EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP/2012-376
2013/04/25

CMS-SMP-12-024

Measurement of the W^+W^- and ZZ production cross sections in pp collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration*

Abstract

The W^+W^- and ZZ production cross sections are measured in proton-proton collisions at $\sqrt{s} = 8$ TeV with the CMS experiment at the LHC in data samples corresponding to an integrated luminosity of up to 5.3 fb^{-1}. The measurements are performed in the leptonic decay modes $W^+W^- \to \ell'\nu\ell''\nu$ and $ZZ \to 2\ell 2\ell'$, where $\ell = e, \mu$ and $\ell'(\ell'') = e, \mu, \tau$. The measured cross sections $\sigma(pp \to W^+W^-) = 69.9 \pm 2.8\,(stat.) \pm 5.6\,(syst.) \pm 3.1\,(lum.)$ pb and $\sigma(pp \to ZZ) = 8.4 \pm 1.0\,(stat.) \pm 0.7\,(syst.) \pm 0.4\,(lum.)$ pb, for both Z bosons produced in the mass region $60 < m_Z < 120$ GeV, are consistent with standard model predictions. These are the first measurements of the diboson production cross sections at $\sqrt{s} = 8$ TeV.

Submitted to Physics Letters B

*See Appendix A for the list of collaboration members

1 Introduction

The study of W^+W^- and ZZ production in proton-proton collisions provides an important test of the standard model (SM). Any deviations of the measured cross sections from SM predictions would indicate new physics. Measurements of electroweak W^+W^- and ZZ production are essential for an accurate estimate of irreducible backgrounds for Higgs boson studies.

Previous measurements of W^+W^- and ZZ production were performed at the Large Hadron Collider (LHC) at a centre-of-mass energy $\sqrt{s} = 7\,\text{TeV}$. With a data set corresponding to an integrated luminosity of $36\,\text{pb}^{-1}$, the Compact Muon Solenoid (CMS) Collaboration measured the W^+W^- cross section $\sigma(\text{pp} \to W^+W^-) = 41.1 \pm 15.3\,(\text{stat.}) \pm 5.8\,(\text{syst.}) \pm 4.5\,(\text{lum.})\,\text{pb}$ [1], in good agreement with the SM prediction of $47 \pm 2\,\text{pb}$ from Ref. [2]. The ATLAS Collaboration measured $\sigma(\text{pp} \to W^+W^-) = 51.9 \pm 2.0\,(\text{stat.}) \pm 3.9\,(\text{syst.}) \pm 2.0\,(\text{lum.})\,\text{pb}$ [3] using $4.6\,\text{fb}^{-1}$ of data. The ZZ cross section measurement from CMS used $5\,\text{fb}^{-1}$ of data; the measured value, $\sigma(\text{pp} \to \text{ZZ}) = 6.24\,^{+0.86}_{-0.80}\,(\text{stat.})\,^{+0.41}_{-0.32}\,(\text{syst.}) \pm 0.14\,(\text{lum.})\,\text{pb}$, is consistent with the SM prediction of $6.3 \pm 0.4\,\text{pb}$ for both Z bosons in the mass range $60 < m_Z < 120\,\text{GeV}$ [4]. ATLAS measured $\sigma(\text{pp} \to \text{ZZ}) = 6.7 \pm 0.7\,(\text{stat.})\,^{+0.4}_{-0.3}\,(\text{syst.}) \pm 0.3\,(\text{lum.})\,\text{pb}$ [5] with a data sample corresponding to an integrated luminosity of $4.6\,\text{fb}^{-1}$. Measurements of the W^+W^- and ZZ cross sections performed at the Tevatron are summarized in Refs. [6–10]. All measurements are found to agree well with the corresponding SM predictions.

In this Letter, the first measurements of the W^+W^- and ZZ production cross sections at $\sqrt{s} = 8\,\text{TeV}$ are presented. The analysis is based on data collected in 2012 with the CMS experiment at the LHC, corresponding to an integrated luminosity of $3.5\,\text{fb}^{-1}$ for the W^+W^- measurement and $5.3\,\text{fb}^{-1}$ for the ZZ measurement. The measurements are performed in the $W^+W^- \to \ell'\nu\ell''\nu$ and $\text{ZZ} \to 2\ell 2\ell'$ decay channels, where ℓ is e or μ, and ℓ' (ℓ'') is e, μ, or τ. If a τ lepton is present in the W^+W^- final state, only leptonic decays of the τ lepton are considered. If a τ lepton is present in the ZZ final state, one Z is required to decay either into e^+e^- or $\mu^+\mu^-$, and the second Z into $\tau^+\tau^-$ in four possible final states: $\tau_h\tau_h$, $\tau_e\tau_h$, $\tau_\mu\tau_h$, and $\tau_e\tau_\mu$, where τ_h indicates a τ lepton decaying hadronically, and τ_e and τ_μ indicate taus decaying into an electron and a muon, respectively.

The SM background sources to the W^+W^- event sample include $W\gamma^{(*)}$, top-quark ($t\bar{t}$ and tW), $Z/\gamma^* \to \ell^+\ell^-$, and diboson (WZ and ZZ) production, as well as W+jets and QCD multijet events, where at least one of the jets is misidentified as a lepton. The SM background sources to the ZZ event sample include contributions from $Zb\bar{b}$ and $t\bar{t}$ processes, where the final states contain two isolated leptons and two b jets with secondary leptons, and from Z+jets and ZW+jets processes where the jets are misidentified as leptons.

2 The CMS detector and simulation

While the CMS detector is described in detail elsewhere [11], the key components for this analysis are summarized here. The CMS experiment uses a right-handed coordinate system, with the origin at the nominal interaction point, the x axis pointing to the center of the LHC ring, the y axis pointing up (perpendicular to the plane of the LHC ring), and the z axis along the anticlockwise-beam direction. The polar angle θ is measured from the positive z axis and the azimuthal angle ϕ is measured in the x-y plane. The magnitude of the transverse momentum (p_T) is calculated as $p_T = \sqrt{p_x^2 + p_y^2}$. A superconducting solenoid occupies the central region of the CMS detector, providing an axial magnetic field of 3.8 T parallel to the beam direction. The silicon pixel and strip tracker, the crystal electromagnetic calorimeter, and the brass/scintillator hadron calorimeter are located within the solenoid. A quartz-fibre Cherenkov calorimeter extends the coverage to $|\eta| < 5.0$, where pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$. Muons are measured in gas ionization detectors embedded in the steel flux return yoke outside the solenoid. The first level of the CMS trigger system, composed of custom hardware processors, is designed to select the most interesting events in less than 3 μs using information from the calorimeters and muon detectors. The high-level-trigger processor farm decreases the event rate from 100 kHz delivered by the first level trigger to a few hundred hertz, before data storage.

Several Monte Carlo (MC) event generators are used to simulate the signals and backgrounds. The W^+W^- production via $q\overline{q}$ annihilation is generated with the MADGRAPH [12] event generator, and PYTHIA [13] is used for parton showering, hadronization, and the underlying event simulation. The $gg \to W^+W^-$ process, which is expected to contribute 3% of the total W^+W^- production rate [14], is generated with GG2WW [15]. The ZZ production via $q\overline{q}$ annihilation is generated at next-to-leading order (NLO) with POWHEG 2.0 [16–18]. The $gg \to ZZ$ process is simulated with GG2ZZ [19]. Other diboson processes (WZ, $W\gamma^{(*)}$) and the Z+jets samples are generated with MADGRAPH. The $t\overline{t}$ and tW events are generated at NLO with POWHEG. For leading-order (LO) generators, the default set of parton distribution functions (PDF) used to produce these samples is CTEQ6L [20], while CT10 [21] is used for NLO generators. The τ lepton decays are generated with TAUOLA [22]. For all processes, the detector response is simulated using a detailed description of the CMS detector, based on the GEANT4 package [23], and event reconstruction is performed with the same algorithms as used for data. The simulated samples include additional interactions per bunch crossing (pileup). The simulated events are weighted so that the pileup distribution matches the data, with an average pileup of about 20 interactions per bunch crossing.

