing two same-sign W bosons decaying into either same-sign muon-muon or electron-muon pairs. Several kinematic observables have been studied to identify those that can better discriminate between DPS and the single-parton scattering (SPS) backgrounds. These observables with discriminating power are used as an input to a multivariate analysis based on boosted decision trees. No excess over the expected contributions from SPS processes is observed. A 95% confidence level (CL) upper limit of 0.32 pb is placed on the inclusive cross section for same-sign WW production via DPS. A corresponding 95% CL lower limit of 12.2 mb on the effective double-parton cross section is also derived, compatible with previous measurements as well as with Monte Carlo event generator expectations.

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 centres 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); 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 programme and the European Research Council and Horizon 2020 Grant, contract No. 675440 (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 programme of the Foundation for Polish Science, cofinanced from European Union, Regional Development Fund, the Mobility Plus programme 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 Severo Ochoa del Principado de Asturias; the Thalis and Aristeia programmes 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); the Welch Foundation, contract C-1845; and the Weston Havens Foundation (USA).

References

[1] T. Sjöstrand and M. Van Zijl, “A multiple interaction model for the event structure in hadron collisions”, Phys. Rev. D 36 (1987) 2019,[doi:10.1103/PhysRevD.36.2019]

[2] D. d’Enterria and A. Snigirev, “Double, triple, and $n$-parton scatterings in high-energy proton and nuclear collisions”, (2017).[arXiv:1708.07519]

[3] J. R. Gaunt, C.-H. Kom, A. Kulesza, and W. J. Stirling, “Same-sign $W$ pair production as a probe of double-parton scattering at the LHC”, Eur. Phys. J. C 69 (2010) 53,[doi:10.1140/epjc/s10052-010-1362-y][arXiv:1003.3953]

[4] G. Calucci and D. Treleani, “Disentangling correlations in multiple parton interactions”, Phys. Rev. D 83 (2011) 016012,[doi:10.1103/PhysRevD.83.016012][arXiv:1009.5881]
[5] M. Rinaldi, S. Scopetta, M. Traini, and V. Vento, “Double parton correlations and constituent quark models: a Light Front approach to the valence sector”, *JHEP* 12 (2014) 028, doi:10.1007/JHEP12(2014)028 arXiv:1409.1500

[6] M. Diehl, D. Ostermeier, and A. Schäfer, “Elements of a theory for multiparton interactions in QCD”, *JHEP* 03 (2012) 89, doi:10.1007/JHEP03(2012)089 arXiv:1111.0910

[7] F. A. Ceccopieri, M. Rinaldi, and S. Scopetta, “Parton correlations in same-sign W pair production via double parton scattering at the LHC”, *Phys. Rev. D* 95 (2017) 114030, doi:10.1103/PhysRevD.95.114030 arXiv:1702.05363

[8] M. Y. Hussein, “A double parton scattering background to associate WH and ZH production at the LHC”, *Nucl. Phys. Proc. Suppl.* 174 (2007) 55, doi:10.1016/j.nuclphysbps.2007.08.086 arXiv:hep-ph/0610207

[9] D. Bandurin, G. Golovanov, and N. Skachkov, “Double parton interactions as a background to associated HW production at the Tevatron”, *JHEP* 04 (2011) 054, doi:10.1007/JHEP04(2011)054 arXiv:1011.2186

[10] M. Mekhfi, “Multiparton processes: an application to double Drell–Yan”, *Phys. Rev. D* 32 (1985) 2371, doi:10.1103/PhysRevD.32.2371

[11] R. M. Godbole, S. Gupta, and J. Lindfors, “Double parton scattering contribution to W + Jets”, *Z. Phys. C* 47 (1990) 69, doi:10.1007/BF01551914

[12] R. Kumar, M. Bansal, S. Bansal, and J. B. Singh, “New observables for multiple-parton interactions measurements using Z+jets processes at the LHC”, *Phys. Rev. D* 93 (2016) 054019, doi:10.1103/PhysRevD.93.054019 arXiv:1602.05392

[13] B. Humpert and R. Odorico, “Multiparton scattering and QCD radiation as sources of four jet events”, *Phys. Lett. B* 154 (1985) 211, doi:10.1016/0370-2693(85)90587-8

[14] L. Ametller, N. Paver, and D. Treleani, “Possible signature of multiple parton interactions in collider four jet events”, *Phys. Lett. B* 169 (1986) 289, doi:10.1016/0370-2693(86)90668-4

[15] UA2 Collaboration, “A study of multi-jet events at the CERN √s = 63 GeV” *pp collisions at √s = 63 GeV*, *Z. Phys. C* 34 (1987) 163, doi:10.1007/BF01566757

[16] Axial Field Spectrometer Collaboration, “Double parton scattering in pp collisions at √s = 63 GeV”, *Z. Phys. C* 34 (1987) 163

