Eur. Phys. J. C (2013) 73:2610
DOI 10.1140/epjc/s10052-013-2610-8

THE EUROPEAN
PHYSICAL JOURNAL C

Letter

Measurement of the W^+W^- cross section in pp collisions at $\sqrt{s} = 7$ TeV and limits on anomalous WWγ and WWZ couplings

The CMS Collaboration *
CERN, Geneva, Switzerland

Received: 5 June 2013 / Revised: 20 September 2013 / Published online: 26 October 2013

Abstract A measurement of W^+W^- production in pp collisions at $\sqrt{s} = 7$ TeV is presented. The data were collected with the CMS detector at the LHC, and correspond to an integrated luminosity of 4.92 ± 0.11 fb^{-1}. The W^+W^- candidates consist of two oppositely charged leptons, electrons or muons, accompanied by large missing transverse energy. The W^+W^- production cross section is measured to be 52.4 ± 2.0 (stat.) $\pm$ 4.5 (syst.) $\pm$ 1.2 (lum.) pb. This measurement is consistent with the standard model prediction of 47.0 ± 2.0 pb at next-to-leading order. Stringent limits on the WWγ and WWZ anomalous triple gauge-boson couplings are set.

1 Introduction

The standard model (SM) description of electroweak and strong interactions can be tested through measurements of the W^+W^- production cross section at a hadron collider. The s-channel and t-channel $q\overline{q}$ annihilation diagrams, shown in Fig. 1, correspond to the dominant process in the SM, at present energies. The gluon–gluon diagrams, which contain a loop at lowest order, contribute only 3 % of the total cross section [1] at $\sqrt{s} = 7$ TeV. WWγ and WWZ triple gauge-boson couplings (TGCs) [2], responsible for s-channel W^+W^- production, are sensitive to possible new physics processes at a higher mass scale. Anomalous values of the TGCs would change the W^+W^- production rate and potentially certain kinematic distributions from the SM prediction. Aside from tests of the SM, W^+W^- production represents an important background source for new particle searches, e.g. for Higgs boson searches [3–5]. Next-to-leading-order (NLO) calculations of W^+W^- production in pp collisions at $\sqrt{s} = 7$ TeV predict a cross section of $\sigma^{\mathrm{NLO}}(pp \to W^+W^-) = 47.0 \pm 2.0$ pb [1].

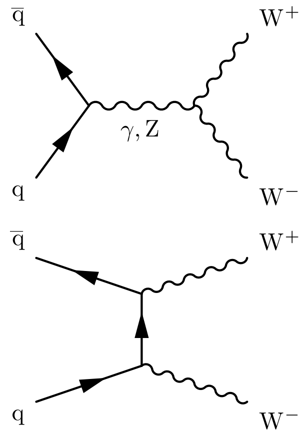

Fig. 1 Leading-order Feynman diagrams for $q\overline{q}$ annihilation, for s-channel (*top*) and t-channel (*bottom*) production of W pairs. The triple gauge-boson vertex corresponds to the WWγ(Z) interaction in the first diagram

This paper reports a measurement of the W^+W^- cross section in the $W^+W^- \to \ell^+\nu\ell^-\overline{\nu}$ final state in pp collisions at $\sqrt{s} = 7$ TeV and constraints on anomalous triple gauge-boson couplings. The measurement is performed with the Compact Muon Solenoid (CMS) detector at the Large Hadron Collider (LHC) using the full 2011 data sample, corresponding to an integrated luminosity of 4.92 ± 0.11 fb^{-1}, more than two orders of magnitude larger than data used in the first measurements with the CMS [6] and ATLAS [7] experiments at the LHC, and comparable in size to the data sets more recently analyzed by ATLAS [8, 9].

2 The CMS detector and simulations

The CMS detector is described in detail elsewhere [10] so only the key components for this analysis are summarised here. 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. A silicon pixel and strip tracker, a crystal electromagnetic calorimeter, and a brass/scintillator hadron calorimeter are located within the

---

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

solenoid. A quartz-fiber Cherenkov calorimeter extends the coverage to $|\eta| < 5.0$, where pseudorapidity is defined as $\eta = -\ln[\tan(\theta/2)]$, and θ is the polar angle of the particle trajectory with respect to the anticlockwise-beam direction. Muons are measured in gas-ionisation detectors embedded in the steel magnetic-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 further decreases the rate of stored events to a few hundred hertz for subsequent analysis.

This measurement exploits W^+W^- pairs in which both bosons decay leptonically, yielding an experimental signature of two isolated, high transverse momentum (p_T), oppositely charged leptons (electrons or muons) and large missing transverse energy (E_T^{miss}) due to the undetected neutrinos. The E_T^{miss} is defined as the modulus of the vectorial sum of the transverse momenta of all reconstructed particles, charged and neutral, in the event. This variable, together with the full event selection, is explained in detail in Sect. 3.

Several SM processes constitute backgrounds for the W^+W^- sample. These include W + jets and quantum chromodynamics (QCD) multijet events where at least one of the jets is misidentified as a lepton, top-quark production ($t\bar{t}$ and tW), Drell–Yan $Z/\gamma^* \to \ell^+\ell^-$, and diboson production ($W\gamma^{(*)}$, WZ, and ZZ) processes.

A number of Monte Carlo (MC) event generators are used to simulate the signal and backgrounds. The $q\bar{q} \to W^+W^-$ signal, W + jets, WZ, and $W\gamma^{(*)}$ processes are generated using the MADGRAPH 5.1.3 [11] event generator. The $gg \to W^+W^-$ signal component is simulated using GG2WW [12]. The POWHEG 2.0 program [13] provides event samples for the Drell–Yan, $t\bar{t}$, and tW processes. The remaining background processes are simulated using PYTHIA 6.424 [14].

The default set of parton distribution functions (PDFs) used to produce the LO MC samples is CTEQ6L [15], while CT10 [16] is used for NLO generators. The NLO calculations are used for background cross sections. For all processes, the detector response is simulated using a detailed description of the CMS detector, based on the GEANT4 package [17].

The simulated samples include the effects of multiple pp interactions in each beam crossing (pileup), and are reweighted to match the pileup distribution as measured in data.

3 Event selection

This measurement considers signal candidates in three final states: e^+e^-, $\mu^+\mu^-$, and $e^\pm\mu^\mp$. The $W \to \ell\nu_\ell$ ($\ell = e$ or μ) decays are the main signal components; $W \to \tau\nu_\tau$ events with leptonic τ decays are included, although the analysis is not optimised for this final state. The trigger requires the presence of one or two high-p_T electrons or muons. For single lepton triggers the p_T threshold for the selection is 27 (15) GeV for electrons (muons). For double lepton triggers, the p_T thresholds, for pairs of leptons of the same flavour, are lowered to 18 and 8 GeV for the first and second electrons, respectively, and to 7 GeV for the each of the two muons. Different flavour lepton triggers are also used. The overall trigger efficiency for signal events is measured to be approximately 98 % using data.

Two oppositely charged lepton candidates are required, both with $p_T > 20$ GeV. Electron candidates are selected using a multivariate approach that exploits correlations between the selection variables described in Ref. [18] to improve identification performance, while muon candidates [19] are identified using a selection close to that described in Ref. [6]. Charged leptons from W boson decays are expected to be isolated from any other activity in the event. The lepton candidates are required to be consistent with originating at the primary vertex of the event, which is chosen as the vertex with the highest $\sum p_T^2$ of its associated tracks. This criterion provides the correct assignment for the primary vertex in more than 99 % of events for the pileup distribution observed in the data. The efficiency is measured by checking how often a primary vertex with the highest $\sum p_T^2$ of the constituent tracks is consistent with the vertex formed by the two primary leptons. This is done in MC and checked in data.

The particle-flow (PF) technique [20] that combines the information from all CMS subdetectors to reconstruct each individual particle is used to calculate the isolation variable. For each lepton candidate, a cone around the lepton direction at the event vertex is reconstructed, defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where $\Delta\eta$ and $\Delta\phi$ are the distances from the lepton track in η and azimuthal angle, ϕ (in radians), respectively; ΔR takes a value of 0.4 (0.3) for electrons (muons). The scalar sum of the transverse momentum is calculated for the particles reconstructed with the PF algorithm that are contained within the cone, excluding the contribution from the lepton candidate itself. If this sum exceeds approximately 10 % of the candidate p_T, the lepton is rejected; the exact requirement depends on the lepton flavour and on η.