3 Event reconstruction

Both the W^+W^- and ZZ event selections begin with the reconstruction and identification of lepton candidates. Electrons are reconstructed by combining information from the electromagnetic calorimeter and tracker [24, 25]. Their identification relies on a multivariate technique that combines observables sensitive to the amount of bremsstrahlung along the electron trajectory, the geometrical and momentum matching between the electron trajectory in the tracker and the energy deposit in the calorimeter, as well as the shower shape [24]. Muons are reconstructed [26] with information from both the tracker and the muon spectrometer, and are required to pass selection criteria similar to those described in Ref. [1]. A particle-flow (PF) technique [27] is used to reconstruct τ_h candidates with the "hadron plus strip" (HPS) algorithm [28], which is designed to optimize the performance of τ_h identification and reconstruction by considering specific τ_h decay modes. In the PF approach, information from all subdetectors is combined to reconstruct and identify particles produced in the collision. The particles are classified into mutually exclusive categories: charged hadrons, photons, neutral hadrons, muons, and electrons. These particles are used to reconstruct the τ_h candidates; the neutrinos produced in all τ decays escape detection and are ignored in the τ_h reconstruction. The lepton candidates are required to be consistent with the primary vertex of the event, which is chosen as the vertex with highest $\sum p_T^2$ of its associated tracks. This criterion provides the correct assignment for the primary vertex in more than 99% of both signal and background events for the pileup distribution observed in the data.

Charged leptons from W and Z boson decays are usually isolated from other activity in the event. For each electron or muon candidate, a cone is constructed around the track direction at the event vertex. The scalar sum of the transverse momenta of all reconstructed particles consistent with the chosen primary vertex and contained within the cone is calculated, excluding the contribution from the lepton candidate itself. To improve the discrimination against non-isolated muons from the W+jets background in the W^+W^- selection, this procedure is repeated with several cones of different widths. This isolation information is then combined by means of a multivariate technique. For both electrons and muons a correction is applied to account for the energy contribution in the isolation cone due to pileup. A median transverse energy due to pileup is determined event by event and is subtracted from the transverse energy (E_T) in the isolation cone [29]. A similar technique is used to form τ lepton isolation quantities.

Jets are reconstructed from the PF particles using the anti-k_T clustering algorithm [30] with distance parameter of 0.5, as implemented in the FASTJET package [31, 32]. The jet energy is corrected for pileup in a manner similar to the correction of the energy inside a lepton isolation cone. Jet energy corrections are also applied as a function of the jet p_T and η [33]. A multivariate selection is applied to separate jets coming from the primary interaction from those reconstructed using energy deposits associated with pileup. This discrimination is based on the differences in the jet shapes and in the relative multiplicity of charged and neutral components. Tracks associated with a jet are required to be consistent with the primary vertex.

To suppress the top-quark background in events without high-p_T jets, top-quark-tagging techniques are defined with two methods. The first method vetoes events containing muons originating from b quarks [34] appearing in top-quark decays. The second method uses b-jet tagging applied to jets with $15 < p_T < 30$ GeV based on tracks with large impact parameter within jets.

The missing transverse energy $\vec{E}_T^{miss}$ is defined as the negative vector sum of the transverse momenta of all reconstructed particles in the event. A *projected* E_T^{miss} is defined as (i) the magnitude of the $\vec{E}_T^{miss}$ component transverse to the closest lepton, if $\Delta\phi(\ell, \vec{E}_T^{miss}) < \pi/2$, or (ii) the magnitude of the $\vec{E}_T^{miss}$ otherwise. This observable more efficiently rejects $Z/\gamma^* \to \tau^+\tau^-$ background events in which the $\vec{E}_T^{miss}$ is preferentially aligned with the leptons, and $Z/\gamma^* \to \ell^+\ell^-$ events with mismeasured $\vec{E}_T^{miss}$. Since the projected E_T^{miss} resolution is degraded as pileup increases, the minimum of two different observables is used: the first includes all particle candidates in the event, while the second uses only the charged particle candidates associated with the primary vertex.

4 Event selection and background estimates

4.1 W^+W^- production

Events are selected with two oppositely charged electron or muon candidates, both with $p_T > 20$ GeV and with $|\eta| < 2.5$ for the electrons and $|\eta| < 2.4$ for the muons. The τ leptons contribute to the measurement only if they decay to electrons or muons that pass the selection requirements. At the trigger level, events are required to have a pair of electrons or muons where one of the leptons has $p_T > 17$ GeV and the other $p_T > 8$ GeV, or a single electron (muon) with $p_T > 27$ (24) GeV. The trigger efficiency is approximately 98% for both $q\bar{q} \to W^+W^-$ and $gg \to W^+W^-$ processes.

To reduce the background from top-quark decays, events with one or more jets surviving the jet selection criteria and with $p_T > 30$ GeV and $|\eta| < 4.7$ are rejected. The residual top-quark background is further suppressed by 50% after applying the top-quark-tagging techniques.

In order to reduce the Drell–Yan background, the projected E_T^{miss} is required to be above 45 GeV in the e^+e^- and $\mu^+\mu^-$ final states. For the $e^\pm\mu^\mp$ final state, which has a lower contamination from $Z/\gamma^* \to \ell^+\ell^-$ decays, the threshold is reduced to 20 GeV. These requirements remove more than 99% of the Drell–Yan background.

To further reduce the Drell–Yan background in the e^+e^- and $\mu^+\mu^-$ final states, the angle in the transverse plane between the dilepton system total momentum and the most energetic jet with $p_T > 15$ GeV is required to be smaller than 165 degrees. Events with dilepton masses within ± 15 GeV of the Z mass or below 12 GeV are also rejected. Finally, the transverse momentum of the dilepton system, $p_T^{\ell\ell}$, is required to be above 45 GeV to reduce contributions from Drell–Yan background and events containing jets misidentfied as leptons.

To reduce the background from other diboson processes, such as WZ or ZZ production, any event is rejected if it has a third lepton with $p_T > 10$ GeV passing the identification and isolation requirements. The $W\gamma^{(*)}$ production in which the photon converts is suppressed by rejecting electrons consistent with a photon conversion.

The W+jets and QCD multijet backgrounds are estimated from a control region in which one lepton passes the nominal requirements, while the other passes looser criteria on impact parameter and isolation, but fails the nominal requirements. The contribution to the control region from processes with two genuine leptons is subtracted by using simulation. The number of events in the signal region is obtained by scaling the number of events in the control region with the efficiency for loosely identified lepton candidates to pass the tight selection. These efficiencies are measured in data using multijet events and are parametrized according to the p_T and $|\eta|$ of the lepton candidate.

The normalization of the top-quark background that survives the top-quark-tagging requirements is estimated from data by counting the number of top-tagged events and applying the corresponding top-tagging efficiency. The top-tagging efficiency is measured with a control sample dominated by $t\bar{t}$ and tW events, which is selected by requiring a b-tagged jet.

We estimate the Drell–Yan contribution to the e^+e^- and $\mu^+\mu^-$ final states outside of the Z mass window by normalising the event yield from simulation to the observed number of events inside the Z mass window. The methods used to estimate both the top-quark and Drell–Yan backgrounds are described in more detail in Ref. [35].

Finally, a control sample with three reconstructed leptons is used to measure the data-to-MC scaling factor for the $W\gamma^{(*)}$ process. We use only $W\gamma^{(*)} \to \ell\nu\mu^+\mu^-$ events for this measurement because the $\ell\nu e^+e^-$ final state is difficult to separate from other backgrounds. This measurement is used to normalise the simulated $W\gamma^{(*)}$ background contribution from asymmetric gamma decays in which one lepton escapes detection [36].

Other backgrounds, such as WZ and ZZ diboson production, are estimated from simulation.

