Search for the standard model Higgs boson produced in association with W and Z bosons in pp collisions at $\sqrt{s} = 7$ TeV
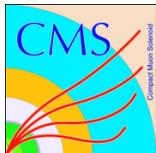
The CMS collaboration

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

ABSTRACT: A search for the Higgs boson produced in association with a W or Z boson in proton-proton collisions at a center-of-mass energy of 7 TeV is performed with the CMS detector at the LHC using the full 2011 data sample, from an integrated luminosity of $5\,\mathrm{fb}^{-1}$. Higgs boson decay modes to $\tau\tau$ and WW are explored by selecting events with three or four leptons in the final state. No excess above background expectations is observed, resulting in exclusion limits on the product of Higgs associated production cross section and decay branching fraction for Higgs boson masses between 110 and 200 GeV in these channels. Combining these results with other CMS associated production searches using the same dataset in the H→ $\gamma\gamma$ and H→ b$\overline{\mathrm{b}}$ decay modes, the cross section for associated Higgs boson production 3.3 times the standard model expectation or larger is ruled out at the 95% confidence level for a Higgs boson mass of 125 GeV.

Contents

1 Introduction

Spontaneous electroweak symmetry breaking is introduced in the standard model (SM) [1–3] to give mass to the vector bosons ($W^\pm$ and Z) that mediate weak interactions, while keeping the photon, which mediates electromagnetic interactions, massless. This mechanism [4–9] results in a single scalar in the SM, the Higgs boson. While the mass of the Higgs boson is a free parameter in the SM, its couplings to the massive vector bosons, Yukawa couplings to fermions, decay branching fractions, and production cross sections in proton-proton collisions are defined and well understood theoretically [10]. Gluon fusion (GF), weak vector boson fusion (VBF), associated production (AP) with weak bosons, and associated production with a $t\bar{t}$ pair ($t\bar{t}H$) are the four most important Higgs boson production mechanisms at the Large Hadron Collider (LHC). Although the cross section for AP is an order of magnitude lower than that of the GF mechanism, the presence of isolated high momentum leptons originating from W and Z decays suppresses the backgrounds dramatically, making these channels viable for searches for the Higgs boson.

Direct searches at the Large Electron-Positron Collider (LEP) have excluded a Higgs boson with a mass $m_H < 114.4\,\mathrm{GeV}$ at 95% confidence level (CL) [11]. The ATLAS experiment has excluded the SM Higgs boson in the mass ranges 111–122 and 131–559 GeV [12], and the CMS experiment in the mass ranges 110–121.5 [13] and 127–600 GeV [14]. Both experiments have reported the observation of a new boson with a mass near 125 GeV [12, 13], predominantly in channels sensitive to Higgs bosons decaying to photon or Z boson pairs.

Tevatron experiments have reported an excess of events in the $b\bar{b}$ final state in the mass range 120–135 GeV [15].

This paper reports a search for the SM Higgs boson produced in association with a W boson (WH channel) or a Z boson (ZH channel). The search uses a data sample of proton-proton collisions at $\sqrt{s} = 7$ TeV recorded by the Compact Muon Solenoid (CMS) [16] experiment at the LHC. The data were collected in 2011 from an integrated luminosity of $5.00 \pm 0.11\,\text{fb}^{-1}$ [17]. Throughout this document, the expression "light lepton," or symbol ℓ, will refer to an electron or muon, the symbol τ_h to a hadronically-decaying tau, and the symbol L to an e, μ, or τ_h. The search for WH production is performed in three-lepton ($3L$) events in four final states with three electrons or muons (3ℓ): eee, eeμ, e$\mu\mu$, and $\mu\mu\mu$, and two final states that have a hadronic decay of a tau ($2\ell\tau_h$): e$\mu\tau_h$ and $\mu\mu\tau_h$. The search for ZH production is performed in four-lepton ($4L$) events with a pair of electrons or muons consistent with the decay of a Z boson, and a Higgs boson candidate with one of the following final states: eμ, eτ_h, $\mu\tau_h$, or $\tau_h\tau_h$. These final states can be produced by two Higgs boson decay modes: decays to a pair of W bosons (H $\rightarrow$ W$^+$W$^-$) that both decay to leptons, and decays to a pair of taus (H $\rightarrow \tau^+\tau^-$). The contribution of the H $\rightarrow$ ZZ decay mode is negligible.

While the sensitivity to a Higgs boson of the AP search presented here is lower than previously published results dominated by the GF and VBF production mechanisms, the final states used in this search are essential for determining if the recently observed boson at 125 GeV is consistent with the Higgs boson predicted by the SM. The Tevatron excess has been observed in the associated production H $\rightarrow$ b$\bar{b}$ channel [15]. No evidence for associated Higgs boson production has been observed at the CMS and ATLAS experiments [12, 13, 18]. Furthermore, the exclusive measurement of all three production processes (GF, AP, and VBF) using the H $\rightarrow \tau^+\tau^-$ decay mode will be critical to determine the structure of the Higgs boson couplings [19], as the H $\rightarrow \tau^+\tau^-$ decay mode is the only fermionic decay mode that is experimentally sensitive to both Yukawa coupling (GF) and gauge coupling (AP and VBF) production processes. The fermionic H $\rightarrow$ b$\bar{b}$ decay mode is not experimentally accessible in the GF production mechanism due to the overwhelming multijet background.

We additionally combine the searches described in this paper with previously published CMS AP searches in the H $\rightarrow \gamma\gamma$ [20] and H $\rightarrow$ b$\bar{b}$ [21] decay modes. The H $\rightarrow$ b$\bar{b}$ result has been updated with an improved measurement of the integrated luminosity [17] recorded in 2011 at the CMS experiment, and this is the first time that the AP H $\rightarrow \gamma\gamma$ result has been interpreted in the context of the SM. With the exception of the H $\rightarrow$ b$\bar{b}$ search, none of the searches combined in this paper were used in the CMS observation [13] of the new boson at 125 GeV. This paper presents the first combination of all searches for associated Higgs boson production using the 7 TeV dataset at the CMS experiment.

2 The CMS detector, event reconstruction, and simulation

A more detailed description of the CMS detector can be found in ref. [16]. The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a field of 3.8 T. Within the solenoid are the silicon pixel and strip trackers,

which cover a pseudorapidity region of $|\eta| < 2.5$. Here, the pseudorapidity is defined as $\eta = -\ln\left[\tan\left(\theta/2\right)\right]$, where θ is the polar angle of the trajectory of the particle with respect to the direction of the counterclockwise beam. The lead-tungstate crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL) surround the tracking volume and cover $|\eta| < 3$. The ECAL consists of $75\,848$ lead-tungstate crystals that provide coverage in pseudorapidity $|\eta| < 1.479$ in a barrel region and $1.479 < |\eta| < 3.0$ in two endcap (EE) regions. A preshower detector consisting of two planes of silicon sensors interleaved with a total of $3X_0$ of lead is located in front of the EE. In addition to the barrel and endcap detectors, CMS has forward calorimetry that extends the coverage to $|\eta| < 5$. Muons are measured in gas-ionization detectors embedded in the steel return yoke, with a coverage of $|\eta| < 2.4$.

The identification of electrons, muons, and hadronically-decaying taus relies crucially on the association of tracks in the tracker with energy depositions in the ECAL for electrons, energy depositions in the HCAL for charged hadrons, and track segments in the muon system for muons. Photons are identified as ECAL energy depositions without an associated track. All particles are reconstructed using the particle flow (PF) algorithm [22], which focuses on using an optimized combination of subdetector information to reconstruct each individual particle with the highest fidelity. The energy resolution resulting from this reconstruction is between 1–3% for the momentum range relevant for this analysis for electrons, photons, muons, and taus, depending on the exact kinematics of the particular particle [23–25].

The particles reconstructed by the PF algorithm are used to construct composite objects like jets, hadronically-decaying taus, and missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$), defined as the magnitude of the vector sum of the transverse momenta (p_{T}) of all PF objects. The jets are identified using the anti-k_{T} jet algorithm [26] with a distance parameter of 0.5. In the 2011 dataset, an average of ten interactions (pileup) occur in each proton bunch crossing. To correct for the contribution to the jet energy due to pileup, the transverse energy density per unit area (ρ) of the pileup is computed [27, 28] for each event. The energy due to pileup is estimated as the product of ρ and the area of the jet, and is subtracted from the jet transverse energy (E_{T}) [29]. Subsequent to pileup subtraction, jet energy corrections are applied as a function of the jet E_{T} and η [30] to compensate for residual hadronic energy neglected by the jet clustering algorithm. Hadronically-decaying taus are reconstructed using the "hadron-plus-strips" algorithm [25], which reconstructs candidates with one or three charged pions and up to two neutral pions.