Jets are reconstructed from calorimeter and tracker information using the PF technique [21]. The anti-k_T clustering algorithm [22] with a distance parameter of 0.5, as implemented in the FASTJET package [23, 24], is used. To correct for the contribution to the jet energy from pileup, a median energy density ρ, or energy per area of jet, is determined event by event. The pileup contribution to the jet energy is estimated as the product of ρ and the area of the jet and subsequently subtracted [25] from the jet transverse energy E_T. Jet energy corrections are also applied as a function of the jet E_T and η [26]. To reduce the background from top-quark decays, a jet veto is applied: events with one or more jets with corrected $E_T > 30$ GeV and $|\eta| < 5.0$ are rejected.

To further suppress the top-quark background, two top-quark tagging techniques based on soft-muon and b-jet tagging [27, 28] are applied. The first method vetoes events containing muons from b-quark decays, which can be either low-p_T muons or nonisolated high-p_T muons. The second method uses information from tracks with large impact parameter within jets, and applies a veto on those with the b-jet tagging value above the selected veto threshold. The combined rejection efficiency for these tagging techniques, in the case of $t\bar{t}$ events, is about a factor of two, once the full event selection is applied.

The Drell–Yan background has a production cross section some orders of magnitude larger than the W^+W^- process. To eliminate Drell–Yan events, two different E_T^{miss} vectors are used [29]. The first is reconstructed using the particle-flow algorithm, while the second uses only the charged-particle candidates associated with the primary vertex and is therefore less sensitive to pileup. The *projected* E_T^{miss} is defined as the component of E_T^{miss} transverse to the direction of the nearest lepton, if it is closer than $\pi/2$ in azimuthal angle, and the full E_T^{miss} otherwise. A lower cut on this observable efficiently rejects $Z/\gamma^* \to \tau^+\tau^-$ background events, in which the E_T^{miss} is preferentially aligned with leptons, as well as $Z/\gamma^* \to \ell^+\ell^-$ events with mismeasured E_T^{miss} associated with poorly reconstructed leptons or jets. The minimum of the projections of the two E_T^{miss} vectors is used, exploiting the correlation between them in events with significant genuine E_T^{miss}, as in the signal, and the lack of correlation otherwise, as in Drell–Yan events. The requirement for this variable in the e^+e^- and $\mu^+\mu^-$ final states is *projected* $E_T^{miss} > (37 + N_{vtx}/2)$ GeV, which depends on the number of reconstructed primary vertices (N_{vtx}). In this way the dependence of the Drell–Yan background on pileup is minimised. For the $e^\pm\mu^\mp$ final state, which has smaller contamination from $Z/\gamma^* \to \ell^+\ell^-$ decays, the threshold is lowered to 20 GeV. These requirements remove more than 99 % of the Drell–Yan background, the actual number of accepted background events is obtained from the data, as explained below.

Remaining $Z/\gamma^* \to \ell^+\ell^-$ events in which the Z boson recoils against a jet are reduced by requiring the angle in the transverse plane between the dilepton system and the most energetic jet to be smaller than 165 degrees. This selection is applied only in the e^+e^- and $\mu^+\mu^-$ final states when the leading jet has $E_T > 15$ GeV.

To further reduce the Drell–Yan background in the e^+e^- and $\mu^+\mu^-$ final states, events with a dilepton mass within ±15 GeV of the Z mass are rejected. Events with dilepton masses below 20 GeV are also rejected to suppress contributions from low-mass resonances. The same requirement, where the threshold is lowered to 12 GeV, is also applied in the $e^\pm\mu^\mp$ final state. Finally, the transverse momentum of the dilepton system ($p_T^{\ell\ell}$) is required to be above 45 GeV to reduce both the Drell–Yan background and the contribution from misidentified leptons.

To reduce the background from other diboson processes, such as WZ or ZZ production, any event that has an additional third lepton with $p_T > 10$ GeV passing the identification and isolation requirements is rejected. $W\gamma^{(*)}$ background, in which the photon is misidentified as an electron, is suppressed by stringent γ conversion rejection requirements [18].

4 Estimation of backgrounds

A combination of techniques is used to determine the contributions from backgrounds that remain after the W^+W^- selection. The major contribution at this level comes from the top-quark processes, followed by the W + jets background.

The normalisation of the top-quark background is estimated from data by counting top-quark-tagged events, with the requirements explained in Sect. 3, and applying the corresponding tagging efficiency. The top-quark tagging efficiency ($\epsilon_{\text{top tagged}}$) is measured in a data sample, dominated by $t\bar{t}$ and tW events, that is selected from a phase space close to that for W^+W^- events, but instead requiring one jet with $E_T > 30$ GeV. The residual number of top-quark events ($N_{\text{not tagged}}$) in the signal sample is given by

$$N_{\text{not tagged}} = N_{\text{tagged}} \times (1 - \epsilon_{\text{top tagged}})/\epsilon_{\text{top tagged}},$$

where N_{tagged} is the number of tagged events. The total uncertainty on this background estimation is about 18 %. The main contribution comes from the statistical and systematic uncertainties related to the measurement of $\epsilon_{\text{top tagged}}$.

The W + jets and QCD multijet background with jets misidentified as leptons are estimated by counting the number of events containing one lepton that satisfies the nominal selection criteria and another lepton that satisfies relaxed requirements on impact parameter and isolation but not the nominal criteria. This sample, enriched in W + jets events, is extrapolated to the signal region using the efficiencies for such loosely identified leptons to pass the tight selection. These efficiencies are measured in data using multijet events and are parametrised as functions of the p_T and η of the lepton candidate. QCD backgrounds are found to be negligible. The systematic uncertainties stemming from this efficiency determination dominate the overall uncertainty, which is estimated to be about 36 %. The main contribution to this uncertainty comes from the differences in the p_T spectrum of the jets in the measurement data sample, composed mainly of QCD events, compared to the sample, primarily W + jets, from which the extrapolation is performed.

The residual Drell–Yan contribution to the e^+e^- and $\mu^+\mu^-$ final states outside of the Z boson mass window ($N_{\text{out}}^{\ell\ell,\text{exp}}$) is estimated by normalising the simulation to the observed number of events inside the Z boson mass window in data ($N_{\text{in}}^{\ell\ell}$). The contribution in this region from other processes where the two leptons do not come from a Z boson ($N_{\text{in}}^{\text{non-Z}}$) is subtracted before performing the normalisation. This contribution is estimated on the basis of the number of $e^\pm\mu^\mp$ data events within the Z boson mass window. The WZ and ZZ contributions in the Z mass window ($N_{\text{in}}^{\text{ZV}}$) are also subtracted, using simulation, when leptons come from the same Z boson as in the case of the Drell–Yan production. The residual background in the W^+W^- data outside the Z boson mass window is thus expressed as

$$N_{\text{out}}^{\ell\ell,\text{exp}} = R_{\text{out/in}}^{\ell\ell}\left(N_{\text{in}}^{\ell\ell} - N_{\text{in}}^{\text{non-Z}} - N_{\text{in}}^{\text{ZV}}\right),$$

with

$$R_{\text{out/in}}^{\ell\ell} = N_{\text{out}}^{\ell\ell,\text{MC}}/N_{\text{in}}^{\ell\ell,\text{MC}}.$$

The systematic uncertainty in the final Drell–Yan estimate is derived from the dependence of $R_{\text{out/in}}^{\ell\ell}$ on the value of the $E_{\text{T}}^{\text{miss}}$ requirement.

Finally, a control sample with three reconstructed leptons is defined to rescale the estimate, based on the simulation, of the background $W\gamma^*$ contribution coming from asymmetric γ^* decays, where one lepton escapes detection [30].

Other backgrounds are estimated from simulation. The $W\gamma$ background estimate is cross-checked in data using the events passing all the selection requirements except that the two leptons must have the same charge; this sample is dominated by W + jets and $W\gamma$ events. The $Z/\gamma^* \to \tau^+\tau^-$ contamination is also cross-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, and the results are consistent with the simulation. Other minor backgrounds are WZ and ZZ diboson production where the two selected leptons come from different bosons.