[17] CDF Collaboration, “Study of four jet events and evidence for double parton interactions in pp collisions at √s = 1.8 TeV”, *Phys. Rev. D* 47 (1993) 4857, doi:10.1103/PhysRevD.47.4857

[18] CDF Collaboration, “Double parton scattering in pp collisions at √s = 1.8 TeV”, *Phys. Rev. D* 56 (1997) 3811, doi:10.1103/PhysRevD.56.3811

[19] D0 Collaboration, “Double parton interactions in γ+3 jet events pp collisions at √s = 1.96 TeV”, *Phys. Rev. D* 81 (2010) 052012, doi:10.1103/PhysRevD.81.052012 arXiv:hep-ex/0912.5104
[20] ATLAS Collaboration, “Measurement of hard double-parton interactions in W(\rightarrow \ell \nu) + 2-jet events at \sqrt{s} = 7 TeV with the ATLAS detector”, New J. Phys. 15 (2013) 033038, doi:10.1088/1367-2630/15/3/033038 [arXiv:1301.6872]

[21] CMS Collaboration, “Study of double parton scattering using W + 2-jet events in proton-proton collisions at \sqrt{s} = 7 TeV”, JHEP 03 (2014) 032, doi:10.1007/JHEP03(2014)032 [arXiv:1312.5729]

[22] M. Bähr, M. Myska, M. H. Seymour, and A. Siodmok, “Extracting \sigma_{\text{eff}} from the CDF \gamma + 3 jets measurement”, JHEP 03 (2013) 129, doi:10.1007/JHEP03(2013)129 [arXiv:1302.4325]

[23] A. Del Fabbro and D. Treleani, “Scale factor in double parton collisions and parton densities in transverse space”, Phys. Rev. D 63 (2001) 057901, doi:10.1103/PhysRevD.63.057901 [arXiv:hep-ph/0005273]

[24] D. Treleani, “Double parton scattering, diffraction and effective cross section”, Phys. Rev. D 76 (2007) 076006, doi:10.1103/PhysRevD.76.076006 [arXiv:0708.2603]

[25] 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]

[26] CMS Collaboration, “The CMS trigger system”, JINST 12 (2017) P01020, doi:10.1088/1748-0221/12/01/P01020 [arXiv:1609.02366]

[27] CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004

[28] T. Sjöstrand, S. Mrenna, and P. Skands, “A brief introduction to PYTHIA 8.1”, Comp. Phys. Comm. 178 (2008) 852, doi:10.1016/j.cpc.2008.01.036 [arXiv:0710.3820]

[29] R. Corke and T. Sjöstrand, “Interleaved parton showers and tuning prospects”, JHEP 03 (2011) 032, doi:10.1007/JHEP03(2011)032 [arXiv:1011.1759]

[30] 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]

[31] 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]

[32] H.-L. Lai et al., “Uncertainty induced by QCD coupling in the CTEQ global analysis of parton distributions”, Phys. Rev. D 82 (2010) 054021, doi:10.1103/PhysRevD.82.054021 [arXiv:1004.4624]

[33] 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]

[34] 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]
[35] J. M. Campbell, R. K. Ellis, and C. Williams, “Vector boson pair production at the LHC”, *JHEP* **07** (2011) 018, [doi:10.1007/JHEP07(2011)018](https://doi.org/10.1007/JHEP07(2011)018), [arXiv:1105.0020](https://arxiv.org/abs/1105.0020).

[36] M. Czakon and A. Mitov, “Top++: A program for the calculation of the top-pair cross-section at hadron colliders”, *Comput. Phys. Commun.* **185** (2014) 2930, [doi:10.1016/j.cpc.2014.06.021](https://doi.org/10.1016/j.cpc.2014.06.021), [arXiv:1112.5675](https://arxiv.org/abs/1112.5675).

[37] P. Kant et al., “HatHor for single top-quark production: Updated predictions and uncertainty estimates for single top-quark production in hadronic collisions”, *Comput. Phys. Commun.* **191** (2015) 74, [doi:10.1016/j.cpc.2015.02.001](https://doi.org/10.1016/j.cpc.2015.02.001), [arXiv:1406.4403](https://arxiv.org/abs/1406.4403).

[38] CMS Collaboration, “Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states”, *JHEP* **01** (2014) 096, [doi:10.1007/JHEP01(2014)096](https://doi.org/10.1007/JHEP01(2014)096), [arXiv:1312.1129](https://arxiv.org/abs/1312.1129).

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

[40] CMS Collaboration, “Particle-flow reconstruction and global event description with the CMS detector”, *JINST* **12** (2017) P10003, [doi:10.1088/1748-0221/12/10/P10003](https://doi.org/10.1088/1748-0221/12/10/P10003), [arXiv:1706.04965](https://arxiv.org/abs/1706.04965).

