

CERN-PH-EP/2012-033
2012/02/17

CMS-HIG-11-026

Search for the standard model Higgs boson in the $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ channel in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

Abstract

A search for the standard model Higgs boson in the $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ decay channel, where $\ell = e$ or μ , in pp collisions at a center-of-mass energy of 7 TeV is presented. The data were collected at the LHC, with the CMS detector, and correspond to an integrated luminosity of 4.6 fb^{-1} . No significant excess is observed above the background expectation, and upper limits are set on the Higgs boson production cross section. The presence of the standard model Higgs boson with a mass in the 270–440 GeV range is excluded at 95% confidence level.

Submitted to the Journal of High Energy Physics

*See Appendix A for the list of collaboration members

1 Introduction

The standard model (SM) of particle physics [1–3] accommodates essentially all relevant experimental data. One of the remaining questions is the origin of mass for fundamental particles. Within the SM, vector boson masses arise from the spontaneous breaking of electroweak symmetry [4–9]. The existence of the associated field quantum, the Higgs boson, has yet to be experimentally established. The discovery or exclusion of the SM Higgs boson is one of the main goals of the physics programme at the CERN Large Hadron Collider (LHC).

To date, experimental searches for the SM Higgs boson have yielded null results. Limits at 95% confidence level (CL) on its mass (m_H) have been placed by experiments at the Large Electron-Positron Collider (LEP), $m_H > 114.4$ GeV [10], the Tevatron, $m_H \notin (162\text{--}166)$ GeV [11], and ATLAS, $m_H \notin (145\text{--}206)$, $(214\text{--}224)$, and $(340\text{--}450)$ GeV [12–14]. The primary production mechanism for the Higgs boson at the LHC is through gluon fusion [15–26] with a small contribution from vector boson fusion (VBF) [27–29].

A search for the SM Higgs boson is presented in the $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ channel (where ℓ refers to either e or μ), which is especially sensitive in the high-mass range 250–600 GeV. Results are reported from a data sample corresponding to an integrated luminosity of 4.6 fb^{-1} recorded in 2011 by the Compact Muon Solenoid (CMS) experiment at $\sqrt{s} = 7$ TeV.

2 CMS Detector and Simulations

A detailed description of the CMS detector can be found in Ref. [30]. The key components of the detector include a silicon pixel and a silicon strip tracker, embedded in a 3.8 T solenoidal magnetic field, used to measure the momentum of charged particles. The silicon pixel and strip tracking system covers the pseudorapidity range $|\eta| < 2.5$, where $\eta = -\ln[\tan(\theta/2)]$, and θ is the polar angle of the trajectory of the particle with respect to the beam direction. It is surrounded by a crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadron calorimeter (HCAL). The ECAL and HCAL extend to a pseudorapidity range of $|\eta| < 3.0$. A steel/quartz-fiber Cherenkov forward detector (HF) extends the calorimetric coverage to $|\eta| < 5.2$. The calorimeters are surrounded by the muon system, used to identify muons and measure their momentum. The muon system consists of gas detectors placed in the steel return yoke of the magnet.

The largest background to the SM Higgs boson signal consists of events in which a Z boson is produced in association with jets (Z + jets). The Z + jets cross section is five orders of magnitude larger than the expected production cross section for the signal. The other major backgrounds are top-quark production ($t\bar{t} \rightarrow 2\ell 2\nu 2b$ and $tW \rightarrow 2\ell 2\nu b$), and the diboson production ($WZ \rightarrow 3\ell\nu$, $ZZ \rightarrow 2\ell 2\nu$, and $WW \rightarrow 2\ell 2\nu$).

Several Monte Carlo event generators are used to simulate the signal and background processes. The $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ signal and top-quark background events are generated by using the next-to-leading order (NLO) program POWHEG 2.0 [31]. The Z + jets and diboson backgrounds are simulated by using the MADGRAPH 5.1.3 generator [32]. The diboson backgrounds are also simulated using the PYTHIA 6.4.22 generator for evaluating certain systematic uncertainties. For events generated using POWHEG and MADGRAPH generators, parton showering is simulated by using PYTHIA with the Z2 tune which differs from the Z1 tune described in Ref. [33] as it uses the CTEQ6 [34] parametrization for the parton distribution functions instead of the CTEQ5 [35] parametrization. The signal events are reweighted so that the transverse momentum (p_T) distribution of the Higgs boson agrees with the next-to-next-to-leading

order (NNLO) and next-to-next-to-leading log (NNLL) prediction [36, 37]. The total cross section is taken from Ref. [38] and is scaled by the $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ branching ratio [39–44]. The parton distribution functions (PDF) are modeled through the CTEQ6L [34] parametrization at leading order and the CT10 parametrization [45] at NLO. The NLO contribution to the $q\bar{q} \rightarrow ZZ$ process is taken into account by reweighting the transverse momentum of the visible Z boson to match the prediction from the MCFM 6.0 program [46]. A correction of 12% of the leading order $q\bar{q} \rightarrow ZZ$ cross section is included to account for the $g\bar{g} \rightarrow ZZ$ process [47]. The detector response to the simulated events is modeled with GEANT4 [30, 48] and reconstruction and analysis are performed by using the same software used for data.