The estimated event yields for all processes after the event selection are summarised in Table 1. The distributions of the key analysis variables are shown in Fig. 2.

Table 1 Signal and background predictions, compared to the yield in data. The prediction for the W^+W^- process assumes the SM cross section value

Sample	Yield ± stat. ± syst.
$gg \to W^+W^-$	$46 \pm 1 \pm 14$
$q\bar{q} \to W^+W^-$	$751 \pm 4 \pm 53$
$t\bar{t} + tW$	$129 \pm 13 \pm 20$
W + jets	$60 \pm 4 \pm 21$
WZ + ZZ	$29.4 \pm 0.4 \pm 2.0$
$Z/\gamma^* \to e^+e^-/\mu^+\mu^-$	$11.0 \pm 5.1 \pm 2.6$
$W\gamma^{(*)}$	$18.8 \pm 2.8 \pm 4.7$
$Z/\gamma^* \to \tau^+\tau^-$	$0.0^{+1.0}_{-0.0}\,^{+0.1}_{-0.0}$
Total Background	$247 \pm 15 \pm 30$
Signal + Background	$1044 \pm 15 \pm 62$
Data	1134

5 Efficiencies and systematic uncertainties

The signal efficiency, which includes the acceptance of the detector, is estimated using simulation and including both the $q\bar{q} \to W^+W^-$ and $gg \to W^+W^-$ processes. Residual discrepancies in the lepton reconstruction and identification efficiencies between data and simulation are corrected by determining data-to-simulation scale factors measured using $Z/\gamma^* \to \ell^+\ell^-$ events in the Z peak region [31] that are recorded with unbiased triggers. These factors depend on the lepton p_{T} and $|\eta|$ and are within 4 % (2 %) of unity for electrons (muons). Effects due to $W \to \tau\nu_\tau$ decays with τ leptons decaying into lower-energy electrons or muons are included in the signal efficiency.

The experimental uncertainties in lepton reconstruction and identification efficiency, momentum scale and resolution, $E_{\text{T}}^{\text{miss}}$ modelling, and jet energy scale are applied to the reconstructed objects in simulated events by smearing and scaling the relevant observables and propagating the effects to the kinematic variables used in the analysis. A relative uncertainty of 2.3 % in the signal efficiency due to multiple collisions within a bunch crossing is taken from the observed variation in the efficiency in a comparison of two different pileup scenarios in simulation, reweighted to the observed data.

The relative uncertainty in the signal efficiency due to variations in the PDFs and the value of α_s is 2.3 % (0.8 %) for $q\bar{q}$ (gg) production, following the PDF4LHC prescription [16, 32–36]. The effect of higher-order corrections, studied using the MCFM program [1], is found to be 1.5 % (30 %) for $q\bar{q}$ annihilation (gg) by varying the renormalisation (μ_R) and factorisation (μ_F) scales in the range $(\mu_0/2, 2\mu_0)$, with μ_0 equal to the mass of the W boson, and setting $\mu_R = \mu_F$. The W^+W^- jet veto efficiency in data is estimated from simulation and multiplied by a data-to-simulation scale factor derived from $Z/\gamma^* \to \ell^+\ell^-$ events in the Z peak,

$$\epsilon_{W^+W^-}^{\text{data}} = \epsilon_{W^+W^-}^{\text{MC}} \times \epsilon_{Z}^{\text{data}}/\epsilon_{Z}^{\text{MC}},$$

where $\epsilon_{W^+W^-}^{\text{data}}$ and $\epsilon_{W^+W^-}^{\text{MC}}$ ($\epsilon_{Z}^{\text{data}}$ and ϵ_{Z}^{MC}) are the efficiencies for the jet veto on the W^+W^- (Z) process for data and

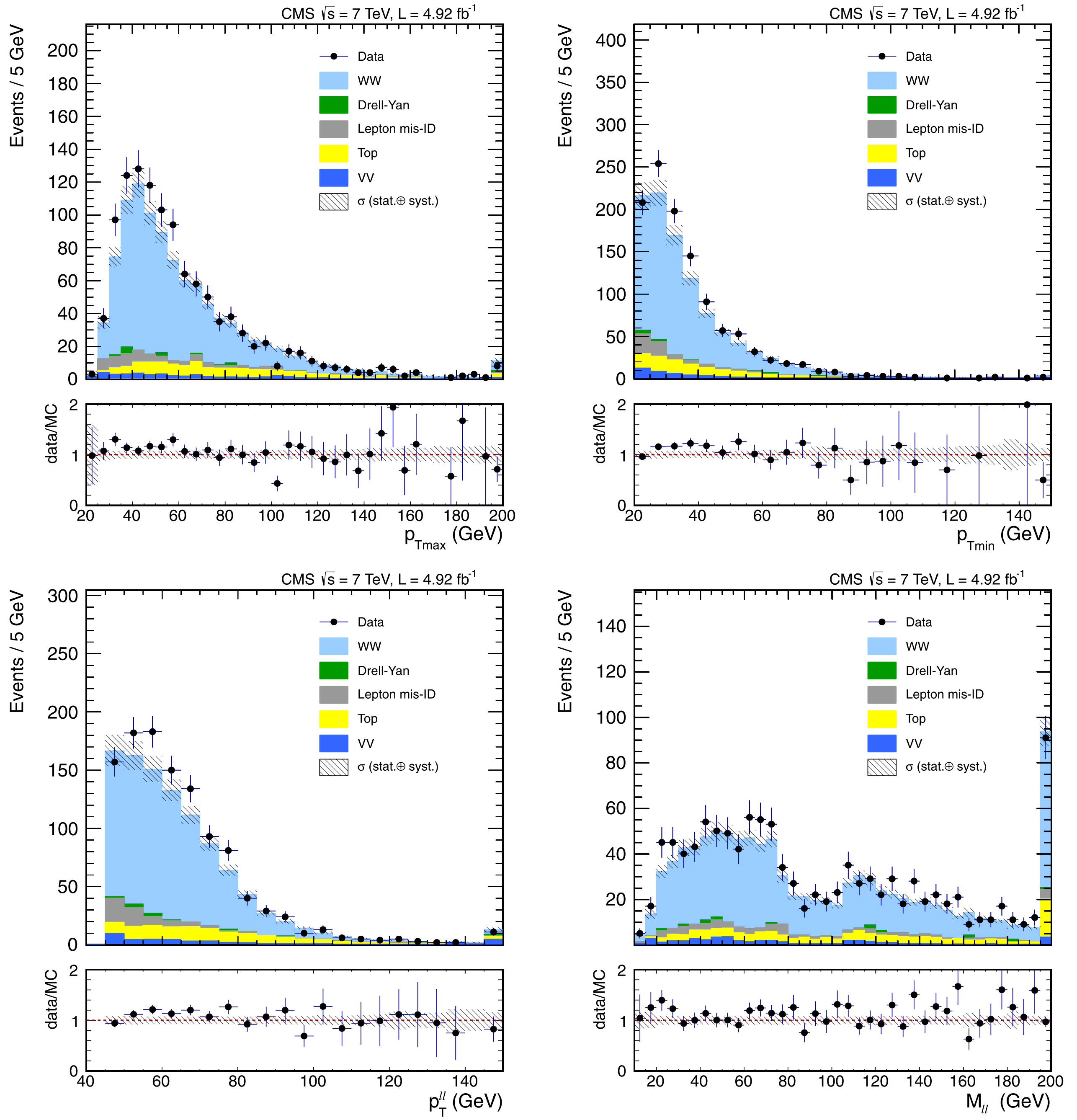

Fig. 2 Distributions of the maximum lepton transverse momentum (p_{Tmax}), the minimum lepton transverse momentum (p_{Tmin}), the dilepton transverse momentum ($p_{\mathrm{T}}^{\ell\ell}$) and invariant mass ($\mathrm{M}_{\ell\ell}$) at the final selection level. Some of the backgrounds have been rescaled to the estimates based on control samples in data, as described in the text. All leptonic channels are combined, and the uncertainty band corresponds to the statistical and systematic uncertainties in the predicted yield. The last bin includes the overflow. In the box below each distribution, the ratio of the observed CMS event yield to the total SM prediction is shown

MC, respectively. The uncertainty in this efficiency is factorised into the uncertainty in the Z efficiency in data and the uncertainty in the ratio of the $\mathrm{W}^+\mathrm{W}^-$ efficiency to the Z efficiency in simulation ($\epsilon^{\mathrm{MC}}_{\mathrm{W}^+\mathrm{W}^-}/\epsilon^{\mathrm{MC}}_{\mathrm{Z}}$). The former, which is dominated by statistics, is 0.3 %. Theoretical uncertainties due to higher-order corrections contribute most to the $\epsilon^{\mathrm{MC}}_{\mathrm{W}^+\mathrm{W}^-}/\epsilon^{\mathrm{MC}}_{\mathrm{Z}}$ ratio uncertainty, which is 4.6 %. The data-to-simulation correction factor is close to unity, using the $\mathrm{Z}/\gamma^* \to \ell^+\ell^-$ events.