The W+jets and $W\gamma^{(*)}$ background estimate is checked using data events that pass all the selection requirements with the exception that the two leptons must have the same charge. After subtraction of the expected WZ background, this sample is dominated by W+jets and $W\gamma^{(*)}$ events. The $Z/\gamma^* \to \tau^+\tau^-$ contamination is checked using $Z/\gamma^* \to e^+e^-$ and $Z/\gamma^* \to \mu^+\mu^-$ events selected in data, where the leptons are replaced with simulated τ lepton decays.

4.2 ZZ production

Selected events are required to have at least one electron or muon with $p_T > 20$ GeV and another one with $p_T > 10$ GeV, and $|\eta| < 2.5$ (2.4) for electrons (muons). All other electrons (muons) are required to have $p_T > 7$ (5) GeV. The τ_h candidates are required to have

$p_T > 20\,\text{GeV}$ and $|\eta| < 2.3$. All leptons must originate from the same vertex and be isolated. At the trigger level, events are required to have a pair of electrons or muons, one lepton with $p_T > 17\,\text{GeV}$ and the other with $p_T > 8\,\text{GeV}$.

The selected events are required to contain two Z candidates. One candidate, denoted by Z_1, should decay into electrons or muons, $Z \to \ell^+\ell^-$, and must have reconstructed invariant mass $60 < m_{\ell\ell} < 120\,\text{GeV}$. If more than one candidate is found, the one with mass closest to the Z mass is considered as Z_1.

The selection requirements for the second Z candidate, denoted by Z_2, depend on the final state. In the 4μ, 4e, and $2e2\mu$ final states the isolation requirements are the same as for the leptons from Z_1. For the $e^+e^-\tau_e^\pm\tau_\mu^\mp$ and $\mu^+\mu^-\tau_e^\pm\tau_\mu^\mp$ final states the electron and muon p_T values are required to exceed $10\,\text{GeV}$. In final states with $Z_2 \to \tau_e\tau_h, \tau_\mu\tau_h$ the isolation requirements for all the electrons and muons are tighter. A study of inclusive $Z \to \tau^+\tau^-$ production [37] shows that modifying the electron and muon isolation requirements is a more effective way to reduce background in such final states than imposing tighter isolation criteria on τ_h.

The invariant mass of the reconstructed Z_2 is required to satisfy $60 < m_{\ell^+\ell^-} < 120\,\text{GeV}$ when Z_2 decays into e^+e^- or $\mu^+\mu^-$. In the $2\ell2\tau$ final states, the visible invariant mass of the reconstructed $Z_2 \to \tau^+\tau^-$ is shifted to smaller values because of undetected neutrinos in τ decays. Therefore, in the final states involving τ leptons, the visible mass is required to satisfy $30 < m_{\tau^+\tau^-} < 90\,\text{GeV}$, and the leptons from the same Z are required to be separated by $\Delta R > 0.4$ for the Z_1, and by $\Delta R > 0.5$ for the Z_2.

Estimated acceptances of the selection requirements defined with respect to the full phase space are 58%, 56%, 54%, and 25% for the 4e, $2e2\mu$, 4μ, and $2\ell2\tau$ final states, respectively.

The major contributions to the background come from Z production in association with jets, WZ production in association with jets, and $t\bar{t}$. In all these cases, a jet or nonisolated lepton is misidentified as an isolated electron, muon, or τ_h. The relative contribution of each source of background depends on the final state.

For the background estimation, two different approaches are used. Both start by relaxing the isolation and identification criteria for two additional reconstructed lepton objects indicated as $\ell_{reco}\ell_{reco}$ in the $Z_1 + \ell_{reco}\ell_{reco}$ event sample. The additional pair of leptons is required to have like-sign charge (to avoid signal contamination) and same flavour ($e^\pm e^\pm, \mu^\pm\mu^\pm$). The first method estimates the number of Z+X background events in the signal region by taking into account the lepton misidentification probability for each of the two additional leptons. The second method uses a control region with two opposite-sign leptons that fail the isolation and identification criteria. The background in the signal region is estimated by weighting the events in the control region with the lepton misidentification probability. In addition, a control region with three passing leptons and one failing lepton is used to account for contributions from backgrounds with three prompt leptons and one misidentified lepton. Comparable background rates in the signal region are found within the uncertainties from both methods.

5 Systematic uncertainties

The uncertainty in the signal acceptance for the two measurements due to variations in the parton distribution functions and the value of α_s is estimated by following the PDF4LHC prescription [38]. Using CT10 [21], MSTW08 [39], and NNPDF [40] sets, the uncertainties are 2.3% (4.0%) for the $q\bar{q} \to W^+W^-(ZZ)$ processes.

The effects of higher-order corrections are found by varying the QCD renormalisation and factorisation scales simultaneously up and down by a factor of two using the MCFM program [14]. The variations in the acceptance are found to be 1.5% for the $q\overline{q} \rightarrow W^+W^-$ process and to be negligible for the $q\overline{q} \rightarrow ZZ$ and $gg \rightarrow ZZ$ processes.

The W^+W^- jet veto efficiencies in data are estimated from simulation, and multiplied by a data-to-simulation scale factor derived from $Z/\gamma^* \rightarrow \ell^+\ell^-$ events in the Z peak: $\epsilon^{data}_{W^+W^-} = \epsilon^{MC}_{W^+W^-} \times \epsilon^{data}_{Z}/\epsilon^{MC}_{Z}$. The uncertainty is thus factorized into the uncertainty in the Z efficiency in data and the uncertainty in the ratio of the W^+W^- efficiency to the Z efficiency in simulation ($\epsilon^{MC}_{W^+W^-}/\epsilon^{MC}_{Z}$). The former, which is statistically dominated, is 0.3%. Theoretical uncertainties due to higher-order corrections contribute most to the W^+W^-/Z efficiency ratio uncertainty, which is estimated to be 4.6% for W^+W^- production. The data-to-simulation correction factor is found to be close to one and is not applied.

Simulated events are scaled according to the lepton efficiency correction factors measured using data control samples, which are typically close to one. The uncertainties in the measured identification and isolation efficiencies are found to be 1–2% for muons and electrons, and 6–7% for τ_h. The uncertainty in the trigger efficiency is 1.5%. The uncertainty in the lepton energy scale is about 3% for τ_h, and 1–2.5% and 1.5% for electrons and muons, respectively.

The uncertainties in the Z+jets, WZ+jets, and $t\bar{t}$ backgrounds to the $ZZ \rightarrow 2\ell 2\ell'$ selection are 30–50% depending on the decay channel. These uncertainties comprise the statistical and systematic uncertainties in the misidentication rates measured in data control samples.

The systematic uncertainties in the W+jets, Z+jets, and top backgrounds to the $W^+W^- \rightarrow \ell'\nu\ell''\nu$ selection are 36%, 24%, and 15%, respectively. The theoretical uncertainties in the WZ and ZZ cross sections are calculated following the same prescription as for the signal acceptance. Including the experimental uncertainties gives a systematic uncertainty in WZ and ZZ backgrounds of approximately 10%.

The uncertainty assigned to the pileup reweighting procedure amounts to 2.3%. The uncertainty in the integrated luminosity is 4.4% [41].

6 Results

6.1 W^+W^- cross section measurement

The observed and expected signal plus background yield is summarized in Table 1. The expected W^+W^- contribution is calculated assuming the SM cross section.

The total background yield is 275 ± 35 events and the expected signal and background yield is 959 ± 60 events, with 1111 events observed.

The measured W^+W^- yield is calculated by subtracting the estimated contributions of the various background processes. The product of the signal efficiency and acceptance averaged over all lepton flavors including τ leptons is $(3.2 \pm 0.2)\%$. Using the $W \rightarrow \ell\nu$ branching ratio of 0.1080 ± 0.0009 from Ref. [42], the W^+W^- production cross section in pp collision data at $\sqrt{s} = 8\,\text{TeV}$ is measured to be

$$\sigma(pp \rightarrow W^+W^-) = 69.9 \pm 2.8\,(\text{stat.}) \pm 5.6\,(\text{syst.}) \pm 3.1\,(\text{lum.})\,\text{pb}.$$

The statistical uncertainty reflects the total number of observed events. The systematic uncertainty includes both the statistical and systematic uncertainties in the background prediction, as well as the uncertainty in the signal efficiency. This measurement is slightly higher than the

Table 1: Expected and observed event yields for the W^+W^- selection. The uncertainties correspond to the statistical and systematic uncertainties added in quadrature.