The Monte Carlo (MC) event generator PYTHIA (version 6.424) [31] is used to generate the simulated Higgs boson samples used in this analysis. The ZZ, WZ, and Zγ diboson background samples are generated using MadGraph 5.1.3 [32]. The generators use the CTEQ6L[33] set of parton distribution functions. While the next-to-leading-order (NLO) calculations are used for background cross sections, the cross sections used for the Higgs boson signal samples are computed at next-to-NLO [10]. For all processes, the detector response is simulated using a detailed description of the CMS detector, based on the GEANT4 package [34]. The simulations include pileup interactions matching the distribution of the number of such interactions observed in data.

3 Trigger and event selection

Candidate signal events are recorded if they pass a trigger requiring the presence of a high-p_T electron pair, muon pair, or electron-muon pair. The leading and subleading triggering lepton candidates are required to have $p_\mathrm{T} > 17\,\mathrm{GeV}$ and $p_\mathrm{T} > 8\,\mathrm{GeV}$, respectively. Offline, electron and muon candidates are subjected to standardized quality criteria described in ref. [35] and refs. [36, 37], respectively, to ensure high efficiency and precision. In the $3L$ channels, the electron candidate is subjected to a multivariate selection exploiting the correlations among electron observables [38] to reduce the rate of quark or gluon jets misidentified as electrons. Three (four) charged-lepton candidates with total charge $\pm 1(0)$ are required for the $3L$ and $4L$ channels, respectively. The two triggering light leptons are required to have $p_\mathrm{T} > 20\,\mathrm{GeV}$ and $p_\mathrm{T} > 10\,\mathrm{GeV}$, respectively. Non-triggering e and μ candidates are required to have $p_\mathrm{T} > 10\,\mathrm{GeV}$. The minimum p_T of τ_h candidates is $20\,\mathrm{GeV}$. Electron, muon, and τ_h candidates are required to originate from the primary vertex of the event, which is chosen as the vertex with highest $\sum p_\mathrm{T}^2$, where the sum is made using the tracks associated with the vertex. In the $4L$ channels, two leptons are required to be compatible with the decay of a Z boson, having the same flavor, opposite charge, and invariant mass within $20\,\mathrm{GeV}$ of the mass of the Z boson.

Leptons from the Higgs or vector-boson decays are typically isolated from the rest of the event activity, in contrast to background from jets, which are immersed in considerable hadronic activity. For each lepton candidate a cone defined by $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where ϕ is the azimuthal angle in radians, is constructed around the lepton direction at the event vertex. The size of the cone is 0.4 for e and μ candidates, and 0.5 for τ_h candidates in the $2\ell\tau_h$ and $4L$ channels. In the 3ℓ channels a smaller $\Delta R = 0.3$ cone is used. An isolation variable is constructed from the scalar sum of the transverse energy of all charged and neutral reconstructed particles contained within the cone, excluding the contribution from the lepton candidate itself. The contributions of charged particles coming from pileup interactions longitudinally displaced from the primary event vertex are excluded from the isolation variable. In the $2\ell\tau_h$ and $4L$ channels, the neutral contribution to the isolation variable from the pileup is estimated using the energy deposited by tracks from pileup vertices which point into the isolation cone, and is subtracted from the isolation variable. In the 3ℓ channels, the neutral contribution from pileup, which is typically composed of many low p_T particle candidates, is mitigated by excluding neutral particle candidates with $p_\mathrm{T} < 1\,\mathrm{GeV}$ from the isolation variable calculation.

For a Higgs boson mass of 125 GeV, the $\mathrm{H} \to \mathrm{WW} \to \ell\ell$ branching fraction is approximately 1.8 times larger than the $\mathrm{H} \to \tau\tau \to \ell\ell$ branching fraction [10]. Accordingly, the expected signal yield in the 3ℓ channel is dominated by the $\mathrm{H} \to \mathrm{WW}$ decay. Conversely, the $\mathrm{H} \to \tau\tau \to \ell\tau_h$ decays dominate the signal yield in the $2\ell\tau_h$ and $4L$ channels, as their branching fraction is 3.6 times larger than the $\mathrm{H} \to \mathrm{WW} \to \ell\tau_h$ branching fraction.

When the Higgs boson mass is above approximately $140\,\mathrm{GeV}$, the $\mathrm{H} \to \mathrm{WW}$ decay dominates in all channels. The topological event selections are optimized for the WWW final states in the 3ℓ channels, and for the $\mathrm{H} \to \tau\tau$ final state in the $2\ell\tau_h$ and $4L$ channels. In all channels, top-quark background events are suppressed by vetoing events containing

jets with $p_T > 20\,\text{GeV}$ that are identified as coming from b quarks [39, 40]. Events with additional isolated leptons (e, μ, or τ_h candidates) are vetoed. In the 3L channels, this requirement removes diboson ZZ $\rightarrow 4\ell$ background events. The lepton veto ensures that each channel is exclusive to all other channels presented in this paper and to the published CMS H $\rightarrow$ ZZ $\rightarrow 4\ell$ analysis [41].

In the 3ℓ channel, the dominant WZ $\rightarrow \ell\nu\ell\ell$ background is reduced by rejecting events with a same-flavor opposite-charge lepton pair with an invariant mass within 25 GeV of the Z-boson mass (m_Z). Events are rejected if there is a jet with $E_T > 40\,\text{GeV}$ to remove $t\bar{t}$ background events, which typically contain multiple high-p_T jets. In WH $\rightarrow$ WWW events, the neutrinos associated with the decays of the W bosons escape detection, resulting in large E_T^{miss}. Drell-Yan background events are expected to have low E_T^{miss}. To mitigate degradation of the E_T^{miss} resolution due to pileup, the minimum of two different observables is defined as the E_T^{miss}. The first includes all PF particle candidates of the event in the computation of E_T^{miss}, while the second uses only the charged PF particle candidates associated with the primary vertex. To improve rejection of background events with E_T^{miss} associated with poorly reconstructed leptons, the "projected" E_T^{miss} [42] is used. This projected E_T^{miss} is defined as the component of E_T^{miss} transverse to the direction of the closest lepton if it is closer than $\pi/2$ in azimuthal angle, and the full E_T^{miss} otherwise. The use of both E_T^{miss} definitions exploits the presence of a correlation between the two observables in signal events with genuine E_T^{miss} and its absence otherwise. Events in the 3ℓ channel are required to have projected E_T^{miss} above 40 GeV. To further reject WZ background events, the constituents of at least one opposite-charge any-flavor (OCAF) lepton pair must be separated by less than 2 in ΔR. Finally, the smallest OCAF pair mass must be above 12 GeV and below 100 GeV to suppress Wγ and WZ events, respectively.

In the 2$\ell\tau_h$ channels, the dominant backgrounds are Z, W, and $t\bar{t}$ events with an additional quark or gluon jet incorrectly identified as an e, μ, or τ_h. The probability for a quark or gluon jet to pass the τ_h identification (misidentified τ_h) is 10 to 100 times greater than the probability for a jet to pass the e or μ identification and isolation requirements. To remove the large Z/$\gamma^* \rightarrow \ell^+\ell^-+$ misidentified τ_h and $t\bar{t}$ backgrounds, the light leptons eμ ($\mu\mu$) are required to have the same charge in the e$\mu\tau_h$ ($\mu\mu\tau_h$) channel. The variable L_T, defined as the scalar sum of the transverse energy of the three lepton candidates in the event, is required to be larger than 80 GeV. This requirement is effective in rejecting some of the background coming from the semi-leptonic decays of heavy quarks, which has a softer p_T spectrum.

The largest background in the 4L channels is the irreducible diboson ZZ background. The dominant reducible backgrounds in the 4L channels are Z + 2 jet events, where both jets are misidentified as leptons, and WZ events with one additional misidentified jet. These backgrounds are highly suppressed by the lepton identification and isolation requirements. There is an additional non-negligible contribution from $t\bar{t} \rightarrow \ell^+\nu\ell^-\bar{\nu}b\bar{b}$ events which is suppressed by the lepton identification, isolation, and the requirement of a Z-boson candidate present in the event.