3 Event Selection

For Higgs boson masses considered in this analysis, the Z bosons from $H \rightarrow ZZ$ decay are typically produced with a substantial p_T . Events are therefore selected to have two well-identified, isolated, opposite-charge leptons of same flavour (e^+e^- or $\mu^+\mu^-$) with $p_T > 20$ GeV that have an invariant mass within 30 GeV window centred on the Z mass. The p_T of the dilepton system is required to be greater than 55 GeV. In the electron channel, these events are collected by using dielectron triggers, with thresholds of $p_T > 17$ GeV and $p_T > 8$ GeV for the leading and the other electron, respectively. The muon channel relies on a combination of single- and double-muon triggers. As instantaneous luminosity increased, the thresholds on the double-muon triggers changed from a requirement of $p_T > 7$ GeV for each of the two muons to $p_T > 17$ GeV and $p_T > 8$ GeV on the leading and the other muon, respectively. The threshold for the single-muon trigger increased from $p_T > 17$ GeV to $p_T > 24$ GeV. The trigger efficiency for signal, for events selected through the full set of offline requirements is measured by using Z decays in data, and ranges from 95% to 97% in the muon channel and exceeds 99% in the electron channel.

Muon candidates are reconstructed by using two algorithms, one in which tracks in the silicon tracker are matched to energy deposits in the muon detectors and another in which a combined fit is performed to signals in both the silicon tracker and the muon system [49]. The muon candidates for analysis are required to be successfully reconstructed through both algorithms. Other identification criteria based on the number of measurements in the tracker and in the muon system, the fit quality of the muon track, and its consistency with the origin from the primary vertex are also imposed on the muon candidates to reduce the misidentification rate.

Electron reconstruction also involves two algorithms [50], one in which energy clusters in the ECAL are matched to signals in the silicon tracker and another in which tracks in the silicon tracker are matched to ECAL clusters. The electron candidates used in the analysis can be reconstructed by either algorithm. More identification criteria based on the distribution of the shower in the ECAL, a matching of the trajectory of an electron track with the cluster in the ECAL, and consistency with origin of the track from the primary vertex are imposed on the electron candidates to reduce the misidentification rate. Electron candidates with an ECAL cluster in the transition region between ECAL barrel and endcap ($1.4442 < |\eta| < 1.566$) are rejected. Additional requirements are imposed to remove electrons produced in photon conversions in the detector material.

Leptons produced in the decay of Z bosons are expected to be isolated from hadronic activity in the event. The sum of scalar transverse momentum depositions in the calorimeters and the transverse momenta of tracks in a cone of radius 0.3 in η - ϕ space around each lepton, where ϕ is the azimuthal angle, is corrected by the contribution from the lepton and the ratio of this corrected sum divided by the lepton p_T is required to be smaller than 15% (10%) for

muons (electrons). To correct for the contribution to the isolation sum from pile-up interactions (overlapping minimum-bias events from other concurrent proton-proton collisions), a median energy density (ρ) is determined event by event [51]. Then the pile-up contribution to the isolation sum is estimated as the product of ρ and the area of the cone in which the isolation sum is computed, and it is subtracted from the isolation sum to make it largely insensitive to pile-up. The combined reconstruction, identification and isolation efficiency is measured in data by using Z decays and ranges between 90% and 97% for muons, and between 70% and 90% for electrons, depending on the p_T and η of the leptons.

The high instantaneous luminosity delivered by the LHC provides an average of about 10 pile-up interactions per bunch crossing, leading to events with several possible primary vertices. The vertex with largest value of $\sum p_T^2$ for the associated tracks is chosen to be the reference vertex. According to simulation, this requirement provides the correct assignment for the primary vertex in more than 99% of both signal and background events.

The presence of a large imbalance in transverse momentum in an event (E_T^{miss}) is a fundamental feature of the signal. The value of E_T^{miss} is the modulus of the \vec{E}_T^{miss} vector computed as the negative of the vector sum of the transverse momenta of all reconstructed objects identified through the particle-flow algorithm, which aims to reconstruct all particles produced in a collision event by combining information from all sub-detectors [52]. A large E_T^{miss} threshold is imposed to suppress the bulk of the Z+jets background, which contains little genuine E_T^{miss} . The region of large E_T^{miss} is populated by Z+jets events in which the E_T^{miss} is largely due to jet mismeasurement. To suppress the background with E_T^{miss} arising from mismeasurement of jets, events are removed if the angle in the azimuthal plane between the E_T^{miss} and the closest jet with transverse energy $E_T > 30$ GeV is smaller than 0.5 radians. For events having no jets with $E_T > 30$ GeV, this requirement is imposed between E_T^{miss} and the closest jet with $E_T > 15$ GeV. Jets are reconstructed from particle-flow candidates [52, 53] by using the anti- k_T clustering algorithm [54] with a distance parameter R of 0.5, as implemented in the FASTJET package [55, 56].