Channel	$\ell'\nu\ell''\nu$
W^+W^-	684 ± 50
$t\bar{t}$ and tW	132 ± 23
W+jets	60 ± 22
WZ and ZZ	27 ± 3
Z/γ^*+jets	43 ± 12
$W\gamma^{(*)}$	14 ± 5
Total background	275 ± 35
Signal + background	959 ± 60
Data	1111

SM expectation of $57.3\,^{+2.3}_{-1.6}$ pb, calculated in Ref. [2] by using MCFM at NLO with the MSTW08 PDF and setting the factorization and renormalization scales to the W mass. Additional processes may increase the production yield in the W^+W^- final state by as much as 5% for the event selection used in this analysis. Higgs boson production would give an additional contribution of about 4% of the cross section given above, based on next-to-next-to-leading-order cross section calculations for the $H \to W^+W^-$ process [43] under the assumption that the newly discovered resonance [44, 45] is a SM-like Higgs boson with a mass of 125 GeV. Contributions from diffractive production [46], double parton scattering, and QED exclusive production [47] are also considered.

The distributions of the leading lepton transverse momentum p_T^{max}, the trailing lepton transverse momentum p_T^{min}, the dilepton transverse momentum $p_T^{\ell\ell}$, and the dilepton invariant mass $m_{\ell\ell}$ are shown in Fig. 1, where the W^+W^- contribution is normalized to the measured cross section.

6.2 ZZ cross section measurement

Table 2 presents the observed and expected yields and the number of the estimated background events in the signal region. There are 71 candidates observed in the $4e, 4\mu$, and $2e2\mu$ channels, to be compared to an expectation of 65.6 ± 4.4 events. Among the expected events 1.4 are from background processes. In the $2\ell 2\tau$ channels 13 candidates are observed. The expected 12.1 ± 1.6 events for $2\ell 2\tau$ channels contain 5.6 events from background processes. The reconstructed four-lepton invariant mass distributions are shown in Figs. 2(a) and (b) for the sum of the $4e, 4\mu$, and $2e2\mu$ channels, and the sum of all the $2\ell 2\tau$ channels. Data are compared to the SM expectations. The shapes of the signal and the background are taken from the MC simulation, with each component normalized to the corresponding estimated value from Table 2. The reconstructed masses in $2\ell 2\tau$ states are shifted downwards with respect to the generated values by about 30% because of the undetected neutrinos in τ decays. Figures 2(c) and (d) demonstrate the relationship between reconstructed Z_1 and Z_2 masses.

To measure the ZZ cross section the numbers of observed events are unfolded in a combined likelihood fit. Each decay mode is treated as a separate channel giving eleven measurements to combine: $4e, 4\mu$, $2e2\mu$, and eight $2\ell 2\tau$ channels. The τ-lepton decay modes are treated separately; the methodology used for event reconstruction and selection ensures that the decay modes are mutually exclusive. The joint likelihood is a combination of the likelihoods for the individual channels, which include the signal and background hypotheses. The statistical and systematic uncertainties are introduced in the form of nuisance parameters via log-normal dis-

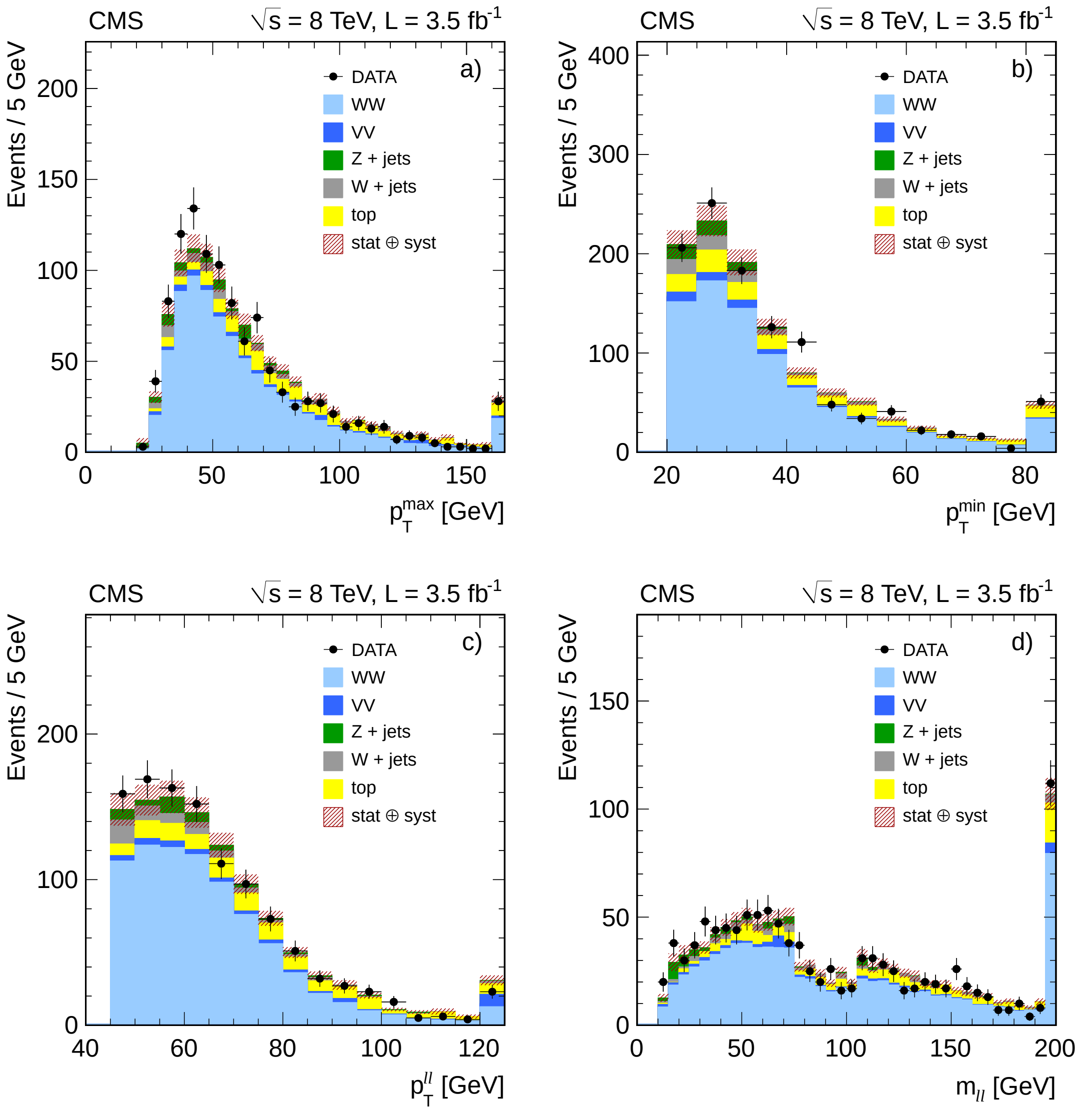

Figure 1: Distributions for W^+W^- candidate events of (a) the leading lepton transverse momentum p_T^{max}, (b) the trailing lepton transverse momentum p_T^{min}, (c) the dilepton transverse momentum $p_T^{\ell\ell}$, and (d) the dilepton invariant mass $m_{\ell\ell}$. Points represent the data, and shaded histograms represent the W^+W^- signal and the background processes. The last bin includes the overflow. The W^+W^- signal is scaled to the measured cross section, and the background processes are normalized to the corresponding estimated values in Table 1.