The resulting signal efficiencies after all selections vary between 0.1% and 12%, depending on production mode, decay channel, and Higgs boson mass, and are given in table 1.
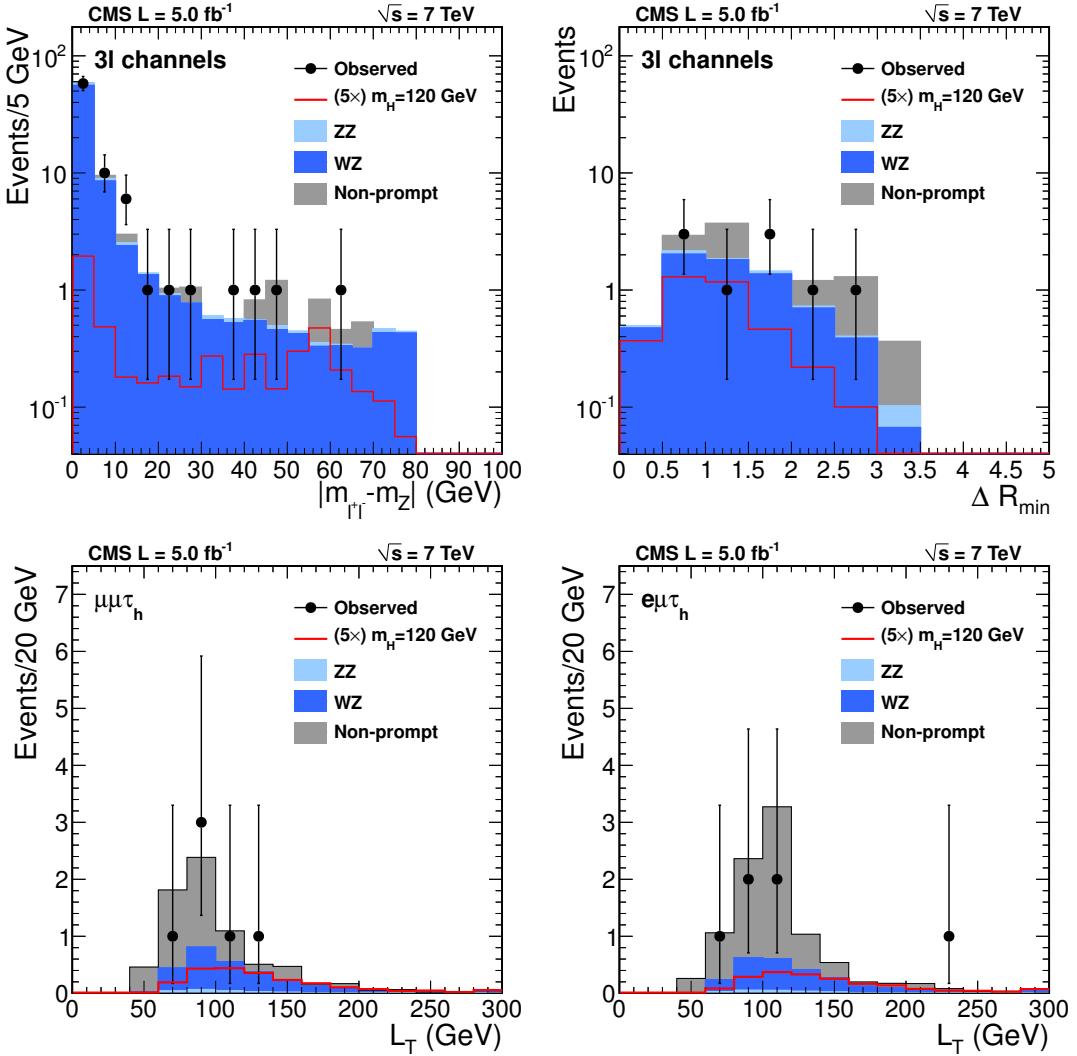
Figure 1. Distributions of the dilepton mass difference with respect to m_Z in the 3ℓ channels (upper left), the smallest ΔR distance between the opposite-charge lepton pairs in the 3ℓ channels (upper right), L_T variable in the $\mu\mu\tau_h$ channel (bottom left), and L_T variable in the $e\mu\tau_h$ channel (bottom right) after applying all other requirements. The WZ, ZZ, and non-prompt backgrounds are estimated using the techniques described in section 4. The expected contribution from a SM Higgs boson with a mass of 120 GeV, scaled up by a factor of five, is also shown.

The performance of the 3ℓ Z-boson mass and minimum ΔR requirements, and the $e\mu\tau_h$ and $\mu\mu\tau_h$ L_T selections are illustrated in figure 1.

The event selections used in the H $\rightarrow \gamma\gamma$ and H $\rightarrow b\bar{b}$ channels are described in detail elsewhere [20, 21]. Briefly, AP H $\rightarrow \gamma\gamma$ candidate events are selected by requiring the presence of two high-p_T photon candidates and an isolated electron or muon. Events in the AP H $\rightarrow b\bar{b}$ analysis are selected by requiring two jets identified as coming from b quarks and a vector boson candidate with high p_T. The vector boson candidate can decay into one light lepton, two light leptons, or high E_T^{miss}, corresponding to the W $\rightarrow \ell\nu$, Z $\rightarrow \ell\ell$, or Z $\rightarrow \nu\nu$ decay modes, respectively.

m_H	3ℓ channels		2$\ell\tau_h$ channels		4L channels	
	WH $\to$ W$\tau\tau$	WH $\to$ WWW	WH $\to$ W$\tau\tau$	WH $\to$ WWW	ZH $\to$ Z$\tau\tau$	ZH $\to$ ZWW
110 GeV	0.12% $\pm$ 0.03%	2.6% $\pm$ 0.2%	0.8% $\pm$ 0.1%	0.2% $\pm$ 0.1%	4.3% $\pm$ 0.8%	-
120 GeV	0.17% $\pm$ 0.02%	3.4% $\pm$ 0.3%	0.9% $\pm$ 0.1%	0.3% $\pm$ 0.1%	4.3% $\pm$ 0.4%	5.1% $\pm$ 1.6%
130 GeV	0.19% $\pm$ 0.03%	4.2% $\pm$ 0.3%	1.1% $\pm$ 0.1%	0.4% $\pm$ 0.1%	4.8% $\pm$ 0.8%	7.0% $\pm$ 2.3%
140 GeV	0.18% $\pm$ 0.03%	4.7% $\pm$ 0.4%	1.2% $\pm$ 0.1%	0.5% $\pm$ 0.1%	5.0% $\pm$ 0.8%	7.1% $\pm$ 2.3%
150 GeV	0.22% $\pm$ 0.03%	5.2% $\pm$ 0.4%	1.4% $\pm$ 0.1%	0.5% $\pm$ 0.1%	4.9% $\pm$ 0.8%	7.7% $\pm$ 2.4%
160 GeV	0.20% $\pm$ 0.04%	6.2% $\pm$ 0.5%	1.6% $\pm$ 0.1%	0.6% $\pm$ 0.1%	5.4% $\pm$ 0.9%	11.2% $\pm$ 3.0%

Table 1. Efficiency for signal events to pass the selections in each channel for the different Higgs boson production and decay modes. The efficiency is defined with respect to WH and ZH events in which the W or Z boson decays to final states containing an e, a μ, or a τ. The residual corrections described in section 5 are applied, and the uncertainties correspond to the combined statistical and systematic uncertainties; theoretical uncertainties are not included. The uncertainty on the efficiency is dominated by the systematic (statistical) uncertainty for the H $\to \tau\tau$ (H $\to$ W$^+$W$^-$) decay in the 2$\ell\tau_h$ and 4L channels, with the reverse being true in the 3ℓ channels.

4 Background estimation

A combination of methods using data control samples and detailed studies with simulated events is used to estimate residual background contributions after selection. There are two background categories: irreducible diboson backgrounds, and events with at least one non-prompt lepton. The irreducible diboson backgrounds consist of WZ and ZZ events with the same number of isolated prompt leptons as the signal processes, and Zγ events with an asymmetric photon conversion. The WZ and ZZ backgrounds are estimated using simulated samples, and are scaled by a residual correction factor obtained by comparing the observed data in diboson-enriched sidebands with the prediction from simulation.