[41] CMS Collaboration, “Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV”, *JINST* **7** (2012) P10002, [doi:10.1088/1748-0221/7/10/P10002](https://doi.org/10.1088/1748-0221/7/10/P10002), [arXiv:1206.4071](https://arxiv.org/abs/1206.4071).

[42] 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](https://doi.org/10.1088/1748-0221/10/06/P06005), [arXiv:1502.02701](https://arxiv.org/abs/1502.02701).

[43] 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](https://doi.org/10.1140/epjc/s10052-012-1896-2), [arXiv:1111.6097](https://arxiv.org/abs/1111.6097).

[44] M. Cacciari and G. P. Salam, “Pileup subtraction using jet areas”, *Phys. Lett. B* **659** (2008) 119, [doi:10.1016/j.physletb.2007.09.077](https://doi.org/10.1016/j.physletb.2007.09.077), [arXiv:0707.1378](https://arxiv.org/abs/0707.1378).

[45] 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](https://doi.org/10.1088/1126-6708/2008/04/063), [arXiv:0802.1189](https://arxiv.org/abs/0802.1189).

[46] CMS Collaboration, “Measurements of differential jet cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV with the CMS detector”, *Phys. Rev. D* **87** (2013) 112002, [doi:10.1103/PhysRevD.87.112002](https://doi.org/10.1103/PhysRevD.87.112002), [arXiv:1212.6660](https://arxiv.org/abs/1212.6660).

[47] CMS Collaboration, “Determination of jet energy calibration and transverse momentum resolution in CMS”, *JINST* **6** (2011) P11002, [doi:10.1088/1748-0221/6/11/P11002](https://doi.org/10.1088/1748-0221/6/11/P11002), [arXiv:1107.4277](https://arxiv.org/abs/1107.4277).

[48] CMS Collaboration, “Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV”, *JINST* **12** (2017) P02014, [doi:10.1088/1748-0221/12/02/P02014](https://doi.org/10.1088/1748-0221/12/02/P02014), [arXiv:1607.03663](https://arxiv.org/abs/1607.03663).

[49] CMS Collaboration, “Identification of b-quark jets with the CMS experiment”, *JINST* **8** (2013) P04013, [doi:10.1088/1748-0221/8/04/P04013](https://doi.org/10.1088/1748-0221/8/04/P04013), [arXiv:1211.4462](https://arxiv.org/abs/1211.4462).
[50] H. Voss, A. Höcker, J. Stelzer, and F. Tegenfeldt, “TMVA, the toolkit for multivariate data analysis with ROOT”, in XIth International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT), p. 40. 2007. arXiv:physics/0703039

[51] CMS Collaboration, “CMS luminosity based on pixel cluster counting - Summer 2013 update”, CMS Physics Analysis Summary CMS-PAS-LUM-13-001, 2013.

[52] CMS Collaboration, “Missing transverse energy performance of the CMS detector”, JINST 6 (2011) P09001, doi:10.1088/1748-0221/6/09/P09001 arXiv:1106.5048

[53] CMS Collaboration, “Performance of b tagging at \( \sqrt{s} = 8 \) TeV in multijet, \( t\bar{t} \) and boosted topology events”, CMS Physics Analysis Summary CMS-PAS-BTV-13-001, 2013.

[54] S. Alekhin et al., “The PDF4LHC Working Group Interim Report”, (2011).

[55] M. Botje et al., “The PDF4LHC Working Group Interim Recommendations”, (2011).

[56] T. Junk, “Confidence level computation for combining searches with small statistics”, Nucl. Inst. Meth. A 434 (1999) 435, doi:10.1016/S0168-9002(99)00498-2 arXiv:hep-ex/9902226

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

[58] A. L. Read, “Presentation of search results: the CLs technique”, J. Phys. G 28 (2002) 2693, doi:10.1088/0954-3899/28/10/313

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

[60] R. Gavin, Y. Li, F. Petriello, and S. Quackenbush, “W Physics at the LHC with FEWZ 2.1”, Comput. Phys. Commun. 184 (2013) 208, doi:10.1016/j.cpc.2012.09.005 arXiv:1201.5896
A The CMS Collaboration

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

Institut für Höcherenergiephysik, Wien, Austria
W. Adam, F. Ambrogi, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth1, V.M. Ghete, J. Grossmann, J. Hrubec, M. Jeitler1, A. König, N. Krammer, I. Krätschmer, D. Liko, T. Madlener, I. Mikulec, E. Pree, D. Rabady, N. Rad, H. Rohringer, J. Schieck1, R. Schöfbeck, M. Spanring, D. Spitzbart, W. Waltenberger, J. Wittmann, C.-E. Wulz1, M. Zarucki