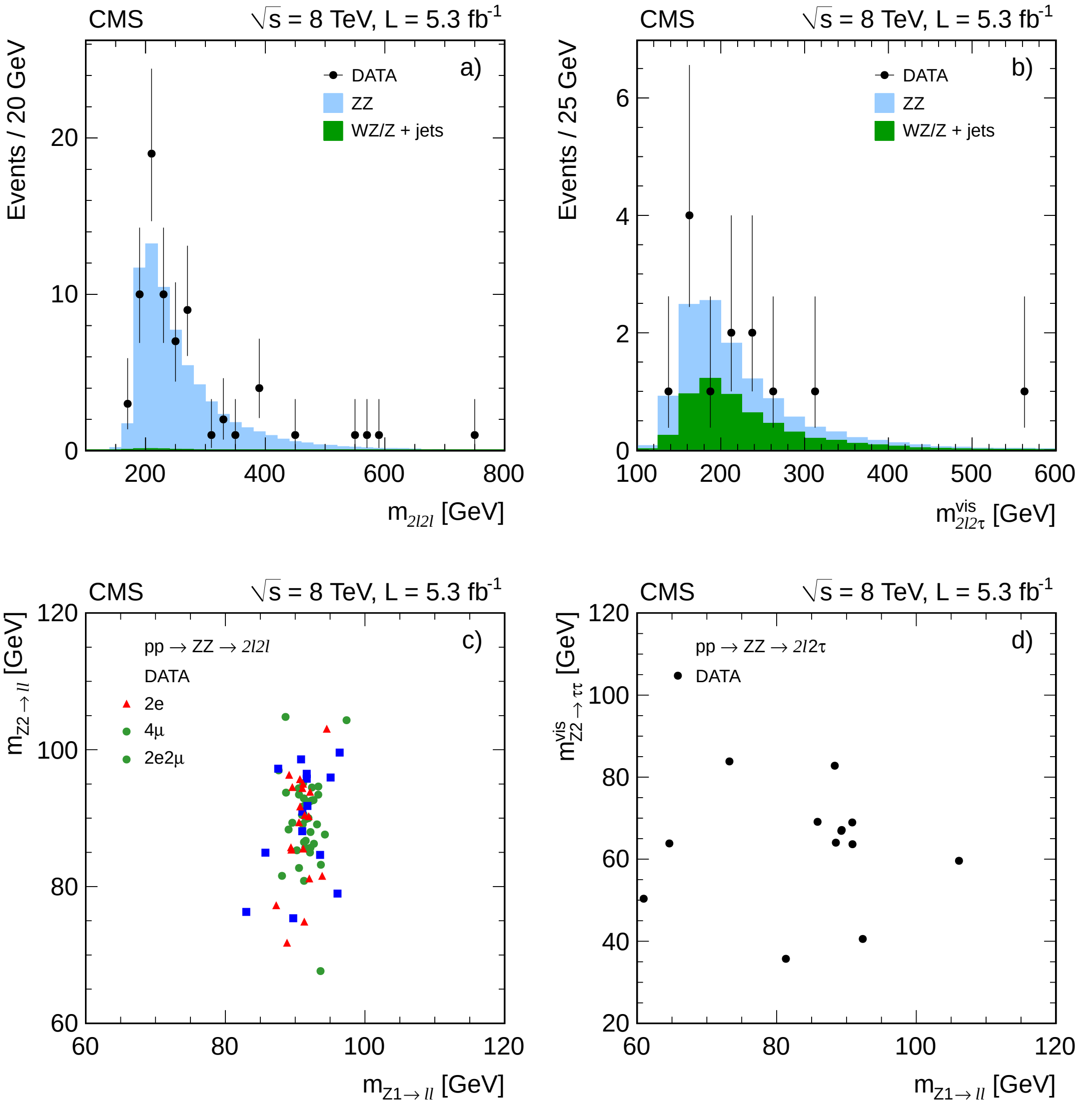

Figure 2: Distributions for ZZ candidate events of (a) the four-lepton reconstructed mass for the sum of the 4e, 4μ, and $2e2\mu$ channels and (b) the sum of the $2\ell2\tau$ channels. Points represent the data, and shaded histograms represent the expected ZZ signal and the reducible background. The shapes of the signal and background are taken from the MC simulation, with each component normalized to the corresponding estimated value from Table 2. The distributions (c) and (d) demonstrate the relationship between the reconstructed Z_1 and Z_2 masses. Different symbols are used to present different decay channels.

Table 2: Expected and observed event yields for the ZZ selection. The uncertainties correspond to the statistical and systematic uncertainties added in quadrature.

Channel	4e	4μ	$2e2\mu$	$2\ell 2\tau$
ZZ	11.6 ± 1.4	20.3 ± 2.2	32.4 ± 3.5	6.5 ± 0.8
Background	0.4 ± 0.2	0.4 ± 0.3	0.5 ± 0.4	5.6 ± 1.4
Signal+background	12.0 ± 1.4	20.7 ± 2.2	32.9 ± 3.5	12.1 ± 1.6
Data	14	19	38	13

tributions around the estimated central values. The resulting cross section is

$$\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 8.4 \pm 1.0\,(\mathrm{stat.}) \pm 0.7\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{lum.})\,\mathrm{pb}.$$

This is to be compared to the theoretical value of 7.7 ± 0.4 pb calculated with MCFM at NLO for $\mathrm{q\overline{q}} \to \mathrm{ZZ}$ and LO for $\mathrm{gg} \to \mathrm{ZZ}$ with MSTW08 PDF, and factorization and renormalization scales set to the Z mass, for both lepton pairs in the mass range $60 < m_{\mathrm{Z}} < 120$ GeV.

7 Summary

The $\mathrm{W^+W^-}$ and ZZ production cross sections have been measured in proton-proton collisions at $\sqrt{s} = 8$ TeV in the $\mathrm{W^+W^-} \to \ell'\nu\ell''\nu$ and $\mathrm{ZZ} \to 2\ell 2\ell'$ decay modes with $\ell = \mathrm{e}, \mu$ and $\ell'(\ell'') = \mathrm{e}, \mu, \tau$. The data samples correspond to an integrated luminosity of 3.5 $\mathrm{fb^{-1}}$ for the $\mathrm{W^+W^-}$ and 5.3 $\mathrm{fb^{-1}}$ for the ZZ measurements. The measured production cross sections $\sigma(\mathrm{pp} \to \mathrm{W^+W^-}) = 69.9 \pm 2.8\,(\mathrm{stat.}) \pm 5.6\,(\mathrm{syst.}) \pm 3.1\,(\mathrm{lum.})$ pb and $\sigma(\mathrm{pp} \to \mathrm{ZZ}) = 8.4 \pm 1.0\,(\mathrm{stat.}) \pm 0.7\,(\mathrm{syst.}) \pm 0.4\,(\mathrm{lum.})$ pb, for both Z bosons produced in the mass region $60 < m_{\mathrm{Z}} < 120$ GeV, are consistent with the standard model predictions. This is the first measurement of the diboson production cross sections at $\sqrt{s} = 8$ TeV.

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 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: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MEYS (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThEPCenter, IPST and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

References

[1] CMS Collaboration, "Measurement of W^+W^- production and search for the Higgs boson in pp collisions at $\sqrt{s} = 7$ TeV", *Phys. Lett. B* **699** (2011) 25, doi:10.1016/j.physletb.2011.03.056, arXiv:1102.5429.

[2] 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, arXiv:1105.0020.

[3] ATLAS Collaboration, "Measurement of W^+W^- production in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector and limits on anomalous WWZ and WWγ couplings", (2012). arXiv:1210.2979.

[4] CMS Collaboration, "Measurement of the ZZ production cross section and search for anomalous couplings in $2\ell 2\ell'$ final states in pp collisions at $\sqrt{s} = 7$ TeV ", (2012). arXiv:1211.4890.

[5] ATLAS Collaboration, "Measurement of ZZ production in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous ZZZ and ZZγ couplings with the ATLAS detector", (2012). arXiv:1211.6096.