The non-prompt lepton backgrounds arise from decays of charm and beauty quarks and hadrons misidentified as leptons. The non-prompt backgrounds are evaluated using data with the "misidentification rate method". The misidentification probabilities as a function of candidate p_T and η, $f(p_\mathrm{T}, \eta)$, for non-prompt lepton candidates (e, μ, or τ_h) to pass the final identification and isolation criteria are measured in independent, highly pure control samples of multijet, W $\to \mu\nu +$ jet, and Z $\to \mu\mu +$ jet events. The control samples are exclusive to the signal sample due to different final state topology requirements. To minimize possible biases, the same trigger, kinematic, and quality criteria used in the final analysis are applied to the control samples. Sidebands are defined for each channel, where all selection criteria are satisfied, with the exception that the final identification or isolation criterion is not satisfied for one or more of the final-state lepton candidates. The sidebands are dominated by the non-prompt backgrounds. The number of non-prompt background events in the final selection is estimated by weighting each observed non-prompt lepton candidate in the sideband by its corrected probability $f(p_\mathrm{T}, \eta)/(1 - f(p_\mathrm{T}, \eta))$ to pass the final identification and isolation criteria. The estimate of the non-prompt yield in the final selection is computed using all sideband events where any two light-lepton candidates pass all requirements and the third candidate fails the isolation requirement. In the 2$\ell\tau_h$ channels, the backgrounds with a misidentified τ_h and two genuine prompt light leptons

(eμ or $\mu\mu$) are negligible, due to the requirement that the two light leptons have the same charge. Accordingly, the misidentified-τ_h sideband is ignored in these channels.

Background processes with more than one non-prompt lepton, such as multijet events, W $\to \tau\nu$ + 2jet in the $2\ell\tau_h$ channels, or Z + 2jet in the $4L$ channels, are counted twice by this method since they are present in both sidebands. The double-counting is corrected using a high-purity control region with two non-prompt leptons selected by requiring two lepton candidates to fail the isolation requirement simultaneously. The observed events in the sideband are weighted by the corrected probability $f_1(1 - f_1)^{-1}f_2(1 - f_2)^{-1}$, where f_1 and f_2 are the mis-identification probabilities for the leading and subleading lepton candidates, respectively, that both candidates will pass the final identification and isolation requirements; the weighted events are an independent estimate of the quantity that was double-counted. The double-counted events are removed from the total background estimate by subtracting the independent estimate of the background with two misidentified leptons.

In the $3L$ channels, the irreducible WZ background normalization is estimated in data using a control sample of observed events with three light leptons where one of the same-flavor opposite-charge lepton pairs is compatible with a Z boson using a ± 15 GeV mass window. The control sample is completely dominated by WZ events. The same trigger and lepton identification requirements described in section 3 are applied. The ZZ background is largely reduced by the veto of events containing an additional e, μ, or τ_h candidate. The theoretical NLO calculation [43] is used as the normalization of the ZZ background. The Zγ background, where the γ is misidentified as an electron through an asymmetric conversion is estimated from simulation. In the 3ℓ channels the expected contribution from this background is negligible after the E_T^{miss} requirement, and it is highly suppressed due to the small branching fraction in the τ_h channels.

In the $4L$ channels, WZ events have at least one non-prompt lepton and are estimated using the misidentification-rate method described above. The dominant background comes from irreducible ZZ events. The number of ZZ background events $N_{\mathrm{ZZ}}^{\mathrm{est}}$ is estimated by scaling the observed inclusive Z yield $N_{\mathrm{Z}}^{\mathrm{obs}}$ by the expected ratio of ZZ and Z production:

$$N_{\mathrm{ZZ}}^{\mathrm{est}} = N_{\mathrm{Z}}^{\mathrm{obs}} \cdot \frac{\sigma_{\mathrm{ZZ}}^{\mathrm{SM}}}{\sigma_{\mathrm{Z}}^{\mathrm{SM}}} \cdot \frac{A_{\mathrm{ZZ}}}{A_{\mathrm{Z}}},$$

where $\sigma_{\mathrm{ZZ}}^{\mathrm{SM}}$ [43] and $\sigma_{\mathrm{Z}}^{\mathrm{SM}}$ are the theoretical SM cross sections, and A_{ZZ} and A_{Z} are the acceptances to pass all event selections for the ZZ and Z processes, respectively. The acceptances A are estimated using MC simulation. The Zγ background is negligible in the $4L$ channels.

5 Efficiencies and systematic uncertainties

The trigger, identification, and isolation efficiencies for electrons and muons are measured with data using the "tag-and-probe" technique [38] in Z $\to \ell\ell$ events. The τ_h identification efficiency is measured with an uncertainty of 6% using the tag-and-probe technique in Z$\to \tau\tau \to \mu\tau_h$ events [25]. Efficiencies for the Higgs boson signal and WZ, ZZ, and Zγ

diboson samples are estimated using MC simulation, and residual differences between the lepton efficiencies in the simulation and data are corrected by scaling the simulation to match the efficiency measured in data. The uncertainty on the residual correction is taken as a systematic uncertainty in the final result. The uncertainty on the b-tagging efficiency is 6% [21]. Uncertainties on the jet energy scale and $E_{\mathrm{T}}^{\mathrm{miss}}$ have been evaluated in Z + jet and γ + jet events [30], and are propagated to systematic uncertainties on the final yields. The uncertainty due to the pileup description is evaluated by varying the distribution of the estimated number of expected pileup interactions per event in data, and is 1% or less. There is a 2.2% uncertainty [17] on the total integrated luminosity of the collected data sample.

Two theoretical systematic uncertainties on the overall signal yield are considered. The uncertainty on the QCD factorization and renormalization scales affects the expected signal cross section and, in the 3ℓ channel, the efficiency of the jet veto. The effect of variations in the parton distribution functions, the value of α_s, and higher-order corrections are propagated to the efficiency of the signal selection using the PDF4LHC prescription [44–48].

The methods to estimate the different backgrounds are explained in section 4. For the $3L$ channels, the associated uncertainty on the diboson backgrounds is 12% and 4% for the WZ and ZZ components, respectively. In the $4L$ channels, the theoretical uncertainty of 10% on the ZZ production cross section [10] dominates the uncertainty on the estimate of the ZZ background. The uncertainty on the estimate of the non-prompt lepton backgrounds is 30% and is dominated by uncertainties in the measurement of the misidentification rate. The final estimate of the non-prompt backgrounds has an additional systematic uncertainty due to the limited number of observed events with leptons failing the isolation requirements. In the $e\mu\tau_h$ and $\mu\mu\tau_h$ mass spectra, a shape uncertainty [49] is added for each bin in the spectra, corresponding to the statistical uncertainty of the control region bin used to compute the non-prompt background estimate.

6 Results

After all selections, a total of 29 events are observed, while 33.5 ± 4.3 are expected from the background. The number of observed and expected background events are enumerated for each channel in table 2. The observed data are consistent with the expected yield from the backgrounds. The efficiency for signal events to pass all selections are detailed for each channel and Higgs boson mass, production mechanism, and decay mode in table 1. The efficiencies are defined with respect to events where all W and Z bosons decay to leptons (excluding $Z \rightarrow \nu\nu$ decays).