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

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

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

Université Libre de Bruxelles, Bruxelles, Belgium
D. Beghin, H. Brun, B. Clerbaux, G. De Lentdecker, H. Delannoy, B. Dorney, G. Fasanella, L. Favart, R. Goldouzian, A. Grebenyuk, G. Karapostoli, T. Lenzi, J. Luetic, T. Maerschalk, A. Marinov, A. Randle-conde, T. Seva, C. Vander Velde, P. Vanlaer, D. Vannerom, R. Yonamine, F. Zenoni, F. Zhang2

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

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

Université de Mons, Mons, Belgium
N. Beliy

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

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato3, E. Coelho, E.M. Da Costa, G.G. Da Silveira4, D. De Jesus Damiao, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, M. Melo De Almeida, C. Mora Herrera, L. Mundim, H. Nogima, A. Santoro, A. Sznajder, E.J. Tonelli Manganote3, F. Torres Da Silva De Araujo, A. Vilela Pereira
Universidade Estadual Paulista $^a$, Universidade Federal do ABC $^b$, São Paulo, Brazil
S. Ahuja$^a$, C.A. Bernardes$^a$, T.R. Fernandez Perez Tomei$^a$, E.M. Gregores$^b$, P.G. Mercadante$^b$, S.F. Novaes$^a$, Sandra S. Padula$^a$, D. Romero Abad$^b$, J.C. Ruiz Vargas$^a$

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

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

Beihang University, Beijing, China
W. Fang$^5$, X. Gao$^5$

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

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

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

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

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

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

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

Charles University, Prague, Czech Republic
M. Finger$^7$, M. Finger Jr.$^7$

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

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran$^{6,9}$, M.A. Mahmoud$^{10,9}$, A. Mahrous$^{11}$

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

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, J. Pekkanen, M. Voutilainen
Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, T. Arndt, C. Asawatangtrakuldee, K. Beernaert, O. Behnke, U. Behrens, A. BERMÚDEZ MARTÍNEZ, A.A. Bin Anuar, K. BORRAS, V. Botta, A. Campbell, P. Connor, C. CONTRERAS-CAMPANA, F. Costanza, C. DIEZ PARDOs, G. Eckerlin, D. Eckstein, T. Eichhorn, E. Eren, E. GALLO, J. GARAY GARCÍA, A. Geiser, A. GIZHKO, J.M. GRADOS LUYANDO, A. Grohsjean, P. Gunnellini, M. Guthoff, A. Harb, J. Hauk, M. HEMPEL, H. Jung, A. KALOGEROPoulos, M. KASEMANN, J. KEAVENey, C. Kleinwort, I. Korol, D. KRÜcker, W. Lange, A. LElek, T. LENz, J. LEONARD, K. LIPKA, W. LOHMANN, R. MANKEL, I.-A. MElzer-Pellmann, A.B. MEYER, G. MITTAG, J. MNIcH, A. MUSGGiller, E. NTOMARI, D. PITZL, A. RASPereZa, B. Roland, M. SAVITSKYI, P. SAXENA, R. SHEVCHenko, S. ŠPANNAgEL, N. STEFANIUK, G.P. VAn OnseM, R. WALsh, Y. WEN, K. WICHMANN, C. WISSing, O. ZENAIev

University of Hamburg, Hamburg, Germany
S. Bein, V. Blobel, M. Centis Vignali, T. Dreyer, E. Garutti, D. Gonzalez, J. Haller, A. Hinzmann, M. Hoffmann, A. Karavdina, R. Klanner, R. Kogler, N. Kovalchuk, S. Kurz, T. Lapsien, I. Marchesini, D. Marconi, M. MEyER, M. Niedziela, D. NOWATsCHin, F. PANTALEO, T. PEIFFER, A. PERIEANu, C. SCARF, P. SCHLEPER, A. SCHMIDT, S. Schumann, J. SCHwandt, J. SONNEVELD, H. Stadie, G. Steinbrück, F.M. STObER, M. STÖVER, H. Tholen, D. Troendle, E. Usai, L. VANELDERen, A. VAnhoefer, B. VORMwald

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
M. AKBIYIK, C. Barth, S. Baur, E. Butz, R. Caspart, T. Chwalek, F. Colombo, W. De Boer, A. Dierlamm, B. Freund, R. Friese, M. Giffels, D. HAITz, F. HARTMANN, S.M. HEINDL, U. HUSEMANN, F. KASKEL, S. KUDELLA, H. MILDNER, M.U. MOZER, Th. Müller, M. Plagge, G. QUAST, K. Rabbertz, M. SCHRÖDER, I. SHVETsov, G. Sieber, H.J. Simonis, R. Ulrich, S. WAYand, M. WEBER, T. Weiler, S. WILliAMsoN, C. WÖHRMANN, R. WOLF

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. GERALIS, V.A. GIakoumopouLOU, A. KYRIAKis, D. Loukas, I. TOPSIs-GOTIS