[6] CDF Collaboration, "Measurement of ZZ production in leptonic final states at $\sqrt{s}$ of 1.96 TeV at CDF", *Phys. Rev. Lett.* **108** (2012) 101801, doi:10.1103/PhysRevLett.108.101801, arXiv:1112.2978.

[7] D0 Collaboration, "Measurement of the ZZ production cross section in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. D* **84** (2011) 011103, doi:10.1103/PhysRevD.84.011103, arXiv:1104.3078.

[8] CDF Collaboration, "Measurement of the W^+W^- Production Cross Section and Search for Anomalous WWγ and WWZ Couplings in $p\overline{p}$ Collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. Lett.* **104** (2010) 201801, doi:10.1103/PhysRevLett.104.201801, arXiv:0912.4500.

[9] D0 Collaboration, "Measurements of W^+W^- and WZ production in W + jets final states in $p\overline{p}$ collisions", *Phys. Rev. Lett.* **108** (2012) 181803, doi:10.1103/PhysRevLett.108.181803, arXiv:1112.0536.

[10] D0 Collaboration, "Measurement of the W^+W^- production cross section with dilepton final states in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV and limits on anomalous trilinear gauge couplings", *Phys. Rev. Lett.* **103** (2009) 191801, doi:10.1103/PhysRevLett.103.191801, arXiv:0904.0673.

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

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

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

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

[15] T. Binoth et al., "Gluon-induced W-boson pair production at the LHC", *JHEP* **12** (2006) 046, doi:10.1088/1126-6708/2006/12/046.

[16] S. Alioli et al., "NLO vector-boson production matched with shower in POWHEG", *JHEP* **07** (2008) 060, doi:10.1088/1126-6708/2008/07/060, arXiv:0805.4802.

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

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

[19] T. Binoth, N. Kauer, and P. Mertsch, "Gluon-induced QCD corrections to $pp \to ZZ \to \ell\bar{\ell}\ell'\bar{\ell}'$", (2008). arXiv:0807.0024.

[20] 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.

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

[22] S. Jadach et al., "The tau decay library TAUOLA: Version 2.4", *Comput. Phys. Commun.* **76** (1993) 361, doi:10.1016/0010-4655(93)90061-G.

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

[24] S. Baffioni et al., "Electron reconstruction in CMS", *Eur. Phys. J. C* **49** (2007) 1099, doi:10.1140/epjc/s10052-006-0175-5.

[25] CMS Collaboration, "Electron Reconstruction and Identification at $\sqrt{s} = 7$ TeV", CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).

[26] 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, arXiv:1206.4071.

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

[28] CMS Collaboration, "Performance of τ-lepton reconstruction and identification in CMS", *JINST* **7** (2012) P01001, doi:10.1088/1748-0221/7/01/P01001.

[29] 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, arXiv:0707.1378.

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

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

[32] M. Cacciari and G. P. Salam, “Dispelling the N^3 myth for the k_t jet-finder”, *Phys. Lett. B* **641** (2006) 57, doi:10.1016/j.physletb.2006.08.037, arXiv:hep-ph/0512210.

[33] 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.

[34] CMS Collaboration, “Identification of b-quark jets with the CMS experiment”, (2012). arXiv:1211.4462. Submitted to *JINST*.

[35] CMS Collaboration, “Search for the standard model Higgs boson decaying to a W pair in the fully leptonic final state in pp collisions at $\sqrt{s} = 7$ TeV”, *Phys. Lett. B* **710** (2012) 91, doi:10.1016/j.physletb.2012.02.076, arXiv:1202.1489.

[36] R. C. Gray et al., “Backgrounds To Higgs Boson Searches from Asymmetric Internal Conversion”, (2011). arXiv:1110.1368.

[37] CMS Collaboration, “Measurement of the inclusive Z cross section via decays to tau pairs in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* **08** (2011) 117, doi:10.1007/JHEP08(2011)117.

[38] M. Botje et al., “The PDF4LHC Working Group Interim Recommendations”, (2011). arXiv:1101.0538.

[39] A. D. Martin et al., “Parton distributions for the LHC”, *Eur. Phys. J. C* **63** (2009) 189, doi:10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002.

[40] D. R. Ball et al., “Impact of Heavy Quark Masses on Parton Distributions and LHC Phenomenology”, *Nucl. Phys. B* **849** (2011) 296, doi:10.1016/j.nuclphysb.2011.03.021, arXiv:1101.1300.

[41] CMS Collaboration, “CMS Luminosity Based on Pixel Cluster Counting - Summer 2012 Update”, CMS Physics Analysis Summary CMS-PAS-LUM-12-001, (2011).

[42] Particle Data Group, J. Beringer et al., “Review of Particle Physics”, *Phys. Rev. D* **86** (2012) 010001, doi:10.1103/PhysRevD.86.010001.

[43] LHC Higgs Cross Section Working Group, S. Dittmaier et al., “Handbook of LHC Higgs Cross Sections: Inclusive Observables”, (2011). arXiv:1101.0593.

[44] CMS Collaboration, “Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC”, *Phys. Lett. B* **716** (2012) 30, doi:10.1016/j.physletb.2012.08.021, arXiv:1207.7235.

[45] ATLAS Collaboration, “Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC”, *Phys. Lett. B* **716** (2012) 1, doi:10.1016/j.physletb.2012.08.020, arXiv:1207.7214.

[46] P. Bruni and G. Ingelman, “Diffractive hard scattering at ep and $p\overline{p}$ colliders”, in *Int. Europhysics Conference on High Energy Physics*, p. 595. Marseilles, France, 1993. Conf. Proc. C 722.

[47] A. Pukhov, “CalcHEP 2.3: MSSM, structure functions, event generation, batchs, and generation of matrix elements for other packages”, (2004). arXiv:hep-ph/0412191.

A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia
S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria
W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan[1], M. Friedl, R. Frühwirth[1], V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer, V. Knünz, M. Krammer[1], I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], D. Rabady[2], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, C.-E. Wulz[1]

National Centre for Particle and High Energy Physics, Minsk, Belarus
V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium
S. Alderweireldt, M. Bansal, S. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium
F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium
B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, T. Reis, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium
V. Adler, K. Beernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[3], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, M. Selvaggi, J.M. Vizan Garcia

Université de Mons, Mons, Belgium
N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil
G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
W.L. Aldá Júnior, W. Carvalho, J. Chinellato[4], A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, L. Soares Jorge, A. Sznajder, E.J. Tonelli Manganote[4], A. Vilela Pereira

Universidade Estadual Paulista [a], Universidade Federal do ABC [b], São Paulo, Brazil
T.S. Anjos[b], C.A. Bernardes[b], F.A. Dias[a,5], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], C. Lagana[a], F. Marinho[a], P.G. Mercadante[b], S.F. Novaes[a], Sandra S. Padula[a]

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
V. Genchev[2], P. Iaydjiev[2], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria
A. Dimitrov, R. Hadjiiska, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China
J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China
C. Asawatangtrakuldee, Y. Ban, Y. Guo, Q. Li, W. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, L. Zhang, W. Zou

Universidad de Los Andes, Bogota, Colombia
C. Avila, C.A. Carrillo Montoya, J.P. Gomez, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[6], D. Polic, I. Puljak

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

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

University of Cyprus, Nicosia, Cyprus
A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

Charles University, Prague, Czech Republic
M. Finger, M. Finger Jr.