The uncertainties in the W + jets and top-quark background predictions are evaluated to be 36 % and 18 %, respectively, as described in Sect. 4. The total uncertainty in

Table 2 Relative systematic uncertainties in the estimated signal and background yields, in units of percent

	$\mathrm{q\bar{q}} \to \mathrm{W^+W^-}$	$\mathrm{gg} \to \mathrm{W^+W^-}$	$\mathrm{t\bar{t}} + \mathrm{tW}$	W + jets	WZ + ZZ	$\mathrm{Z}/\gamma^* \to \ell\ell$	$\mathrm{W} + \gamma$	$\mathrm{W} + \gamma^*$	$\mathrm{Z}/\gamma^* \to \tau\tau$
Luminosity	2.2	2.2	–	–	2.2	–	2.2	–	–
Trigger efficiency	1.5	1.5	–	–	1.5	–	1.5	–	–
Lepton ID efficiency	2.0	2.0	–	–	2.0	–	2.0	–	–
Muon momentum scale	1.5	1.5	–	–	1.5	–	1.5	–	–
Electron energy scale	2.5	2.5	–	–	1.9	–	2.0	–	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	2.0	2.0	–	–	2.0	–	2.0	–	–
Jet veto efficiency	4.7	4.7	–	–	4.7	–	4.7	–	–
Pileup	2.3	2.3	–	–	2.3	–	2.3	–	–
$\mathrm{t\bar{t}} + \mathrm{tW}$ normalisation	–	–	18	–	–	–	–	–	–
W + jets normalisation	–	–	–	36	–	–	–	–	–
$\mathrm{Z}/\gamma^* \to \ell^+\ell^-$ normalisation	–	–	–	–	–	50	–	–	–
$\mathrm{W} + \gamma$ normalisation	–	–	–	–	–	–	30	–	–
$\mathrm{W} + \gamma^*$ normalisation	–	–	–	–	–	–	–	30	–
$\mathrm{Z}/\gamma^* \to \tau^+\tau^-$ normalisation	–	–	–	–	–	–	–	–	10
PDFs	2.3	0.8	–	–	5.9	–	–	–	–
Higher-order corrections	1.5	30	–	–	3.3	–	–	–	–

the $\mathrm{Z}/\gamma^* \to \ell^+\ell^-$ normalisation is about 50 %, including both statistical and systematic contributions.

The theoretical uncertainties in the diboson cross sections are calculated by varying the renormalisation and factorisation scales using the MCFM program [1]. The effect of variations in the PDFs and the value of α_s on the predicted cross section are derived by following the same prescription as for the signal acceptance. Including the experimental uncertainties gives a systematic uncertainty of around 10 % for WZ and ZZ processes. In the case of $\mathrm{W}\gamma^{(*)}$ backgrounds, it rises to 30 %, due to the lack of knowledge of the overall normalisation. The total uncertainty in the background estimates is about 15 %, which is dominated by the systematic uncertainties in the normalisation of the top-quark and W + jets backgrounds. A 2.2 % uncertainty is assigned to the integrated luminosity measurement [37]. A summary of the uncertainties is given in Table 2. For simplicity, averages of the estimates for WZ and ZZ backgrounds are shown.

6 The WW cross section measurement

The number of events observed in the signal region is $N_{\mathrm{data}} = 1134$. The $\mathrm{W^+W^-}$ yield is calculated by subtracting the expected contributions of the various SM background processes, $N_{\mathrm{bkg}} = 247 \pm 15\ (\mathrm{stat.}) \pm 30\ (\mathrm{syst.})$ events. The inclusive cross section is obtained from the expression

$$\sigma_{\mathrm{W^+W^-}} = \frac{N_{\mathrm{data}} - N_{\mathrm{bkg}}}{\mathcal{L}_{\mathrm{int}} \cdot \epsilon \cdot (3 \cdot \mathcal{B}(\mathrm{W} \to \ell\bar{\nu}))^2}, \qquad (1)$$

where the signal selection efficiency ϵ, including the detector acceptance and averaging over all lepton flavours, is found to be $(3.28 \pm 0.02\ (\mathrm{stat.}) \pm 0.26\ (\mathrm{syst.}))$ % using simulation and taking into account the two production modes. As shown in Eq. (1), the efficiency is corrected by the branching fraction for a W boson decaying to each lepton family, $\mathcal{B}(\mathrm{W} \to \ell\bar{\nu}) = (10.80 \pm 0.09)$ % [38], to estimate the final inclusive efficiency for the signal.

The $\mathrm{W^+W^-}$ production cross section in pp collision data at $\sqrt{s} = 7$ TeV is measured to be

$$\sigma_{\mathrm{W^+W^-}} = 52.4 \pm 2.0\ (\mathrm{stat.}) \pm 4.5\ (\mathrm{syst.}) \pm 1.2\ (\mathrm{lum.})\ \mathrm{pb}.$$

The statistical uncertainty is due to the total number of observed events. The systematic uncertainty includes both the statistical component from the limited number of events and systematic uncertainties in the background prediction, as well as the uncertainty in the signal efficiency.

This measurement is consistent with the SM expectation of 47.0 ± 2.0 pb, based on $\mathrm{q\bar{q}}$ annihilation and gluon–gluon fusion. For the event selection used in the analysis, the expected theoretical cross section may be larger by as much as 5 % because of additional $\mathrm{W^+W^-}$ production processes, such as diffractive production [39], double parton scattering, QED exclusive production [40] and Higgs boson production with decay to $\mathrm{W^+W^-}$. The dominant contribution of about 4 % would come from SM Higgs production, assuming its mass to be near 125 GeV [4].

The measured $\mathrm{W^+W^-}$ cross section can be presented in terms of a ratio to the Z boson production cross section in the same data set. The $\mathrm{W^+W^-}$ to Z cross section ratio, $\sigma_{\mathrm{W^+W^-}}/\sigma_{\mathrm{Z}}$, provides a good cross-check of this $\mathrm{W^+W^-}$ cross section measurement, using the precisely known Z boson production cross section as a reference. This ratio has the advantage that some systematic effects cancel. More precise comparisons between measurements from different data-taking periods are possible because the ratio is independent of the integrated luminosity. The PDF uncertainty in the theoretical cross section prediction is also largely cancelled in this ratio, since both $\mathrm{W^+W^-}$ and the Z boson are produced mainly via $\mathrm{q\bar{q}}$ annihilation. The estimated theoretical value for this ratio is $[1.63 \pm 0.07\ (\text{theor.})] \times 10^{-3}$ [31], where the scale uncertainty between both processes is considered uncorrelated, while the PDF uncertainty is assumed fully correlated.

The Z boson production process is measured in the $\mathrm{e^+e^-}/\mu^+\mu^-$ final states using events passing the same lepton selection as in the $\mathrm{W^+W^-}$ measurement and lying within the Z mass window, where the purity of the sample is about 99.8 % [31]. Nonresonant backgrounds (including $\mathrm{Z}/\gamma^* \rightarrow \tau^+\tau^-$) are estimated from $e\mu$ data, while the resonant component of WZ and ZZ processes is normalised to NLO cross sections using MC samples. Correlation of theoretical and experimental uncertainties between the two processes is taken into account. An additional 2 % uncertainty in the shape of the Z resonance due to final-state radiation and higher-order effects is assigned. The latter is based on the difference between the next-to-next-to-leading-order prediction from FEWZ 2.0 [41] simulation code and the MC generator used in the analysis, and on the renormalisation and factorisation scale variation given by FEWZ.