National and Kapodistrian University of Athens, Athens, Greece
G. Karathanasis, S. Kesisoglou, A. PANAGIOTOU, N. SAoulidou

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

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

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

Wigner Research Centre for Physics, Budapest, Hungary
G. Bencze, C. Hajdu, D. Horváth, Á. HUNyADI, F. Sikler, V. Veszpremi, A.J. ZSIGMOND

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. CzellAR, J. Karancsi, A. Makovec, J. Molnar, Z. SzilASz

Institute of Physics, University of Debrecen, Debrecen, Hungary
M. Bartók, P. Raics, Z.L. Trocsanyi, B. Ujvari
Indian Institute of Science (IISc), Bangalore, India
S. Choudhury, J.R. Komaragiri

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

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

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

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

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

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

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

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

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

Institute for Research in Fundamental Sciences (IPM), Teheran, Iran
S. Chenarani\textsuperscript{26}, E. Eskandari Tadavani, S.M. Etessami\textsuperscript{26}, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi\textsuperscript{27}, F. Rezaei Hosseinabadi, B. Safarzadeh\textsuperscript{28}, M. Zeinali

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

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

INFN Sezione di Bologna \textsuperscript{a}, Università di Bologna \textsuperscript{b}, Bologna, Italy
G. Abbiendi\textsuperscript{a}, C. Battilana\textsuperscript{a,b}, D. Bonacorsi\textsuperscript{a,b}, S. Braibant-Giacomelli\textsuperscript{a,b}, R. Campanini\textsuperscript{a,b}, P. Capiluppi\textsuperscript{a,b}, A. Castro\textsuperscript{a,b}, F.R. Cavallo\textsuperscript{a}, S.S. Chhibra\textsuperscript{a}, G. Codispoti\textsuperscript{a,b}, M. Cuffiani\textsuperscript{a,b}, G.M. Dallavalle\textsuperscript{a}, F. Fabbri\textsuperscript{a}, A. Fanfani\textsuperscript{a,b}, D. Fasanella\textsuperscript{a,b}, P. Giacomelli\textsuperscript{a}, C. Grandi\textsuperscript{a}, L. Guiducci\textsuperscript{a,b}, S. Marcellini\textsuperscript{a}, G. Masetti\textsuperscript{a}, A. Montanari\textsuperscript{a}, F.L. Navarria\textsuperscript{a,b}, A. Perrotta\textsuperscript{a}, A.M. Rossi\textsuperscript{a,b}, T. Rovelli\textsuperscript{a,b}, G.P. Siroli\textsuperscript{a,b}, N. Tosi\textsuperscript{a}
INFIN Sezione di Catania, Università di Catania, Catania, Italy
S. Albergento, S. Costa, A. Di Mattia, F. Giordano, R. Potenza, A. Tricomi, C. Tuve

INFIN Sezione di Firenze, Università di Firenze, Firenze, Italy
G. Barbaglia, K. Chatterjee, V. Ciulli, C. Cividini, R. D’Alessandro, E. Focardi, P. Lenzini, M. Meschini, S. Paoletti, L. Russo, G. Sguazzoni, D. Strom, L. Vilian

INFIN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benucci, S. Bianco, F. Fabbri, D. Piccolo, F. Primavera

INFIN Sezione di Genova, Università di Genova, Genova, Italy
V. Calvelli, F. Ferro, E. Robutti, S. Tosi

INFIN Sezione di Milano-Bicocca, Università di Milano-Bicocca, Milano, Italy
A. Benaglia, L. Balian, F. Brivio, V. Cirioli, M.E. Dinardo, S. Fiorenzi, S. Gennai, A. Ghezzi, P. Govoni, M. Malberti, S. Malvezzi, R.A. Manzoni, D. Menasce, L. Moroni, M. Paganoni, K. Pauwels, D. Pedrini, S. Pigazzini, N. Redaelli, T. Tabarelli de Fatis

INFIN Sezione di Napoli, Università di Napoli ‘Federico II’, Napoli, Italy, Università della Basilicata, Potenza, Italy, Università G. Marconi, Roma, Italy
S. Buontempo, N. Cavallo, S. Di Guida, F. Fabozzi, F. Fienga, A.O.M. Iorio, W.A. Khan, L. Lista, M. Meola, P. Paolucci, C. Sciacca, F. Thyssen

INFIN Sezione di Padova, Università di Padova, Padova, Italy, Università di Trento, Trento, Italy
P. Azzi, N. Bacchetta, L. Benato, M. Benettoni, A. Boletti, R. Carlin, A. Carvalho Antunes De Oliveira, P. Checchia, M. Dall’Osso, P. De Castro Manzano, T. Dorigo, U. Dosselli, F. Gasparini, U. Gasparini, A. Gazzello, L. Laprara, P. Lujan, M. Margoni, N. Pozzobon, P. Ronchese, R. Rossin, F. Simonetto, E. Torassa, S. Ventura, M. Zanetti, P. Zotto