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt
Y. Assran[7], S. Elgammal[8], A. Ellithi Kamel[9], A.M. Kuotb Awad[10], M.A. Mahmoud[10], A. Radi[11,12]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Kortelainen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, D. Ungaro, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland
A. Korpela, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France
M. Besancon, S. Choudhury, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[13], P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenauer,

P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
J.-L. Agram[14], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte[14], F. Drouhin[14], J.-C. Fontaine[14], D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici[2], D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[15]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[16]

RWTH Aachen University, III. Physikalisches Institut A, Aachen, Germany
M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, K. Padeken, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, S. Thüer, M. Weber

RWTH Aachen University, III. Physikalisches Institut B, Aachen, Germany
M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann[2], A. Nowack, I.M. Nugent, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[17], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, T. Dorland, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, W. Lohmann[17], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova, F. Nowak, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[17], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany
V. Blobel, H. Enderle, J. Erfle, U. Gebbert, M. Görner, M. Gosselink, J. Haller, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille[18], V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, C. Baus, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff[2], C. Hackstein, F. Hartmann[2], T. Hauth[2], M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov[16], J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, A. Markou, C. Markou, E. Ntomari

University of Athens, Athens, Greece
L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou

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

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath[19], F. Sikler, V. Veszpremi, G. Vesztergombi[20], A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary
N. Beni, S. Czellar, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary
J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India
S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, M. Mittal, N. Nishu, L.K. Saini, A. Sharma, J.B. Singh

University of Delhi, Delhi, India
Ashok Kumar, Arun Kumar, S. Ahuja, A. Bhardwaj, B.C. Choudhary, S. Malhotra, M. Naimuddin, K. Ranjan, P. Saxena, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India
S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India
A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty[2], L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, R.M. Chatterjee, S. Ganguly, M. Guchait[21], A. Gurtu[22], M. Maity[23], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India
S. Banerjee, S. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei[24], H. Bakhshiansohi, S.M. Etesami[25], A. Fahim[24], M. Hashemi[26], H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[27], M. Zeinali

INFN Sezione di Bari [a], Università di Bari [b], Politecnico di Bari [c], Bari, Italy
M. Abbrescia[a,b], L. Barbone[a,b], C. Calabria[a,b,2], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De

Filippis[a,c,2], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], G. Maggi[a,c], M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a], A. Pompili[a,b], G. Pugliese[a,c], G. Selvaggi[a,b], L. Silvestris[a], G. Singh[a,b], R. Venditti[a,b], P. Verwilligen[a], G. Zito[a]

INFN Sezione di Bologna [a], Università di Bologna [b], Bologna, Italy
G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], 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], M. Meneghelli[a,b,2], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], T. Rovelli[a,b], G.P. Siroli[a,b], N. Tosi, R. Travaglini[a,b]

INFN Sezione di Catania [a], Università di Catania [b], Catania, Italy
S. Albergo[a,b], G. Cappello[a,b], M. Chiorboli[a,b], S. Costa[a,b], R. Potenza[a,b], A. Tricomi[a,b], C. Tuve[a,b]

INFN Sezione di Firenze [a], Università di Firenze [b], Firenze, Italy
G. Barbagli[a], V. Ciulli[a,b], C. Civinini[a], R. D'Alessandro[a,b], E. Focardi[a,b], S. Frosali[a,b], E. Gallo[a], S. Gonzi[a,b], M. Meschini[a], S. Paoletti[a], G. Sguazzoni[a], A. Tropiano[a,b]

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Colafranceschi[28], F. Fabbri, D. Piccolo

INFN Sezione di Genova [a], Università di Genova [b], Genova, Italy
P. Fabbricatore[a], R. Musenich[a], S. Tosi[a,b]

INFN Sezione di Milano-Bicocca [a], Università di Milano-Bicocca [b], Milano, Italy
A. Benaglia[a], F. De Guio[a,b], L. Di Matteo[a,b,2], S. Fiorendi[a,b], S. Gennai[a,2], A. Ghezzi[a,b], M.T. Lucchini[2], S. Malvezzi[a], R.A. Manzoni[a,b], A. Martelli[a,b], A. Massironi[a,b], D. Menasce[a], L. Moroni[a], M. Paganoni[a,b], D. Pedrini[a], S. Ragazzi[a,b], N. Redaelli[a], T. Tabarelli de Fatis[a,b]

INFN Sezione di Napoli [a], Università di Napoli 'Federico II' [b], Università della Basilicata (Potenza) [c], Università G. Marconi (Roma) [d], Napoli, Italy
S. Buontempo[a], N. Cavallo[a,c], A. De Cosa[a,b,2], O. Dogangun[a,b], F. Fabozzi[a,c], A.O.M. Iorio[a,b], L. Lista[a], S. Meola[a,d,2], M. Merola[a], P. Paolucci[a,2]

INFN Sezione di Padova [a], Università di Padova [b], Università di Trento (Trento) [c], Padova, Italy
P. Azzi[a], N. Bacchetta[a,2], D. Bisello[a,b], A. Branca[a,b,2], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], M. Galanti[a,b], F. Gasparini[a,b], U. Gasparini[a,b], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a], I. Lazzizzera[a,c], 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. Tosi[a,b], S. Vanini[a,b], P. Zotto[a,b], A. Zucchetta[a,b], G. Zumerle[a,b]

INFN Sezione di Pavia [a], Università di Pavia [b], Pavia, Italy
M. Gabusi[a,b], S.P. Ratti[a,b], C. Riccardi[a,b], P. Torre[a,b], P. Vitulo[a,b]

INFN Sezione di Perugia [a], Università di Perugia [b], Perugia, Italy
M. Biasini[a,b], G.M. Bilei[a], L. Fanò[a,b], P. Lariccia[a,b], G. Mantovani[a,b], M. Menichelli[a], A. Nappi[a,b†], F. Romeo[a,b], A. Saha[a], A. Santocchia[a,b], A. Spiezia[a,b], S. Taroni[a,b]

INFN Sezione di Pisa [a], Università di Pisa [b], Scuola Normale Superiore di Pisa [c], Pisa, Italy
P. Azzurri[a,c], G. Bagliesi[a], J. Bernardini[a], T. Boccali[a], G. Broccolo[a,c], R. Castaldi[a], R.T. D'Agnolo[a,c,2], R. Dell'Orso[a], F. Fiori[a,b,2], L. Foà[a,c], A. Giassi[a], A. Kraan[a], F. Ligabue[a,c], T. Lomtadze[a], L. Martini[a,29], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], A.T. Serban[a,30], P. Spagnolo[a], P. Squillacioti[a,2], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a]

INFN Sezione di Roma [a], Università di Roma [b], Roma, Italy
L. Barone[a,b], F. Cavallari[a], D. Del Re[a,b], M. Diemoz[a], C. Fanelli[a,b], M. Grassi[a,b,2], E. Longo[a,b], P. Meridiani[a,2], F. Micheli[a,b], S. Nourbakhsh[a,b], G. Organtini[a,b], R. Paramatti[a], S. Rahatlou[a,b], L. Soffi[a,b]

INFN Sezione di Torino [a], Università di Torino [b], Università del Piemonte Orientale (Novara) [c], Torino, Italy
N. Amapane[a,b], R. Arcidiacono[a,c], S. Argiro[a,b], M. Arneodo[a,c], C. Biino[a], N. Cartiglia[a], S. Casasso[a,b], M. Costa[a,b], N. Demaria[a], C. Mariotti[a,2], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a,2], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], A. Solano[a,b], A. Staiano[a]

INFN Sezione di Trieste [a], Università di Trieste [b], Trieste, Italy
S. Belforte[a], V. Candelise[a,b], M. Casarsa[a], F. Cossutti[a,2], G. Della Ricca[a,b], B. Gobbo[a], M. Marone[a,b,2], D. Montanino[a,b], A. Penzo[a], A. Schizzi[a,b]

Kangwon National University, Chunchon, Korea
T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea
S. Chang, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, D.C. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
J.Y. Kim, Zero J. Kim, S. Song

Korea University, Seoul, Korea
S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, Y. Roh

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

Sungkyunkwan University, Suwon, Korea
Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, E. Kwon, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania
M.J. Bilinskas, I. Grigelionis, M. Janulis, A. Juodagalvis

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico
H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, J. Martínez-Ortega, A. Sanchez-Hernandez, L.M. Villasenor-Cendejas

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

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico
H.A. Salazar Ibarguen

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico
E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

University of Auckland, Auckland, New Zealand
D. Krofcheck

University of Canterbury, Christchurch, New Zealand
A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan
M. Ahmad, M.I. Asghar, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Warsaw, Poland
G. Brona, K. Bunkowski, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, W. Wolszczak