The ratio of the inclusive $\mathrm{W^+W^-}$ cross section to the Z cross section in the dilepton mass range between 60 and 120 GeV is measured to be

$$\sigma_{\mathrm{W^+W^-}}/\sigma_{\mathrm{Z}} = \bigl[1.79 \pm 0.16\ (\text{stat.}\oplus\text{syst.})\bigr] \times 10^{-3},$$

in agreement with the theoretical expectation. The Z cross section resulting from this ratio, assuming the standard model value for the $\mathrm{W^+W^-}$ cross section, is 1.1 % higher than the inclusive Z cross section measurement in CMS using the 2010 data set [31], which had an integrated luminosity of 36 $\mathrm{pb^{-1}}$, but well within the systematic uncertainties of both measurements.

7 Limits on the anomalous triple gauge–boson couplings

A search for anomalous TGCs is done using the effective Lagrangian approach with the LEP parametrisation [2] without form factors. The most general form of such a Lagrangian has 14 complex couplings (seven for WWZ and seven for $\mathrm{WW}\gamma$). Assuming electromagnetic gauge invariance and charge and parity symmetry conservation, that number is reduced to five real couplings: $\Delta\kappa_Z$, Δg_1^Z, $\Delta\kappa_\gamma$, λ_Z and λ_γ. Applying gauge invariance constraints leads to

$$\Delta\kappa_{\mathrm{Z}} = \Delta g_1^{\mathrm{Z}} - \Delta\kappa_\gamma \tan^2(\theta_{\mathrm{W}}),$$

$$\lambda_{\mathrm{Z}} = \lambda_\gamma,$$

which reduces the number of independent couplings to three. In the SM, all five couplings are zero. The coupling constants Δg_1^{Z} and $\Delta\kappa_\gamma$ parametrise the differences from the standard model values of 1 for both g_1^{Z} and κ_γ, which are measures of the WWZ and $\mathrm{WW}\gamma$ coupling strengths, respectively.

The presence of anomalous TGCs would enhance the production rate for diboson processes at high boson p_{T} and high invariant mass. The effect of these couplings is ascertained by evaluating the expected distribution of p_{Tmax}, the transverse momentum of the leading (highest-p_{T}) lepton, and by comparing it to the measured distribution, using a maximum-likelihood fit. The p_{Tmax} is a very sensitive observable for these searches, and it is widely used in the fully leptonic final states, since the total mass of the event cannot be fully reconstructed. The likelihood L is defined as a product of Poisson probability distribution functions for the observed number of events (N_{obs}) and the combined one for each event, $P(p_{\mathrm{T}})$:

$$L = \mathrm{e}^{-N_{\mathrm{exp}}} (N_{\mathrm{exp}})^{N_{\mathrm{obs}}} \prod_{i=1}^{N_{\mathrm{obs}}} P(p_{\mathrm{T}i}), \tag{2}$$

where N_{exp} is the expected number of signal and background events. The leading lepton p_{T} distributions with anomalous couplings are simulated using the MCFM NLO generator, taking into account the detector effects. The distributions are corrected for the acceptance and lepton reconstruction efficiency, as described in Sect. 5. The uncertainties in the quoted integrated luminosity, signal selection and background fraction are assumed to be Gaussian. These uncertainties are incorporated in the likelihood function in Eq. (2) by introducing nuisance parameters with Gaussian constraints. A set of points with nonzero anomalous couplings is used and distributions between the points are extrapolated assuming a quadratic dependence of the differential cross section as a function of the anomalous couplings.

Figure 3 shows the measured leading lepton p_{T} distributions in data and the predictions for the SM $\mathrm{W^+W^-}$ signal and background processes, as well as the expected distributions with non-negative anomalous couplings, in the two-dimensional model λ_{Z}–Δg_1^{Z}.

No evidence for anomalous couplings is found. The 95 % confidence level (CL) intervals of allowed anomalous couplings values, setting the other two couplings to their SM expected values, are

$$-0.048 \le \lambda_{\mathrm{Z}} \le 0.048,$$

$$-0.095 \le \Delta g_1^{\mathrm{Z}} \le 0.095,$$

$$-0.21 \le \Delta\kappa_\gamma \le 0.22.$$

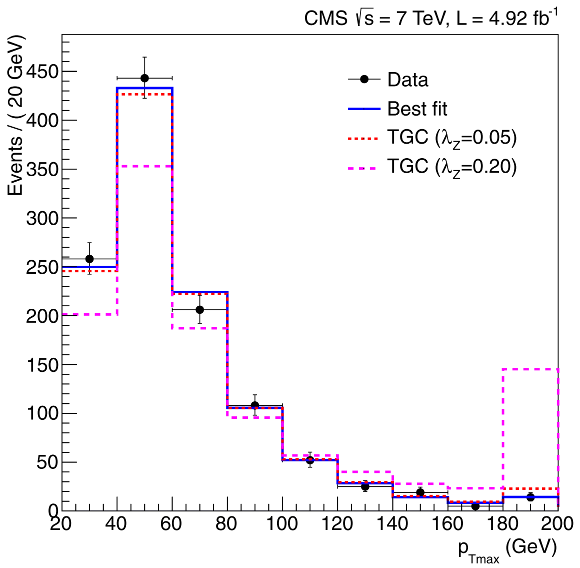

Fig. 3 Leading lepton p_{T} distribution in data (*points with error bars*) overlaid with the best fit using a two-dimensional λ_Z–Δg_1^Z model (*solid histogram*) and two expected distributions with anomalous coupling value, $\lambda_Z \neq 0$ (*dashed and dotted histograms*). In the SM, $\lambda_Z = 0$. The last bin includes the overflow

The results presented here are comparable with the measurements performed by the ATLAS Collaboration [8] using the LEP parametrisation. These results are also comparable upon those obtained at the Tevatron [42, 43], which are based on the HISZ parametrisation [44] and LEP parametrisation with form factors, but they are not as precise as the combination of the LEP experiments [45–47]. Recently, CMS has set limits on these couplings [48], using a different final-state channel. Our measurements clearly demonstrate that both the WWZ and WWγ couplings exist, as predicted in the standard model ($g_1^Z = 1$, $\kappa_\gamma = 1$). Figure 4 displays the contour plots at the 68 % and 95 % CL for the $\Delta\kappa_\gamma = 0$ and $\Delta g_1^Z = 0$ scenarios.

8 Summary

This paper reports a measurement of the W^+W^- cross section in the $W^+W^- \rightarrow \ell^+\nu\ell^-\overline{\nu}$ decay channel in proton-proton collisions at a centre of mass energy of 7 TeV, using the full CMS data set of 2011. The W^+W^- cross section is measured to be $52.4 \pm 2.0\,(\mathrm{stat.}) \pm 4.5\,(\mathrm{syst.}) \pm 1.2\,(\mathrm{lum.})$ pb, consistent with the NLO theoretical prediction, $\sigma^{\mathrm{NLO}}(\mathrm{pp} \rightarrow W^+W^-) = 47.0 \pm 2.0$ pb. No evidence for anomalous WWZ and WWγ triple gauge-boson couplings is found, and stringent limits on their magnitude are set.