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

INFIN Sezione di Perugia, Università di Perugia, Perugia, Italy
L. Alunni Solestizi, M. Biasini, G.M. Bileri, C. Cecchi, D. Ciangottini, L. Fano, P. Lariccia, R. Leonardi, E. Manoni, G. Mantovani, V. Marian, M. Menichelli, A. Rossi, A. Santocchia, D. Spiga

INFIN Sezione di Pisa, Università di Pisa, Scuola Normale Superiore di Pisa, Pisa, Italy
K. Androsov, P. Azzurri, G. Bagliesi, T. Boccali, L. Borrello, R. Castaldi, M.A. Ciocci, R. Dell’Orso, G. Fedi, L. Giannini, A. Giassi, M.T. Grippo, F. Ligabue, T. Lomtadze, E. Manca, G. Mandorlini, L. Martinetti, A. Messineo, F. Palla, A. Rizzetto, A. Savoy-Navarro, P. Spagnolo, R. Tenchini, G. Tonelli, A. Venturi, P.G. Verdini

INFIN Sezione di Roma, Sapienza Università di Roma, Rome, Italy
L. Barone, F. Cavallari, M. Cipriani, N. Daci, D. Del Re, E. Di Marco, M. Diemoz, S. Gelli, E. Longo, F. Margaroli, B. Marzocchi, P. Meridioni, G. Organtini, R. Paramatti, F. Preiatto, S. Rahatlou, C. Roveri, F. Santanastasio

INFIN Sezione di Torino, Università di Torino, Torino, Italy, Università del Piemonte Orientale, Novara, Italy
N. Amapane, R. Arcidiacono, S. Argiro, M. Arneodo, N. Bartosik, R. Bellan,
C. Biino\textsuperscript{a}, N. Cartiglia\textsuperscript{a}, F. Cenna\textsuperscript{a,b}, M. Costa\textsuperscript{a,b}, R. Covarelli\textsuperscript{a,b}, A. Degano\textsuperscript{a,b}, N. Demaria\textsuperscript{a}, B. Kiani\textsuperscript{a,b}, C. Mariotti\textsuperscript{a}, S. Maselli\textsuperscript{a}, E. Migliore\textsuperscript{a,b}, V. Monaco\textsuperscript{a,b}, E. Montei\textsuperscript{a,b}, M. Monteno\textsuperscript{a}, M.M. Obertino\textsuperscript{a,b}, L. Pacher\textsuperscript{a,b}, N. Pastrone\textsuperscript{a}, M. Pelliccioni\textsuperscript{a}, G.L. Pinna Angioni\textsuperscript{a,b}, F. Ravera\textsuperscript{a,b}, A. Romero\textsuperscript{a,b}, M. Ruspa\textsuperscript{a,c}, R.Sacchi\textsuperscript{a,b}, K. Shchelina\textsuperscript{a,b}, V. Sola\textsuperscript{a}, A. Solano\textsuperscript{a,b}, A. Staiano\textsuperscript{a}, P. Traczyk\textsuperscript{a,b}

\textbf{INFN Sezione di Trieste} \textsuperscript{a}, \textbf{Università di Trieste} \textsuperscript{b}, Trieste, Italy

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

\textbf{Kyungpook National University}, Daegu, Korea

D.H. Kim, G.N. Kim, M.S. Kim, J. Lee, S. Lee, S.W. Lee, C.S. Moon, Y.D. Oh, S. Sekmen, D.C. Son, Y.C. Yang

\textbf{Chonbuk National University}, Jeonju, Korea

A. Lee

\textbf{Chonnam National University, Institute for Universe and Elementary Particles}, Kwangju, Korea

H. Kim, D.H. Moon, G. Oh

\textbf{Hanyang University}, Seoul, Korea

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

\textbf{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

\textbf{Seoul National University, Seoul, Korea}

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

\textbf{University of Seoul, Seoul, Korea}

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

\textbf{Sungkyunkwan University, Suwon, Korea}

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

\textbf{Vilnius University, Vilnius, Lithuania}

V. Dudenas, A. Juodagalvis, J. Vaitkus

\textbf{National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur, Malaysia}

I. Ahmed, Z.A. Ibrahim, M.A.B. Md Ali\textsuperscript{32}, F. Mohamad Idris\textsuperscript{33}, W.A.T. Wan Abdullah, M.N. Yusli, Z. Zolkapli

\textbf{Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico}

Reyes-Almanza, R, Ramirez-Sanchez, G., Duran-Osuna, M. C., H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz\textsuperscript{34}, Rabadan-Trejo, R. I., R. Lopez-Fernandez, J. Mejia Guisao, A. Sanchez-Hernandez