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Seixas[2], J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
I. Belotelov, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

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

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

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, I. Shreyber, V. Stolin, E. Vlasov, A. Zhokin

P.N. Lebedev Physical Institute, Moscow, Russia
V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, M. Dubinin[5], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, A. Popov, L. Sarycheva[†], V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[2], V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic[31], M. Djordjevic, M. Ekmedzic, D. Krpic[31], J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo

Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain
C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad de Oviedo, Oviedo, Spain
H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

Instituto de Física de Cantabria (IFCA), CSIC-Universidad de Cantabria, Santander, Spain
J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[32], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland
D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J. Bendavid, J.F. Benitez, C. Bernet[6], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. d'Enterria, A. Dabrowski, A. De Roeck, S. De Visscher, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M. Mulders, P. Musella, E. Nesvold, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[33], C. Rovelli[34], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[35], D. Spiga, A. Tsirou, G.I. Veres[20], J.R. Vlimant, H.K. Wöhri, S.D. Worm[36], W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland
W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland
F. Bachmair, L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[37], P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov[38], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Universität Zürich, Zurich, Switzerland
C. Amsler[39], V. Chiochia, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan

M. Cardaci, Y.H. Chang, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, A.P. Singh, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan
P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, X. Wan, M. Wang

Chulalongkorn University, Bangkok, Thailand
B. Asavapibhop, E. Simili, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[40], S. Cerci[41], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar[42], A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[43], A. Polatoz, K. Sogut[44], D. Sunar Cerci[41], B. Tali[41], H. Topakli[40], M. Vergili

Middle East Technical University, Physics Department, Ankara, Turkey
I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, B. Isildak[45], M. Kaya[46], O. Kaya[46], S. Ozkorucuklu[47], N. Sonmez[48]

Istanbul Technical University, Istanbul, Turkey
H. Bahtiyar[49], E. Barlas, K. Cankocak, Y.O. Günaydin[50], F.I. Vardarlı, M. Yücel

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

University of Bristol, Bristol, United Kingdom
J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[36], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[51], K.W. Bell, A. Belyaev[51], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom
R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[38], J. Pela, M. Pesaresi, K. Petridis, M. Pioppi[52], D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

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

Baylor University, Waco, USA
K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA
O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, USA
A. Avetisyan, T. Bose, C. Fantasia, A. Heister, P. Lawson, D. Lazic, J. Rohlf, D. Sperka, J. St. John, L. Sulak

Brown University, Providence, USA
J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer

University of California, Davis, Davis, USA
R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, M. Caulfield, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, R. Yohay

University of California, Los Angeles, USA
V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, G. Rakness, P. Schlein[†], P. Traczyk, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA
J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA
W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[53], F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA
D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA
A. Apresyan, A. Bornheim, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA
J.P. Cumalat, B.R. Drell, W.T. Ford, A. Gaz, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, B. Heltsley, W. Hopkins, A. Khukhunaishvili, B. Kreis, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Ryd, E. Salvati, W. Sun, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA
D. Winn

Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos[54], J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[55], C. Newman-Holmes, V. O'Dell, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

University of Florida, Gainesville, USA
D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[56], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA
V. Gaultney, S. Hewamanage, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, USA
T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA
M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopiyanov, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, C. O'Brien, C. Silkworth, D. Strom, P. Turner, N. Varelas

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki[57], W. Clarida, K. Dilsiz, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya[58], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, H. Ogul, Y. Onel, F. Ozok[49], S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA
B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA
P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood

Kansas State University, Manhattan, USA
A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Lawrence Livermore National Laboratory, Livermore, USA
J. Gronberg, D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, USA
A. Baden, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, USA
A. Apyan, G. Bauer, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, Y. Kim, M. Klute, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

University of Minnesota, Minneapolis, USA
B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, USA
L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders

University of Nebraska-Lincoln, Lincoln, USA
E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, M. Eads, J. Keller, I. Kravchenko, J. Lazo-Flores, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA
A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio, Z. Wan

Northeastern University, Boston, USA
G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA
A. Anastassov, K.A. Hahn, A. Kubik, L. Lusito, N. Mucia, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

University of Notre Dame, Notre Dame, USA
D. Berry, A. Brinkerhoff, K.M. Chan, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, M. Planer, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

The Ohio State University, Columbus, USA
L. Antonelli, B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, G. Smith, C. Vuosalo, G. Williams, B.L. Winer

Princeton University, Princeton, USA
E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

University of Puerto Rico, Mayaguez, USA
E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

Purdue University, West Lafayette, USA
E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA
S. Guragain, N. Parashar

Rice University, Houston, USA
A. Adair, B. Akgun, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

University of Rochester, Rochester, USA
B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA
A. Bhatti, R. Ciesielski, L. Demortier, K. Goulianos, G. Lungu, S. Malik, C. Mesropian

Rutgers, the State University of New Jersey, Piscataway, USA
S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, M. Walker

University of Tennessee, Knoxville, USA
G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

Texas A&M University, College Station, USA
R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[59], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, USA
E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, P. Kurt, C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

Wayne State University, Detroit, USA
S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, A. Sakharov

University of Wisconsin, Madison, USA
M. Anderson, D.A. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, E. Friis, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, R. Loveless, A. Mohapatra, M.U. Mozer, I. Ojalvo, F. Palmonari, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased
1: Also at Vienna University of Technology, Vienna, Austria
2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
3: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
4: Also at Universidade Estadual de Campinas, Campinas, Brazil

5: Also at California Institute of Technology, Pasadena, USA
6: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
7: Also at Suez Canal University, Suez, Egypt
8: Also at Zewail City of Science and Technology, Zewail, Egypt
9: Also at Cairo University, Cairo, Egypt
10: Also at Fayoum University, El-Fayoum, Egypt
11: Also at British University in Egypt, Cairo, Egypt
12: Now at Ain Shams University, Cairo, Egypt
13: Also at National Centre for Nuclear Research, Swierk, Poland
14: Also at Université de Haute Alsace, Mulhouse, France
15: Also at Joint Institute for Nuclear Research, Dubna, Russia
16: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
17: Also at Brandenburg University of Technology, Cottbus, Germany
18: Also at The University of Kansas, Lawrence, USA
19: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
20: Also at Eötvös Loránd University, Budapest, Hungary
21: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
22: Now at King Abdulaziz University, Jeddah, Saudi Arabia
23: Also at University of Visva-Bharati, Santiniketan, India
24: Also at Sharif University of Technology, Tehran, Iran
25: Also at Isfahan University of Technology, Isfahan, Iran
26: Also at Shiraz University, Shiraz, Iran
27: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
28: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
29: Also at Università degli Studi di Siena, Siena, Italy
30: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
31: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
32: Also at University of California, Los Angeles, USA
33: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
34: Also at INFN Sezione di Roma, Roma, Italy
35: Also at University of Athens, Athens, Greece
36: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
37: Also at Paul Scherrer Institut, Villigen, Switzerland
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
40: Also at Gaziosmanpasa University, Tokat, Turkey
41: Also at Adiyaman University, Adiyaman, Turkey
42: Also at Izmir Institute of Technology, Izmir, Turkey
43: Also at The University of Iowa, Iowa City, USA
44: Also at Mersin University, Mersin, Turkey
45: Also at Ozyegin University, Istanbul, Turkey
46: Also at Kafkas University, Kars, Turkey
47: Also at Suleyman Demirel University, Isparta, Turkey
48: Also at Ege University, Izmir, Turkey
49: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
50: Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey
51: Also at School of Physics and Astronomy, University of Southampton, Southampton,

United Kingdom
52: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
53: Also at Utah Valley University, Orem, USA
54: Now at University of Edinburgh, Scotland, Edinburgh, United Kingdom
55: Also at Institute for Nuclear Research, Moscow, Russia
56: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
57: Also at Argonne National Laboratory, Argonne, USA
58: Also at Erzincan University, Erzincan, Turkey
59: Also at Kyungpook National University, Daegu, Korea