In the $2\ell\tau_h$ channels, it is not possible to definitively assign the same-charge electrons or muons to either the W or the Higgs boson candidate. However, as the signal is dominated by H $\rightarrow \tau\tau$ decays, the final-state light leptons produced in the decays of the τ leptons have a softer p_{T} spectrum than light leptons from W $\rightarrow \ell\nu$ decays, as they are associated with two neutrinos instead of one. Accordingly, we define the subleading light lepton and τ_h as the Higgs boson candidate. The invariant mass of the Higgs boson candidate is shown for the final selected events in the $2\ell\tau_h$ and $4L$ channels in figure 2.

| Channel | SM Higgs boson (120 GeV) | | Observed | All bkg. | ZZ | WZ | Non-prompt bkg. |
	H → ττ	H → WW			→ 4ℓ	→ 3ℓ	
3ℓ	0.13 ± 0.01	0.55 ± 0.04	7	8.45 ± 1.33	0.27 ± 0.06	5.65 ± 0.59	2.52 ± 1.19
2ℓτ_h	0.71 ± 0.06	0.05 ± 0.00	10	13.24 ± 2.62	0.38 ± 0.04	4.39 ± 0.60	8.47 ± 2.54
4L	0.55 ± 0.06	0.14 ± 0.05	12	11.82 ± 2.36	6.04 ± 0.62	5.78 ± 2.28	

Table 2. Observed number of events and expected number of signal and background (bkg) events for the different channels. The uncertainties correspond to the combined statistical and systematic uncertainty. The second and third columns give the expected yield of a Higgs boson signal ($m_H = 120\,\text{GeV}$) from the H → ττ and H → WW decays, respectively. The theoretical uncertainties on the signal yields are not included.
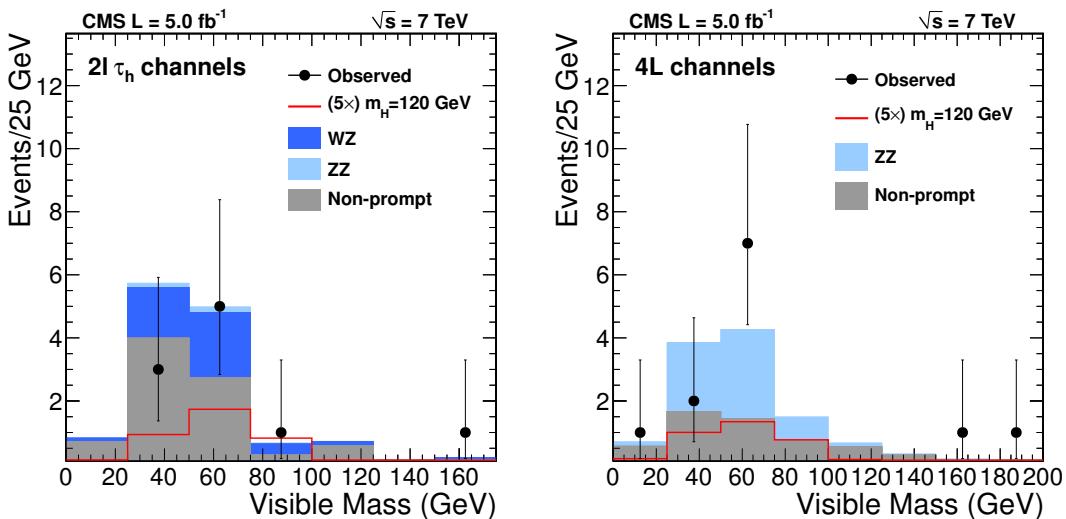
Figure 2. Visible invariant mass of the Higgs candidate in the $2\ell\tau_h$ channels (left), and $4L$ (right) channels after all selections. The WZ, ZZ, and non-prompt backgrounds are estimated using the techniques described in section 4. The expected contribution from a SM Higgs boson with a mass of 120 GeV, scaled up by a factor of five, is also shown.

7 Limits on SM Higgs boson production

In the searches presented in this paper, the observed events show no evidence for the presence of a Higgs boson signal, and we set 95% CL upper bounds on the Higgs boson associated production cross section. To obtain exclusion limits we use the CL_s method [50–52] based on a binned likelihood of the invariant mass spectrum in the $e\mu\tau_h$ and $\mu\mu\tau_h$ channels (figure 2), and the number of observed and expected events in the 3ℓ and $4L$ channels. The non-prompt background mass spectra for the $2\ell\tau_h$ channels has a shape uncertainty for each bin in the spectra. Systematic uncertainties are represented in the limit computation by nuisance parameters using a log-normal constraint. Correlated uncertainties among channels are represented by common nuisance parameters. The nuisance parameters are varied from one pseudoexperiment to the next in the calculation of the CL_s test statistic.

Figure 3 shows the observed and median expected 95% CL upper limits on SM Higgs boson production set by this analysis for each channel individually and for the combination of all three. The limit is expressed in terms of the ratio of the Higgs boson cross section

Channel	-2σ	-1σ	Expected	$+1\sigma$	$+2\sigma$	Observed
3ℓ	4.93	5.99	8.28	11.78	16.47	7.21
$2\ell\tau_h$	7.95	8.69	11.09	15.95	24.74	11.81
$4L$	6.79	8.90	12.31	17.49	24.62	12.27
$\gamma\gamma$	5.82	6.51	7.62	10.86	15.80	8.67
$b\overline{b}$	2.31	2.92	3.94	5.73	8.34	5.25
Combined	1.65	1.89	2.69	3.79	5.43	3.32

Table 3. Exclusive observed and expected limits for each sub-channel and for the total combination, at 95% CL, on SM Higgs boson production for a Higgs boson mass of 125 GeV.

times the relevant branching fractions, to that predicted in the SM, $\sigma/\sigma_{\mathrm{SM}}$. The two bands give the variation around the median expected limit by one and two standard deviations. We set a 95% CL upper limit on $\sigma/\sigma_{\mathrm{SM}}$ in the range 3.1–9.1.

We additionally combine the searches presented here with the CMS AP Higgs boson searches, using the same dataset, in the H $\rightarrow$ $\gamma\gamma$ [20] and H $\rightarrow$ b$\overline{b}$ [21] decay modes. The H $\rightarrow$ $\gamma\gamma$ and H $\rightarrow$ b$\overline{b}$ searches are included in the limit combination for Higgs boson masses below 150 GeV and 135 GeV, respectively. The treatment of systematic uncertainties in these channels is similar to that described in section 5. The potential contributions of the VBF and GF SM Higgs boson production mechanisms to these analyses are negligible. The associated t$\overline{t}$H production mechanism contributes approximately 5% and 14% of the expected signal yield in the $4L$ and AP H $\rightarrow$ $\gamma\gamma$ channels, respectively. The contributions from t$\overline{t}$H to the other channels are negligible. The limits for each sub-channel and for the combination of all CMS AP searches are shown in figure 4. The full combination excludes, at 95% CL, the associated production of SM Higgs bosons at 2.1–3.7 times the SM prediction for Higgs boson masses below 170 GeV. The observed and expected limits for a Higgs boson mass of 125 GeV are enumerated for the full combination and for each exclusive sub-channel in table 3.