\textbf{Universidad Iberoamericana, Mexico City, Mexico}

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

\textbf{Benemerita Universidad Autonoma de Puebla, Puebla, Mexico}

I. Pedraza, H.A. Salazar Ibarguen, C. Uribe Estrada

\textbf{Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico}

A. Morelos Pineda
University of Auckland, Auckland, New Zealand
D. Krofcheck

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

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

National Centre for Nuclear Research, Swierk, Poland
K. Bunkowski, A. Byszuk, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, A. Pyskir, M. Walczak

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

Joint Institute for Nuclear Research, Dubna, Russia
A. Baginyan, A. Golunov, I. Golutvin, V. Karjavin, V. Korenkov, G. Kozlov, A. Lanev, A. Malakhov, V. Matveev, V.V. Mitsyn, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, N. Voytishin, B.S. Yuldashev, A. Zarubin, V. Zhiltsov

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

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

National Research Nuclear University ‘Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia
M. Chadeeva, P. Parygin, D. Philippov, S. Polikarpov, E. Popova, V. Rusinov

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

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

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

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

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

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

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

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

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

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

ETH Zurich - Institute for Particle Physics and Astrophysics (IPA), Zurich, Switzerland
L. Bäni, P. Berger, L. Bianchini, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, T. Klijnsma, W. Listermann, B. Mangano, M. Marionneau, M.T. Meinhard, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi,
J. Pata, F. Pauss, G. Perrin, L. Perrozzi, M. Quittnat, M. Reichmann, M. Schönenberger, L. Shchutska, V.R. Tavolaro, K. Theofilatos, M.L. Vesterbacka Olsson, R. Wallny, D.H. Zhu

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

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

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

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

Çukurova University, Physics Department, Science and Art Faculty, Adana, Turkey
M.N. Bakirci, F. Boran, S. Cerci, S. Damarseckin, Z.S. Demiroglu, C. Dozen, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, I. Hos, E.E. Kangal, O. Kara, U. Kiminsu, M. Oglakci, G. Onengut, K. Ozdemir, A. Polatoz, H. Topakli, S. Turkapar, I.S. Zorbakir, C. Zorbilmez

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

Bogazici University, Istanbul, Turkey
E. Gülmez, M. Kaya, O. Kaya, S. Tekten, E.A. Yetkin

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

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

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

University of Bristol, Bristol, United Kingdom
R. Aggleton, F. Ball, L. Beck, J.J. Brooke, D. Burns, E. Clement, D. Cussans, O. Davignon, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, D.M. Newbold, 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, C. Brew, R.M. Brown, L. Calligaris, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams

Imperial College, London, United Kingdom
G. Auzinger, R. Bainbridge, J. Borg, S. Breeze, O. Buchmuller, A. Bundock, S. Casasso, M. Citron, D. Colling, L. Corpe, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, R. Di Maria, A. Elwood, Y. Haddad, G. Hall, G. Iles, T. James, R. Lane, C. Laner, L. Lyons, A.-M. Magnan, S. Malik, L. Mastrolorenzo, T. Matsushita, J. Nash, A. Nikitenko, V. Palladino, M. Pesaresi,
D.M. Raymond, A. Richards, A. Rose, E. Scott, C. Seez, A. Shtipliyski, S. Summers, A. Tapper, K. Uchida, M. Vazquez Acosta, T. Virdee, N. Wardle, D. Winterbottom, J. Wright, S.C. Zenz

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

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

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

The University of Alabama, Tuscaloosa, USA
J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

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

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

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

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

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

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

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

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

Carnegie Mellon University, Pittsburgh, USA
M.B. Andrews, T. Ferguson, T. Mudholkar, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev, M. Weinberg
University of Colorado Boulder, Boulder, USA
J.P. Cumalat, W.T. Ford, F. Jensen, A. Johnson, M. Krohn, S. Leontsinis, T. Mulholland, K. Stenson, S.R. Wagner

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

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

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

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

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

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

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

The University of Iowa, Iowa City, USA
B. Bilki, S. Clarida, K. Dilisz, S. Durgut, R.P. Gandjariya, M. Haytmuradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok, A. Penzo, C. Snyder, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, USA
B. Blumenfeld, A. Cocores, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, J. Roskes, U. Sarica, M. Swartz, M. Xiao, C. You

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

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

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

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

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

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

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

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

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

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

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

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

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

**Princeton University, Princeton, USA**
S. Cooperstein, O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S. Higinbotham, D. Lange, J. Luo, D. Marlow, K. Mei, I. Ojalvo, J. Olsen, C. Palmer, P. Piroué, D. Stickland, C. Tully
University of Puerto Rico, Mayaguez, USA
S. Malik, S. Norberg