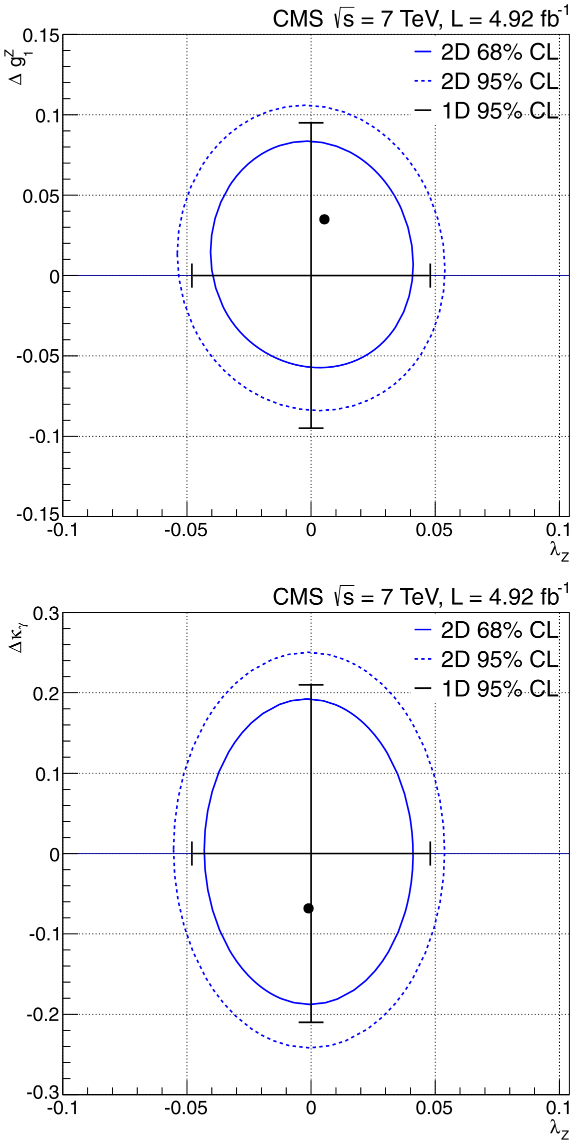

Fig. 4 The 68 % (*solid line*) and 95 % CL (*dashed line*) limit contours, as well as the central value (*point*) of the fit results using unbinned fits, for $\Delta\kappa_\gamma = 0$ (*top*) and $\Delta g_1^Z = 0$ (*bottom*). The one-dimensional 95 % CL limit for each coupling is also shown

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).

Individuals have received support from the Marie-Curie programme and the European Research Council and EPLANET (European Union); the Leventis Foundation; the A. P. Sloan Foundation; the Alexander von Humboldt Foundation; the Belgian Federal Science Policy Office; the Fonds pour la Formation à la Recherche dans l'Industrie et dans l'Agriculture (FRIA-Belgium); the Agentschap voor Innovatie door Wetenschap en Technologie (IWT-Belgium); the Ministry of Education, Youth and Sports (MEYS) of Czech Republic; the Council of Science and Industrial Research, India; the Compagnia di San Paolo (Torino); the HOMING PLUS programme of Foundation for Polish Science, cofinanced by EU, Regional Development Fund; and the Thalis and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF.

References

1. J.M. Campbell, R.K. Ellis, C. Williams, Vector boson pair production at the LHC. J. High Energy Phys. **07**, 018 (2011). doi:10.1007/JHEP07(2011)018, arXiv:1105.0020
2. G. Gounaris et al., Triple gauge boson couplings. Physics at LEP2 52 (1996). doi:10.5170/CERN-1996-001-V-1, arXiv:hep-ph/9601233
3. CMS Collaboration, Search for the standard model Higgs boson decaying to W^+W^- in the fully leptonic final state in pp collisions at $\sqrt{s} = 7$ TeV. Phys. Lett. B **710**, 91 (2012). doi:10.1016/j.physletb.2012.02.076, arXiv:1202.1489
4. CMS Collaboration, Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC. Phys. Lett. B **716**, 30 (2012). doi:10.1016/j.physletb.2012.08.021, arXiv:1207.7235
5. 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**, 1 (2012). doi:10.1016/j.physletb.2012.08.020, arXiv:1207.7214
6. 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**, 25 (2011). doi:10.1016/j.physletb.2011.03.056, arXiv:1102.5429
7. ATLAS Collaboration, Measurement of the W^+W^- cross section in $\sqrt{s} = 7$ TeV pp collisions with ATLAS. Phys. Rev. Lett. **107**, 041802 (2011). doi:10.1103/PhysRevLett.107.041802, arXiv:1104.5225
8. ATLAS Collaboration, Measurement of the W^+W^- cross section in $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector and limits on anomalous gauge couplings. Phys. Lett. B **712**, 289 (2012). doi:10.1016/j.physletb.2012.05.003, arXiv:1203.6232
9. 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. Phys. Rev. D **87**, 112001. doi:10.1103/PhysRevD.87.112001, arXiv:1210.2979
10. CMS Collaboration, The CMS experiment at the CERN LHC. J. Instrum. **3**, S08004 (2008). doi:10.1088/1748-0221/3/08/S08004
11. J. Alwall et al., MadGraph 5: going beyond. J. High Energy Phys. **06**, 128 (2011). doi:10.1007/JHEP06(2011)128, arXiv:1106.0522
12. T. Binoth, M. Ciccolini, N. Kauer, M. Krämer, Gluon-induced W-boson pair production at the LHC. J. High Energy Phys. **12**, 046 (2006). doi:10.1088/1126-6708/2006/12/046, arXiv:hep-ph/0611170
13. S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method. J. High Energy Phys. **11**, 070 (2007). doi:10.1088/1126-6708/2007/11/070, arXiv:0709.2092.
14. T. Sjöstrand, S. Mrenna, P. Skands, PYTHIA 6.4 physics and manual. J. High Energy Phys. **05**, 026 (2006). doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175
15. H.-L. Lai et al., Uncertainty induced by QCD coupling in the CTEQ global analysis of parton distributions. Phys. Rev. D **82**, 054021 (2010). doi:10.1103/PhysRevD.82.054021, arXiv:1004.4624
16. H.-L. Lai et al., New parton distributions for collider physics. Phys. Rev. D **82**, 074024 (2010). doi:10.1103/PhysRevD.82.074024, arXiv:1007.2241
17. GEANT4 Collaboration, GEANT4—a simulation toolkit. Nucl. Instrum. Methods A **506**, 250 (2003). doi:10.1016/S0168-9002(03)01368-8
18. CMS Collaboration, Electron reconstruction and identification at $\sqrt{s} = 7$ TeV. CMS Physics Analysis Summary CMS-PAS-EGM-10-004 (2010)
19. CMS Collaboration, Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV. J. Instrum. **7**, P10002 (2012). doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071
20. CMS Collaboration, Particle flow event reconstruction in CMS and performance for jets, taus, and MET. CMS Physics Analysis Summary CMS-PAS-PFT-09-001 (2009)
21. CMS Collaboration, Jet performance in pp collisions at $\sqrt{s} = 7$ TeV. CMS Physics Analysis Summary CMS-PAS-JME-10-003 (2010)
22. M. Cacciari, G.P. Salam, G. Soyez, The anti-k_t jet clustering algorithm. J. High Energy Phys. **04**, 063 (2008). doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189
23. M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual. Eur. Phys. J. C **72**, 1896 (2012). doi:10.1140/epjc/s10052-012-1896-2, arXiv:1111.6097v1
24. M. Cacciari, G.P. Salam, Dispelling the N^3 myth for the k_t jet-finder. Phys. Lett. B **641**, 57 (2006). doi:10.1016/j.physletb.2006.08.037, arXiv:hep-ph/0512210
25. M. Cacciari, G.P. Salam, Pileup subtraction using jet areas. Phys. Lett. B **659**, 119 (2008). doi:10.1016/j.physletb.2007.09.077, arXiv:0707.1378
26. CMS Collaboration, Determination of jet energy calibration and transverse momentum resolution in CMS. J. Instrum. **6**, 11002 (2011). doi:10.1088/1748-0221/6/11/P11002, arXiv:1107.4277
27. CMS Collaboration, Identification of b-quark jets with the CMS experiment. J. Instrum. **8**, P04013 (2013). doi:10.1088/1748-0221/8/04/P04013, arXiv:1211.4462
28. CMS Collaboration, Commissioning of b-jet identification with pp collisions at $\sqrt{s} = 7$ TeV. CMS Physics Analysis Summary CMS-PAS-BTV-10-001 (2010)
29. CMS Collaboration, Missing transverse energy performance of the CMS detector. J. Instrum. **6**, P09001 (2011). doi:10.1088/1748-0221/6/09/P09001, arXiv:1106.5048
30. R.C. Gray et al., Backgrounds to Higgs boson searches from asymmetric internal conversion (2011). arXiv:1110.1368
31. CMS Collaboration, Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV. J. High Energy Phys. **11**, 080 (2011). doi:10.1007/JHEP01(2011)080, arXiv:1012.2466
32. M. Botje et al., The PDF4LHC Working Group Interim Recommendations (2011). arXiv:1101.0538
33. S. Alekhin et al., The PDF4LHC Working Group Interim Report (2011). arXiv:1101.0536