8 Summary

A search for the standard model Higgs boson, produced in association with a W or Z boson, has been described. The search is conducted using final states with three or four isolated leptons in the entire 2011 CMS dataset. The analysis is sensitive to associated production where the Higgs boson decays into either a τ pair or W-boson pair. A total of 29 events are observed, and are compatible with the background prediction. Upper limits of about 2.6–9 times greater than the predicted value are set at 95% CL for the product of the SM Higgs boson associated production cross section and decay branching fraction in the mass range $110 < m_{\mathrm{H}} < 200$ GeV. The searches presented in this paper are combined with two other CMS associated production Higgs boson searches using the H $\rightarrow$ $\gamma\gamma$ and H $\rightarrow$ b$\overline{b}$ decay modes. While the inclusive combination excludes, at 95% CL, the associated production of SM Higgs bosons at 3.3 times the SM prediction for a Higgs boson with a mass of 125 GeV, all of the exclusive limits in each decay mode, and the inclusive combined limit, are consistent with the predictions of the SM.
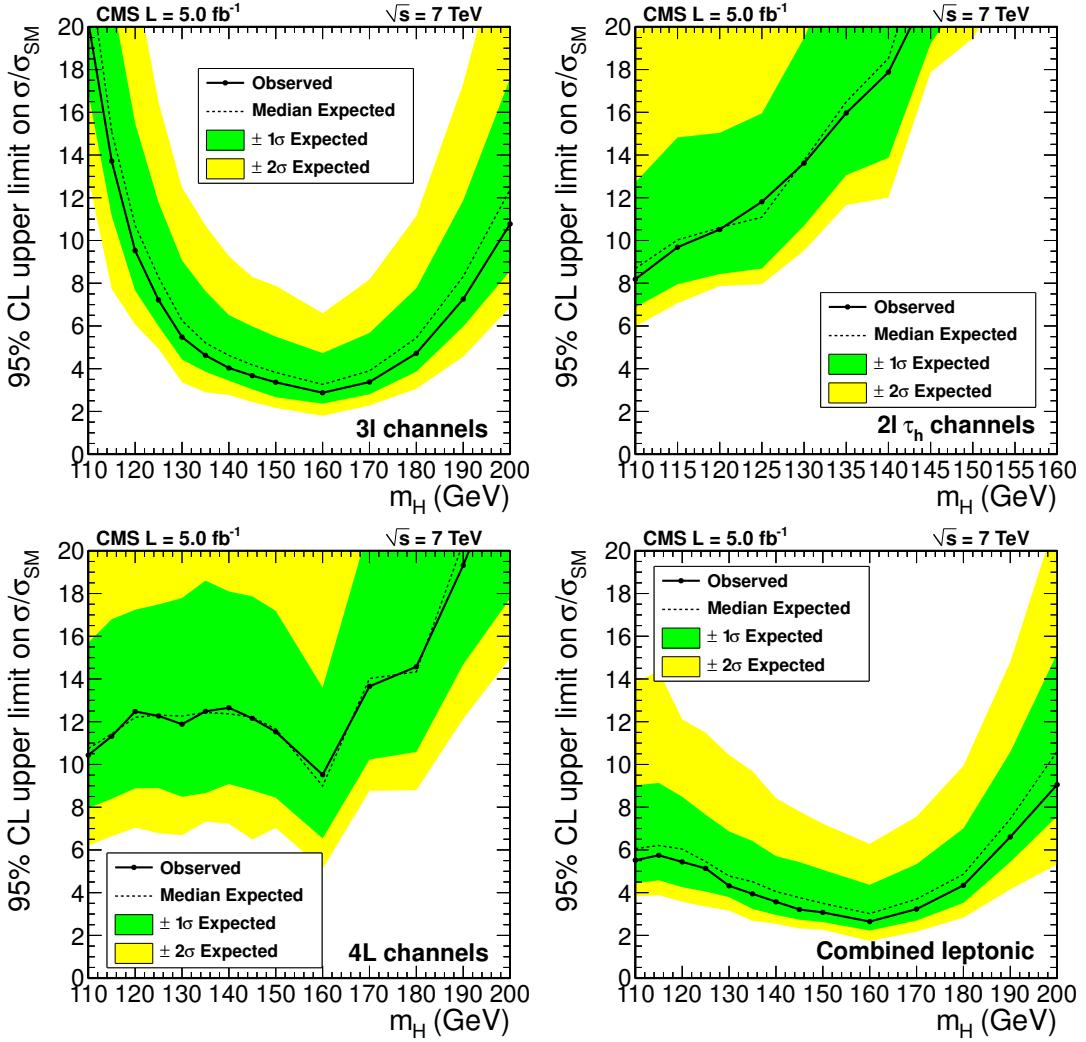
Figure 3. Observed and expected limits, at 95% CL, on SM Higgs boson production using the 3ℓ (top left), $2\ell\tau_h$ (top right), and $4L$ (bottom left) channels. The combination of the three channels is shown bottom right.

Figure 4. At left, the observed and expected limits, at 95% CL, on SM Higgs boson production combining the AP searches presented in this paper with the previously published AP $H \to \gamma\gamma$ [20] and $H \to b\bar{b}$ [21] searches. At right, the exclusive observed and expected limits (indicated by the solid and dashed lines respectively) are shown for each sub-channel.

References

[1] S.L. Glashow, *Partial-symmetries of weak interactions*, *Nucl. Phys.* **22** (1961) 579 [INSPIRE].

[2] S. Weinberg, *A model of leptons*, *Phys. Rev. Lett.* **19** (1967) 1264 [INSPIRE].

[3] A. Salam, *Weak and electromagnetic interactions*, in *Elementary particle physics: relativistic groups and analyticity*, N. Svartholm, ed., Almqvist & Wiksell, Sweden (1968).

[4] F. Englert and R. Brout, *Broken symmetry and the mass of gauge vector mesons*, *Phys. Rev. Lett.* **13** (1964) 321 [INSPIRE].

[5] P.W. Higgs, *Broken symmetries, massless particles and gauge fields*, *Phys. Lett.* **12** (1964) 132 [INSPIRE].

[6] P.W. Higgs, *Broken symmetries and the masses of gauge bosons*, *Phys. Rev. Lett.* **13** (1964) 508 [INSPIRE].

[7] G. Guralnik, C. Hagen and T. Kibble, *Global conservation laws and massless particles*, *Phys. Rev. Lett.* **13** (1964) 585 [INSPIRE].

[8] P.W. Higgs, *Spontaneous symmetry breakdown without massless bosons*, *Phys. Rev.* **145** (1966) 1156 [INSPIRE].

[9] T. Kibble, *Symmetry breaking in nonAbelian gauge theories*, *Phys. Rev.* **155** (1967) 1554 [INSPIRE].

[10] LHC HIGGS CROSS SECTION WORKING GROUP, *Handbook of LHC Higgs cross sections: inclusive observables*, CERN-2011-002 (2011) [arXiv:1101.0593].

[11] LEP WORKING GROUP FOR HIGGS BOSON SEARCHES, ALEPH, DELPHI, L3, OPAL collaboration, R. Barate et al., *Search for the standard model Higgs boson at LEP*, *Phys. Lett.* **B 565** (2003) 61 [hep-ex/0306033] [INSPIRE].

[12] ATLAS collaboration, G. Aad et al., *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 [arXiv:1207.7214] [INSPIRE].

[13] CMS collaboration, S. Chatrchyan et al., *Observation of a new boson at a mass of* 125 *GeV with the CMS experiment at the LHC*, *Phys. Lett.* **B 716** (2012) 30 [arXiv:1207.7235] [INSPIRE].

[14] CMS collaboration, S. Chatrchyan et al., *Combined results of searches for the standard model Higgs boson in pp collisions at* $\sqrt{s} = 7$ *TeV*, *Phys. Lett.* **B 710** (2012) 26 [arXiv:1202.1488] [INSPIRE].

[15] CDF COLLABORATION, D0 collaboration, T. Aaltonen et al., *Evidence for a particle produced in association with weak bosons and decaying to a bottom-antibottom quark pair in Higgs boson searches at the Tevatron*, *Phys. Rev. Lett.* **109** (2012) 071804 [arXiv:1207.6436] [INSPIRE].

[16] CMS collaboration, *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004.

[17] CMS collaboration, *Absolute calibration of the luminosity measurement at CMS: winter 2012 update*, PAS-SMP-12-008 (2012).

[18] ATLAS collaboration, G. Aad et al., *Search for the standard model Higgs boson produced in association with a vector boson and decaying to a b-quark pair with the ATLAS detector*, arXiv:1207.0210 [INSPIRE].

[19] A. Azatov et al., *Determining Higgs couplings with a model-independent analysis of* $h \to \gamma\gamma$, *JHEP* **06** (2012) 134 [arXiv:1204.4817] [INSPIRE].

[20] CMS collaboration, S. Chatrchyan et al., *Search for a fermiophobic Higgs boson in pp collisions at* $\sqrt{s} = 7$ *TeV*, *JHEP* **09** (2012) 111 [arXiv:1207.1130] [INSPIRE].

[21] CMS collaboration, S. Chatrchyan et al., *Search for the standard model Higgs boson decaying to bottom quarks in pp collisions at* $\sqrt{s} = 7$ *TeV*, *Phys. Lett.* **B 710** (2012) 284 [arXiv:1202.4195] [INSPIRE].

[22] CMS collaboration, *Particle-flow event reconstruction in CMS and performance for jets, taus and MET*, PAS-PFT-09-001 (2009).

[23] CMS collaboration, *Electron reconstruction and identification at $\sqrt{s} = 7$ TeV*, PAS-EGM-10-004 (2010).

[24] CMS collaboration, *Performance of CMS muon reconstruction in cosmic-ray events*, 2010 *JINST* **5** T03022.

[25] CMS collaboration, *Performance of τ-lepton reconstruction and identification in CMS*, 2011 *JINST* **7** P01001.

[26] M. Cacciari, G.P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [InSPIRE].

[27] M. Cacciari, G.P. Salam and G. Soyez, *FastJet user manual*, *Eur. Phys. J.* **C 72** (2012) 1896 [arXiv:1111.6097] [InSPIRE].