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

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

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

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

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

Rutgers, The State University of New Jersey, Piscataway, USA
A. Agapitos, J.P. Chou, Y. Gersten, T.A. Gómez Espinosa, E. Halkiadakis, M. Heindl,
E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, S. Kyriacou, A. Lath, R. Montalvo, K. Nash,
M. Osherson, H. Saka, S. Salur, S. Schneiter, 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, A. Castaneda Hernandez, A. Celik, M. Dalchenko, M. De Mattia, A. Delgado,
S. Dildick, R. Eusebi, J. Gilmore, T. Huang, T. Kamon, R. Mueller, Y. Pakhotin, R. Patel,
A. Perloff, L. Perniè, D. Rathjens, A. Safonov, A. Tatarinov, K.A. Ulmer

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

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

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

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

University of Wisconsin - Madison, Madison, WI, USA
M. Brodski, J. Buchanan, C. Caillot, S. Dasu, L. Dodd, S. Duric, B. Gomber, M. Grothe,
M. Herndon, A. Hervé, U. Hussain, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless,
G. Polese, T. Ruggles, A. Savin, N. Smith, W.H. Smith, D. Taylor, N. Woods
†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
3: Also at Universidade Estadual de Campinas, Campinas, Brazil
4: Also at Universidade Federal de Pelotas, Pelotas, Brazil
5: Also at Université Libre de Bruxelles, Bruxelles, Belgium
6: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
7: Also at Joint Institute for Nuclear Research, Dubna, Russia
8: Also at Suez University, Suez, Egypt
9: Now at British University in Egypt, Cairo, Egypt
10: Also at Fayoum University, El-Fayoum, Egypt
11: Now at Helwan University, Cairo, Egypt
12: Also at Université de Haute Alsace, Mulhouse, France
13: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
14: Also at Tbilisi State University, Tbilisi, Georgia
15: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
16: Also at RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
17: Also at University of Hamburg, Hamburg, Germany
18: Also at Brandenburg University of Technology, Cottbus, Germany
19: Also at MTA-ELTE Lendület CMS Particle and Nuclear Physics Group, Eötvös Loránd University, Budapest, Hungary
20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
21: Also at Institute of Physics, University of Debrecen, Debrecen, Hungary
22: Also at Indian Institute of Technology Bhubaneswar, Bhubaneswar, India
23: Also at Institute of Physics, Bhubaneswar, India
24: Also at University of Visva-Bharati, Santiniketan, India
25: Also at University of Ruhuna, Matara, Sri Lanka
26: Also at Isfahan University of Technology, Isfahan, Iran
27: Also at Yazd University, Yazd, Iran
28: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
29: Also at Università degli Studi di Siena, Siena, Italy
30: Also at INFN Sezione di Milano-Bicocca; Università di Milano-Bicocca, Milano, Italy
31: Also at Purdue University, West Lafayette, USA
32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
35: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
36: Also at Institute for Nuclear Research, Moscow, Russia
37: Now at National Research Nuclear University ‘Moscow Engineering Physics Institute’ (MEPhI), Moscow, Russia
38: Also at Institute of Nuclear Physics of the Uzbekistan Academy of Sciences, Tashkent, Uzbekistan
39: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
40: Also at University of Florida, Gainesville, USA
41: Also at P.N. Lebedev Physical Institute, Moscow, Russia
42: Also at Budker Institute of Nuclear Physics, Novosibirsk, Russia
43: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
44: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
45: Also at Scuola Normale e Sezione dell’INFN, Pisa, Italy
46: Also at National and Kapodistrian University of Athens, Athens, Greece
47: Also at Riga Technical University, Riga, Latvia
48: Also at Universität Zürich, Zurich, Switzerland
49: Also at Stefan Meyer Institute for Subatomic Physics (SMI), Vienna, Austria
50: Also at Gaziosmanpasa University, Tokat, Turkey
51: Also at Adiyaman University, Adiyaman, Turkey
52: Also at Istanbul Aydin University, Istanbul, Turkey
53: Also at Mersin University, Mersin, Turkey
54: Also at Cag University, Mersin, Turkey
55: Also at Piri Reis University, Istanbul, Turkey
56: Also at Izmir Institute of Technology, Izmir, Turkey
57: Also at Necmettin Erbakan University, Konya, Turkey
58: Also at Marmara University, Istanbul, Turkey
59: Also at Kafkas University, Kars, Turkey
60: Also at Istanbul Bilgi University, Istanbul, Turkey
61: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
62: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
63: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
64: Also at Utah Valley University, Orem, USA
65: Also at Beykent University, Istanbul, Turkey
66: Also at Bingol University, Bingol, Turkey
67: Also at Erzincan University, Erzincan, Turkey
68: Also at Sinop University, Sinop, Turkey
69: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
70: Also at Texas A&M University at Qatar, Doha, Qatar
71: Also at Kyungpook National University, Daegu, Korea