34. A.D. Martin, W.J. Stirling, R.S. Thorn, G. Watt, Parton distributions for the LHC. Eur. Phys. J. C **63**, 189 (2009). doi:10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002
35. NNPDF Collaboration, Impact of heavy quark masses on parton distributions and LHC phenomenology. Nucl. Phys. B **849**, 296 (2011). doi:10.1016/j.nuclphysb.2011.03.021, arXiv:1101.1300
36. LHC Higgs Cross Section Working Group, Handbook of LHC Higgs cross sections: inclusive observables (2011). arXiv:1101.0593
37. CMS Collaboration, Absolute calibration of the luminosity measurement at CMS: winter 2012 update. CMS Physics Analysis Summary CMS-PAS-SMP-12-008 (2012)
38. J. Beringer et al. (Particle Data Group), Review of particle physics. Phys. Rev. D **86**, 010001 (2012). doi:10.1103/PhysRevD.86.010001
39. P. Bruni, G. Ingelman, Diffractive hard scattering at ep and $\mathrm{p\overline{p}}$ colliders, in *Int. Europhysics Conference on High Energy Physics*. Conf. Proc. C, vol. 722, Marseilles, France (1993), p. 595
40. A. Pukhov, CalcHEP 2.3: MSSM, structure functions, event generation, batchs, and generation of matrix elements for other packages (2004). arXiv:hep-ph/0412191
41. R. Gavin, Y. Li, F. Petriello, S. Quackenbush, FEWZ 2.0: a code for hadronic Z production at next-to-next-to-leading order. Comput. Phys. Commun. **182**, 2388 (2011). doi:10.1016/j.cpc.2011.06.008, arXiv:1011.3540v1
42. CDF Collaboration, Measurement of the WZ cross section and triple gauge couplings in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV. Phys. Rev. D **86**, 031104 (2012). doi:10.1103/PhysRevD.86.031104
43. D0 Collaboration, Limits on anomalous trilinear gauge boson couplings from WW, WZ and Wγ production in $\mathrm{p\overline{p}}$ collisions at $s = 1.96$ TeV. Phys. Lett. B **718**, 451 (2012). doi:10.1016/j.physletb.2012.10.062, arXiv:1208.5458
44. K. Hagiwara, S. Ishihara, R. Szalapski, D. Zeppenfeld, Low energy effects of new interactions in the electroweak boson sector. Phys. Rev. D **48**, 2182 (1993). doi:10.1103/PhysRevD.48.2182
45. ALEPH Collaboration, Improved measurement of the triple gauge-boson couplings γWW and ZWW in $\mathrm{e^+e^-}$ collisions. Phys. Lett. B **614**, 7 (2005). doi:10.1016/j.physletb.2005.03.058
46. L3 Collaboration, Measurement of triple-gauge-boson couplings of the W boson at LEP. Phys. Lett. B **586**, 151 (2004). doi:10.1016/j.physletb.2004.02.045, arXiv:hep-ex/0402036
47. OPAL Collaboration, Measurement of charged current triple gauge boson couplings using W pairs at LEP. Eur. Phys. J. C **33**, 463 (2004). doi:10.1140/epjc/s2003-01524-6, arXiv:hep-ex/0308067
48. CMS Collaboration, Measurement of the sum of WW and WZ production with W+dijet events in pp collisions at $\sqrt{s} =$ 7 TeV. Eur. Phys. J. C **73**, 2283 (2013). doi:10.1140/epjc/s10052-013-2283-3, arXiv:1210.7544

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, 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, D. Rabady[2], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Treberer-Treberspurg, 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, A. Knutsson, 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, A. Kalogeropoulos, J. Keaveney, 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, L. Favart, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, A. Mohammadi, L. Perniè, T. Reis, T. Seva, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wang

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, L. Benucci, A. Cimmino, S. Costantini, S. Dildick, G. Garcia, 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, C. Beluffi[3], G. Bruno, R. Castello, A. Caudron, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco[4], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, A. Popov[5], 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[6], 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[6], 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,7], T.R. Fernandez Perez Tomei[a], E.M. Gregores[b], C. Lagana[a], F. Marinho[a], P.G. Mercadante[b], S.F. Novaes[a], S.S. Padula[a]

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

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, J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina[8], 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[9], A. Ellithi Kamel[10], M.A. Mahmoud[11], A. Mahrous[12], A. Radi[13,14]

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, 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, 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[15], 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[16], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, E.C. Chabert, C. Collard, E. Conte[16], F. Drouhin[16], J.-C. Fontaine[16], D. Gelé, U. Goerlach, C. Goetzmann, P. Juillot, A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules, CNRS/IN2P3, Villeurbanne, France
S. Gadrat

Université de Lyon, Université Claude Bernard Lyon 1, CNRS-IN2P3, Institut de Physique Nucléaire de Lyon, Villeurbanne, France
S. Beauceron, N. Beaupere, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici, 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, M. Vander Donckt, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia
Z. Tsamalaidze[17]

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany
C. Autermann, S. Beranek, B. Calpas, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[5]

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
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, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany
M. Aldaya Martin, I. Asin, N. Bartosik, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[18], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, F. Costanza, 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, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, K. Lipka, W. Lohmann[18], B. Lutz, R. Mankel, I. Marfin, 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, R. Placakyte, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M.Ö. Sahin, J. Salfeld-Nebgen, R. Schmidt[18], T. Schoerner-Sadenius, N. Sen, 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, K. Heine, R.S. Höing, G. Kaussen, H. Kirschenmann, R. Klanner, R. Kogler, 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[19], V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, D. Troendle, 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[5], J.R. Komaragiri, A. Kornmayer[2], P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, J. Ott, G. Quast,

K. Rabbertz, F. Ratnikov, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institute of Nuclear and Particle Physics (INPP), NCSR 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, E. Stiliaris

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

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath[20], B. Radics, F. Sikler, V. Veszpremi, G. Vesztergombi[21], 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

National Institute of Science Education and Research, Bhubaneswar, India
S.K. Swain[22]

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
A. Kumar, A. 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, A. Topkar

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, R.M. Chatterjee, S. Ganguly, S. Ghosh, M. Guchait[23], A. Gurtu[24], G. Kole, S. Kumar, M. Maity[25], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage[26]

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

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei[27], H. Bakhshiansohi, S.M. Etesami[28], A. Fahim[27], H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[29], M. Zeinali

University College Dublin, Dublin, Ireland
M. Grunewald

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], 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], R. Campanini[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,2], M. Meneghelli[a,b], 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[a,b], R. Travaglini[a,b]

INFN Sezione di Catania[a] , Università di Catania[b] , Catania, Italy
S. Albergo[a,b], M. Chiorboli[a,b], S. Costa[a,b], F. Giordano[a,2], 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], V. Gori[a,b], P. Lenzi[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, 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], S. Fiorendi[a,b], S. Gennai[a], A. Ghezzi[a,b], P. Govoni[a,b], M.T. Lucchini[a,b,2], S. Malvezzi[a], R.A. Manzoni[a,b,2], A. Martelli[a,b,2], 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], 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], P. Bellan[a,b], D. Bisello[a,b], A. Branca[a,b], R. Carlin[a,b], P. Checchia[a], T. Dorigo[a], M. Galanti[a,b,2], F. Gasparini[a,b], U. Gasparini[a,b], P. Giubilato[a,b], F. Gonella[a], A. Gozzelino[a], K. Kanishchev[a,c], S. Lacaprara[a], I. Lazzizzera[a,c], M. Margoni[a,b], A.T. Meneguzzo[a,b], F. Montecassiano[a], M. Passaseo[a], 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], 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. 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]