[28] M. Cacciari and G.P. Salam, *Dispelling the N^3 myth for the k_t jet-finder*, *Phys. Lett.* **B 641** (2006) 57 [hep-ph/0512210] [InSPIRE].

[29] M. Cacciari and G.P. Salam, *Pileup subtraction using jet areas*, *Phys. Lett.* **B 659** (2008) 119 [arXiv:0707.1378] [InSPIRE].

[30] CMS collaboration, S. Chatrchyan et al., *Determination of jet energy calibration and transverse momentum resolution in CMS*, 2011 *JINST* **6** P11002 [arXiv:1107.4277] [InSPIRE].

[31] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [hep-ph/0603175] [InSPIRE].

[32] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, *MadGraph 5: going beyond*, *JHEP* **06** (2011) 128 [arXiv:1106.0522] [InSPIRE].

[33] H.-L. Lai et al., *Uncertainty induced by QCD coupling in the CTEQ global analysis of parton distributions*, *Phys. Rev.* **D 82** (2010) 054021 [arXiv:1004.4624] [InSPIRE].

[34] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [InSPIRE].

[35] CMS collaboration, *Electron reconstruction and identification at $\sqrt{s} = 7$ TeV*, PAS-EGM-10-004 (2010).

[36] CMS collaboration, *Performance of muon identification in pp collisions at $\sqrt{s} = 7$ TeV*, PAS-MUO-10-002 (2010).

[37] CMS collaboration, S. Chatrchyan et al., *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 [arXiv:1202.1489] [InSPIRE].

[38] CMS collaboration, V. Khachatryan et al., *Measurements of inclusive W and Z cross sections in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **01** (2011) 080 [arXiv:1012.2466] [InSPIRE].

[39] CMS collaboration, *Algorithms for b jet identification in CMS*, PAS-BTV-09-001 (2009).

[40] CMS collaboration, *Commissioning of b-jet identification with pp collisions at $\sqrt{s} = 7$ TeV*, PAS-BTV-10-001 (2010).

[41] CMS collaboration, S. Chatrchyan et al., *Search for the standard model Higgs boson in the decay channel $H \to ZZ \to 4$ leptons in pp collisions at $\sqrt{s} = 7$ TeV*, *Phys. Rev. Lett.* **108** (2012) 111804 [arXiv:1202.1997] [InSPIRE].

[42] CDF collaboration, T. Aaltonen et al., *Measurement of the W^+W^- production cross section and search for anomalous $WW\gamma$ and WWZ couplings in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **104** (2010) 201801 [arXiv:0912.4500] [InSPIRE].

[43] J.M. Campbell and R. Ellis, *MCFM for the Tevatron and the LHC*, *Nucl. Phys. Proc. Suppl.* **205-206** (2010) 10 [arXiv:1007.3492] [ɪɴSPIRE].

[44] M. Botje et al., *The PDF4LHC working group interim recommendations*, arXiv:1101.0538 [ɪɴSPIRE].

[45] S. Alekhin et al., *The PDF4LHC working group interim report*, arXiv:1101.0536 [ɪɴSPIRE].

[46] H.-L. Lai et al., *New parton distributions for collider physics*, *Phys. Rev.* **D 82** (2010) 074024 [arXiv:1007.2241] [ɪɴSPIRE].

[47] A. Martin, W. Stirling, R. Thorne and G. Watt, *Parton distributions for the LHC*, *Eur. Phys. J.* **C 63** (2009) 189 [arXiv:0901.0002] [ɪɴSPIRE].

[48] R.D. Ball et al., *Impact of heavy quark masses on parton distributions and LHC phenomenology*, *Nucl. Phys.* **B 849** (2011) 296 [arXiv:1101.1300] [ɪɴSPIRE].

[49] J.S. Conway, *Nuisance parameters in likelihoods for multisource spectra*, in the proceedings of *PHYSTAT 2011 workshop on statistical issues related to discovery claims in search experiments and unfolding*, Januray 17–20, CERN, Switzerland (2011) CERN-2011-006 (2011).

[50] T. Junk, *Confidence level computation for combining searches with small statistics*, *Nucl. Instrum. Meth.* **A 434** (1999) 435 [hep-ex/9902006] [ɪɴSPIRE].

[51] A.L. Read, *Presentation of search results: The CL(s) technique*, *J. Phys.* **G 28** (2002) 2693 [ɪɴSPIRE].

[52] ATLAS, CMS collaboration, LHC HIGGS COMBINATION GROUP, *Procedure for the LHC Higgs boson search combination in summer 2011*, CMS-NOTE-2011-005 (2011).

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, J. Hammer, N. Hörmann, J. Hrubec, M. Jeitler[1], W. Kiesenhofer, V. Knünz, M. Krammer[1], D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, G. Walzel, E. Widl, 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. Bansal, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, Z. Staykova, 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, 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, N. Strobbe, F. Thyssen, M. Tytgat, P. Verwilligen, 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[2], J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul, 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, D. De Jesus Damiao, 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, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, L. Soares Jorge, A. Sznajder

Instituto de Fisica Teorica, Universidade Estadual Paulista, Sao Paulo, Brazil

C.A. Bernardes[3], F.A. Dias[4], T.R. Fernandez Perez Tomei, E.M. Gregores[3], C. Lagana, F. Marinho, P.G. Mercadante[3], S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev[5], P. Iaydjiev[5], 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 Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China

C. Asawatangtrakuldee, Y. Ban, S. Guo, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, D. Wang, L. Zhang, B. Zhu, W. Zou

Universidad de Los Andes, Bogota, Colombia

C. Avila, 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[5]

University of Split, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, S. Morovic

University of Cyprus, Nicosia, Cyprus

A. Attikis, M. Galanti, 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], S. Khalil[8], M.A. Mahmoud[10], A. Radi[11,12]

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

M. Kadastik, M. Müntel, 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

K. Banzuzi, A. Karjalainen, A. Korpela, T. Tuuva

DSM/IRFU, CEA/Saclay, Gif-sur-Yvette, France

M. Besancon, S. Choudhury, 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, I. Shreyber, M. Titov

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj[13], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, 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, M. Cardaci, E.C. Chabert, C. Collard, E. Conte[14], F. Drouhin[14], C. Ferro, J.-C. Fontaine[14], D. Gelé, U. Goerlach, 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, Villeurbanne, France

F. Fassi, D. Mercier

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, J. Chasserat, R. Chierici[5], D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, 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

G. Anagnostou, S. Beranek, 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, J. Lingemann, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

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

M. Bontenackels, V. Cherepanov, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, 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, 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, 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, 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

C. Autermann, V. Blobel, J. Draeger, H. Enderle, J. Erfle, U. Gebbert, M. Görner, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, B. Mura, F. Nowak, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff[5], C. Hackstein, F. Hartmann, T. Hauth[5], M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, 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, A. Scheurer, 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. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, 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[5], P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary

G. Bencze, C. Hajdu[5], P. Hidas, D. Horvath[18], F. Sikler, V. Veszpremi, G. Vesztergombi[19]

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

M. Bansal, S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Kaur, M.Z. Mehta, 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, V. Sharma, R.K. Shivpuri

Saha Institute of Nuclear Physics, Kolkata, India

S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, P. Mehta, A.K. Mohanty[5], L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, S. Ganguly, M. Guchait[20], M. Maity[21], 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, H. Bakhshiansohi[22], S.M. Etesami[23], A. Fahim[22], M. Hashemi, H. Hesari, A. Jafari[22], M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh[24], M. Zeinali[23]

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,5], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c,5], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c], M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], A. Pompili[a,b], G. Pugliese[a,c], G. Selvaggi[a,b], L. Silvestris[a], G. Singh[a,b], R. Venditti[a,b], 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,5], P. Giacomelli[a], C. Grandi[a], L. Guiducci[a,b], S. Marcellini[a], G. Masetti[a], M. Meneghelli[a,b,5], 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], 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,5}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, S. Colafranceschi^{25}, 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,b,5}, F. De Guio^{a,b}, L. Di Matteo^{a,b,5}, S. Fiorendi^{a,b}, S. Gennai^{a,5}, A. Ghezzi^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b,5}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, S. Sala^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^{a}, Università di Napoli "Federico II" ^{b}, Napoli, Italy

S. Buontempo^a, C.A. Carrillo Montoya^{a,5}, N. Cavallo^{a,26}, A. De Cosa^{a,b,5}, O. Dogangun^{a,b}, F. Fabozzi^{a,26}, A.O.M. Iorio^a, L. Lista^a, S. Meola^{a,27}, M. Merola^{a,b}, P. Paolucci^{a,5}

INFN Sezione di Padova ^{a}, Università di Padova ^{b}, Università di Trento (Trento) ^{c}, Padova, Italy

P. Azzi^a, N. Bacchetta^{a,5}, D. Bisello^{a,b}, A. Branca^{a,b,5}, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, F. 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}, F. Montecassiano^a, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b,5}, 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}, A. Lucaroni^{a,b,5}, 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,5}

INFN Sezione di Pisa ^{a}, Università di Pisa ^{b}, Scuola Normale Superiore di Pisa ^{c}, Pisa, Italy

P. Azzurri^{a,c}, G. Bagliesi^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c}, R. Dell'Orso^a, F. Fiori^{a,b,5}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,28}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A.T. Serban^{a,29}, P. Spagnolo^a, P. Squillacioti^{a,5}, R. Tenchini^a, G. Tonelli^{a,b,5}, A. Venturi^{a,5}, P.G. Verdini^a

INFN Sezione di Roma ^{a}, Università di Roma "La Sapienza" ^{b}, Roma, Italy

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b,5}, M. Diemoz^a, M. Grassi^{a,b,5}, E. Longo^{a,b}, P. Meridiani^{a,5}, F. Micheli^{a,b}, S. Nourbakhsh^{a,b}, G. Organtini^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, M. Sigamani^a, 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, M. Costa^{a,b}, N. Demaria^a, C. Mariotti^{a,5}, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^{a,5}, 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, A. Vilela Pereira^a

INFN Sezione di Trieste ^{a}**, Università di Trieste** ^{b}**, Trieste, Italy**

S. Belforte^a, V. Candelise^{a,b}, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, M. Marone^{a,b,5}, D. Montanino^{a,b,5}, A. Penzo^a, A. Schizzi^{a,b}

Kangwon National University, Chunchon, Korea

S.G. Heo, T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea

S. Chang, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, S.R. Ro, D.C. Son, T. 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

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

Y. Cho, 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, R. Magaña Villalba, J. Martínez-Ortega, A. Sánchez-Hernández, 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, 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, R. Gokieli, 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

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, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

P. Bunin, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, M. Savina, 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[5], N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia

A. Belyaev, E. Boos, V. Bunichev, M. Dubinin[4], 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

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin, I. Dremin, M. Kirakosyan, A. Leonidov, G. Mesyats, S.V. Rusakov, A. Vinogradov

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin[5], V. Kachanov, D. Konstantinov, A. Korablev, 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[30], M. Djordjevic, M. Ekmedzic, D. Krpic[30], 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[31], 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, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, 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. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, P. Musella, E. Nesvold, T. Orimoto, 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[32], T. Rommerskirchen, C. Rovelli[33], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[34], D. Spiga, A. Tsirou, G.I. Veres[19], J.R. Vlimant, H.K. Wöhri, S.D. Worm[35], 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, J. Sibille[36]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, 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, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tupputi, M. Verzetti

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, 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

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci[39], S. Cerci[40], C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar[41], A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk[42], A. Polatoz, K. Sogut[43], D. Sunar Cerci[40], B. Tali[40], H. Topakli[39], L.N. Vergili, 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, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey

E. Gülmez, B. Isildak[44], M. Kaya[45], O. Kaya[45], S. Ozkorucuklu[46], N. Sonmez[47]

Istanbul Technical University, Istanbul, Turkey

K. Cankocak

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

L. Levchuk

University of Bristol, Bristol, United Kingdom

F. Bostock, 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[35], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso[48], K.W. Bell, A. Belyaev[48], 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, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[38], A. Papageorgiou, J. Pela[5], M. Pesaresi, K. Petridis, M. Pioppi[49], D.M. Raymond, S. Rogerson, A. Rose, M.J. Ryan, 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, C. Henderson, P. Rumerio

Boston University, Boston, USA

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

Brown University, Providence, USA

J. Alimena, S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, D. Nguyen, M. Segala, T. Sinthuprasith, T. Speer, K.V. Tsang

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, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, T. Miceli, D. Pellett, F. Ricci-tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Jarvis, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, 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, G.Y. Jeng[50], 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, F. Golf, 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[51], 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, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, 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[4], V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

B. Akgun, V. Azzolini, 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, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, 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, 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. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, 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. Kilminster, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, J. Linacre, D. Lincoln, R. Lipton,

J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[52], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, 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[53], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, P. Sellers, 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

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

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavanaugh, C. Dragoiu, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki[54], W. Clarida, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya[55], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok, S. Sen, 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, S. Rappoccio, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA

P. Baringer, A. Bean, G. Benelli, O. Grachov, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood, V. Zhukova

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, D. Wright

University of Maryland, College Park, USA

A. Baden, M. Boutemeur, 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, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA

A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, Y. Kim, M. Klute, K. Krajczar[56], W. Li, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, USA

S.I. Cooper, 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, J. Butt, D.R. Claes, A. Dominguez, M. Eads, J. Keller, I. Kravchenko, J. Lazo-Flores, H. Malbouisson, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

U. Baur, A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S.P. Shipkowski, K. Smith

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, D. Trocino, D. Wood, J. Zhang

Northwestern University, Evanston, USA

A. Anastassov, A. Kubik, 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

L. Antonelli, D. Berry, A. Brinkerhoff, M. Hildreth, C. Jessop, D.J. Karmgard, J. Kolb, K. Lannon, W. Luo, S. Lynch, N. Marinelli, D.M. Morse, T. Pearson, R. Ruchti, J. Slaunwhite, N. Valls, M. Wayne, M. Wolf

The Ohio State University, Columbus, USA

B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalo, G. Williams, B.L. Winer

Princeton University, Princeton, USA

N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, D. Lopes Pegna, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, P. Piroué, X. Quan, A. Raval, B. Safdi, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, USA

J.G. Acosta, E. Brownson, X.T. Huang, A. Lopez, H. Mendez, S. Oliveros, J.E. Ramirez Vargas, A. Zatserklyaniy

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, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, 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, 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

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[57], 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, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, I. Volobouev

Vanderbilt University, Nashville, USA

E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, C. Johnston, 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, R. Yohay

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, M. Bachtis, D. 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, J. Leonard, R. Loveless, A. Mohapatra, 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 National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, USA
5: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
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, 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: Now at Joint Institute for Nuclear Research, Dubna, Russia
16: Also at Moscow State University, Moscow, Russia
17: Also at Brandenburg University of Technology, Cottbus, Germany
18: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
19: Also at Eötvös Loránd University, Budapest, Hungary
20: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
21: Also at University of Visva-Bharati, Santiniketan, India
22: Also at Sharif University of Technology, Tehran, Iran
23: Also at Isfahan University of Technology, Isfahan, Iran
24: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
25: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
26: Also at Università della Basilicata, Potenza, Italy
27: Also at Università degli Studi Guglielmo Marconi, Roma, Italy

28: Also at Università degli Studi di Siena, Siena, Italy
29: Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania
30: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
31: Also at University of California, Los Angeles, Los Angeles, USA
32: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
33: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
34: Also at University of Athens, Athens, Greece
35: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
36: Also at The University of Kansas, Lawrence, USA
37: Also at Paul Scherrer Institut, Villigen, Switzerland
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Gaziosmanpasa University, Tokat, Turkey
40: Also at Adiyaman University, Adiyaman, Turkey
41: Also at Izmir Institute of Technology, Izmir, Turkey
42: Also at The University of Iowa, Iowa City, USA
43: Also at Mersin University, Mersin, Turkey
44: Also at Ozyegin University, Istanbul, Turkey
45: Also at Kafkas University, Kars, Turkey
46: Also at Suleyman Demirel University, Isparta, Turkey
47: Also at Ege University, Izmir, Turkey
48: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
49: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
50: Also at University of Sydney, Sydney, Australia
51: Also at Utah Valley University, Orem, USA
52: Also at Institute for Nuclear Research, Moscow, Russia
53: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
54: Also at Argonne National Laboratory, Argonne, USA
55: Also at Erzincan University, Erzincan, Turkey
56: Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
57: Also at Kyungpook National University, Daegu, Korea