INFN Sezione di Pisa[a] , Università di Pisa[b] , Scuola Normale Superiore di Pisa[c] , Pisa, Italy
K. Androsov[a,30], P. Azzurri[a], G. Bagliesi[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,c], L. Foà[a,c], A. Giassi[a], A. Kraan[a], F. Ligabue[a,c], T. Lomtadze[a], L. Martini[a,30], A. Messineo[a,b], F. Palla[a], A. Rizzi[a,b], A.T. Serban[a], P. Spagnolo[a], P. Squillacioti[a], R. Tenchini[a], G. Tonelli[a,b], A. Venturi[a], P.G. Verdini[a], C. Vernieri[a,c]

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], F. Margaroli[a,b], P. Meridiani[a], 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], G. Dellacasa[a], N. Demaria[a], C. Mariotti[a], S. Maselli[a], E. Migliore[a,b], V. Monaco[a,b], M. Musich[a], M.M. Obertino[a,c], N. Pastrone[a], M. Pelliccioni[a,2], A. Potenza[a,b], A. Romero[a,b], M. Ruspa[a,c], R. Sacchi[a,b], A. Solano[a,b], A. Staiano[a], U. Tamponi[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], C. La Licata[a,b], M. Marone[a,b], D. Montanino[a,b], A. Penzo[a], A. Schizzi[a,b], A. Zanetti[a]

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

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

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

Korea University, Seoul, Korea
S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, 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
I. Grigelionis, 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[31], 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. Rodrigues Antunes, J. Seixas[2], J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, N. Skatchkov, V. Smirnov, 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, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, A. Spiridonov, 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[7], L. Dudko, A. Ershov, A. Gribushin, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

State Research Center of Russian Federation, Institute for High Energy Physics, Protvino, Russia
I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, 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[32], M. Ekmedzic, D. Krpic[32], J. Milosevic

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain
M. Aguilar-Benitez, J. Alcaraz Maestre, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas[2], 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, E. Navarro De Martino, 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, 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. 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[8], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, O. Bondu, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, S. Colafranceschi[33], D. d'Enterria, A. Dabrowski, A. De Roeck, S. De Visscher, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, J. Eugster, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, S. Gowdy, R. Guida, J. Hammer, M. Hansen, P. Harris, C. Hartl, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, E. Karavakis, K. Kousouris, K. Krajczar, P. Lecoq, Y.-J. Lee, C. Lourenço, N. Magini, 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, G. Rolandi[34], C. Rovelli[35], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[36], D. Spiga, M. Stoye, A. Tsirou, G.I. Veres[21], J.R. Vlimant, H.K. Wöhri, S.D. Worm[37], 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, 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, C. Grab, D. Hits, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[38], 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[39], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber

Universität Zürich, Zurich, Switzerland
C. Amsler[40], V. Chiochia, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Taroni, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan
M. Cardaci, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, 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, M. Wang

Chulalongkorn University, Bangkok, Thailand
B. Asavapibhop, N. Suwonjandee

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci[41], S. Cerci[42], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, A. Kayis Topaksu, G. Onengut[43], K. Ozdemir, S. Ozturk[41], A. Polatoz, K. Sogut[44], D. Sunar Cerci[42], B. Tali[42], H. Topakli[41], 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, G. Karapinar[45], K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, Turkey
E. Gülmez, B. Isildak[46], M. Kaya[47], O. Kaya[47], S. Ozkorucuklu[48], N. Sonmez[49]

Istanbul Technical University, Istanbul, Turkey
H. Bahtiyar[50], E. Barlas, K. Cankocak, Y.O. Günaydin[51], F.I. Vardarlı, M. Yücel

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

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[37], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso[52], K.W. Bell, A. Belyaev[52], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, 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, O. Buchmuller, D. Burton, 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, R. Lane, R. Lucas[37], L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[39], J. Pela, M. Pesaresi, K. Petridis, M. Pioppi[53], D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, 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
J. Dittmann, K. Hatakeyama, A. Kasmi, 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, 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, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, 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, S. Wilbur, R. Yohay

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

University of California, Riverside, Riverside, USA
J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, 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[54], 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, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, D. Kcira, 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, J. Russ, 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, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, USA
J. Alexander, A. Chatterjee, N. Eggert, L.K. Gibbons, 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, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, L. Gray, D. Green, O. Gutsche, D. Hare, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, 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, O. Prokofyev, N. Ratnikova, 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. 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, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

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

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, L. Apanasevich, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, P. Kurt, F. Lacroix, D.H. Moon, 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, H. Ogul, Y. Onel, F. Ozok[50], S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin[59], K. Yi

Johns Hopkins University, Baltimore, USA
B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, 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, J.S. Wood

Kansas State University, Manhattan, USA
A.F. Barfuss, 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, 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, Y.S. Lai, 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, 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, J. Haupt, 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, D. Summers

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

State University of New York at Buffalo, Buffalo, USA
J. Dolen, 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, 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, H. Wolfe

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, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, K. Jung, O. Koybasi, M. Kress, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, F. Wang, L. Xu, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

S. Guragain, N. Parashar

Rice University, Houston, USA

A. Adair, B. Akgun, 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, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, A. Garcia-Bellido, P. Goldenzweig, J. Han, A. Harel, D.C. Miner, G. Petrillo, 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

O. Bouhali[60], R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[61], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, 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, S. Greene, A. Gurrola, W. Johns, C. Maguire, Y. Mao, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA

M.W. Arenton, 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, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, K. Kaadze, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, R. Loveless, A. Mohapatra, M.U. Mozer, I. Ojalvo, 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 Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France
4: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
5: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia
6: Also at Universidade Estadual de Campinas, Campinas, Brazil
7: Also at California Institute of Technology, Pasadena, USA
8: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
9: Also at Suez Canal University, Suez, Egypt
10: Also at Cairo University, Cairo, Egypt
11: Also at Fayoum University, El-Fayoum, Egypt
12: Also at Helwan University, Cairo, Egypt
13: Also at British University in Egypt, Cairo, Egypt
14: Now at Ain Shams University, Cairo, Egypt
15: Also at National Centre for Nuclear Research, Swierk, Poland
16: Also at Université de Haute Alsace, Mulhouse, France
17: Also at Joint Institute for Nuclear Research, Dubna, Russia
18: Also at Brandenburg University of Technology, Cottbus, Germany
19: Also at The University of Kansas, Lawrence, USA
20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
21: Also at Eötvös Loránd University, Budapest, Hungary
22: Also at Tata Institute of Fundamental Research - EHEP, Mumbai, India
23: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
24: Now at King Abdulaziz University, Jeddah, Saudi Arabia
25: Also at University of Visva-Bharati, Santiniketan, India
26: Also at University of Ruhuna, Matara, Sri Lanka
27: Also at Sharif University of Technology, Tehran, Iran
28: Also at Isfahan University of Technology, Isfahan, Iran
29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
30: Also at Università degli Studi di Siena, Siena, Italy
31: Also at Universidad Michoacana de San Nicolas de Hidalgo, Morelia, Mexico
32: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
33: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
34: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
35: Also at INFN Sezione di Roma, Roma, Italy
36: Also at University of Athens, Athens, Greece
37: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
38: Also at Paul Scherrer Institut, Villigen, Switzerland
39: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
40: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
41: Also at Gaziosmanpasa University, Tokat, Turkey
42: Also at Adiyaman University, Adiyaman, Turkey
43: Also at Cag University, Mersin, Turkey
44: Also at Mersin University, Mersin, Turkey
45: Also at Izmir Institute of Technology, Izmir, Turkey
46: Also at Ozyegin University, Istanbul, Turkey
47: Also at Kafkas University, Kars, Turkey
48: Also at Suleyman Demirel University, Isparta, Turkey
49: Also at Ege University, Izmir, Turkey
50: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
51: Also at Kahramanmaras Sütcü Imam University, Kahramanmaras, Turkey

52: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
53: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
54: Also at Utah Valley University, Orem, USA
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 Yildiz Technical University, Istanbul, Turkey
60: Also at Texas A&M University at Qatar, DOHA, Qatar
61: Also at Kyungpook National University, Daegu, Korea