Top-quark decays are characterized by the presence of jets originating from b quarks (bjets), which are tagged on the basis of impact parameters of tracks in a jet, relative to the primary vertex [57, 58]. The top-quark background is suppressed by applying a veto on events having a b tagged jet with transverse energy greater than 30 GeV that lies within the tracker volume ($|\eta| < 2.4$). To further suppress the top-quark background, a veto is applied on events containing a ‘‘soft muon’’ with $p_T > 3$ GeV, which is typically produced in the leptonic decay of a b quark. The soft-muon veto along with the b-jet veto reduces the top-quark background by a factor of six. To reduce the WZ background in which both bosons decay leptonically, any event with a third lepton (e or μ) with $p_T > 10$ GeV and passing the identification and isolation requirements is rejected.

4 Analysis Strategy

The search for the SM Higgs boson is performed by using a transverse mass (M_T) variable as the final discriminant in searching for an excess of events from the presence of the signal. The transverse mass is defined as follows:

$$M_T^2 = \left(\sqrt{p_T(\ell\ell)^2 + M(\ell\ell)^2} + \sqrt{E_T^{\text{miss}2} + M(\ell\ell)^2} \right)^2 - (\vec{p}_T(\ell\ell) + \vec{E}_T^{\text{miss}})^2.$$

where $p_T(\ell\ell)$ and $M(\ell\ell)$ are the transverse momentum and invariant mass of dilepton system, respectively.

Two approaches are considered: a “cut-based” and a “shape-based” analysis. The same set of event selection criteria is used by both the analyses, except for requirements on the E_T^{miss} and M_T variables. In both cases, requirements on E_T^{miss} and M_T vary with the Higgs mass hypothesis, but are typically more relaxed for the shape-based analysis.

In the cut-based analysis, the Higgs boson search is performed by looking for an excess of events above the standard model background expectation after applying selection criteria that are tuned for a given Higgs boson mass hypothesis. The E_T^{miss} and M_T selection listed in Table 1 was optimized by using a genetic algorithm for rectangular cuts optimization, GARCON [59], with the expected 95% CL limit on the cross section normalized to the standard model Higgs boson cross section as a figure of merit. Optimization was performed on six m_H points, and a smooth-fit interpolation for the cut values was performed to provide optimal cut values for every explored Higgs mass point.

In the shape-based analysis, the Higgs boson search is performed by using a binned likelihood fit to the M_T distribution obtained after applying the selection given in Table 1. The range of M_T is varied as a function of m_H to ensure that the expected signal distribution is fully contained. The shape-based analysis is found to have the best expected signal sensitivity and is considered as the main result in the paper.

Table 1: Higgs boson mass-dependent selection for E_T^{miss} and M_T variables in the cut-based and shape-based analyses.

m_H (GeV)	250	300	350	400	500	600
Cut-based analysis selection						
E_T^{miss} (GeV)	> 70	> 79	> 95	> 115	> 150	> 161
M_T (GeV)	[222, 272]	[264, 331]	[298, 393]	[327, 460]	[382, 605]	[452, 767]
Shape-based analysis selection						
E_T^{miss} (GeV)	> 70	> 80	> 80	> 80	> 80	> 80
M_T (GeV)	[180, 300]	[250, 350]	[250, 400]	[250, 450]	[250, 600]	[250, 750]

5 Background Estimation

For both types of analyses, the ZZ and WZ backgrounds are modeled using Monte Carlo simulation, and are normalized to their respective NLO cross sections. The remaining backgrounds are estimated using control samples in data.

The Z+jets background is simulated from a control sample of events with a single photon produced in association with jets (γ + jets). This obviates the need for using less reliable Monte Carlo simulation of the E_T^{miss} distribution arising from mismeasurement of jets. The γ + jets cross section is much larger than Z + jets. The jets must have a minimum E_T of 15 GeV to reduce contamination from processes that have a photon produced in association with genuine E_T^{miss} , such as $W(\ell\nu) + \gamma$, $W(\ell\nu)$ +jets, where the jet is mismeasured as a photon, and $Z(\nu\nu) + \gamma$ events. The kinematics and overall normalization of γ + jets events are matched to Z + jets in data through an event-by-event reweighting as a function of the boson p_T , and the number of jets with $E_T > 30$ GeV, to account for the dependence of the E_T^{miss} on the associated hadronic activity. Residual differences from pile-up are taken into account by reweighting events ac-

ording to the number of reconstructed vertices. This procedure yields an accurate model of the E_T^{miss} distribution in Z+jets events, as shown in Fig. 1, which compares the E_T^{miss} distribution of the reweighted γ +jets events along with other backgrounds to the E_T^{miss} distribution of the dilepton events in data. To compute the M_T for each γ +jets event, the value of $\vec{p}_T(\ell\ell)$ is defined as the photon \vec{p}_T and the value of $M(\ell\ell)$ term is chosen according to a probability density function constructed from the measured dilepton invariant mass distribution in Z+jets events.

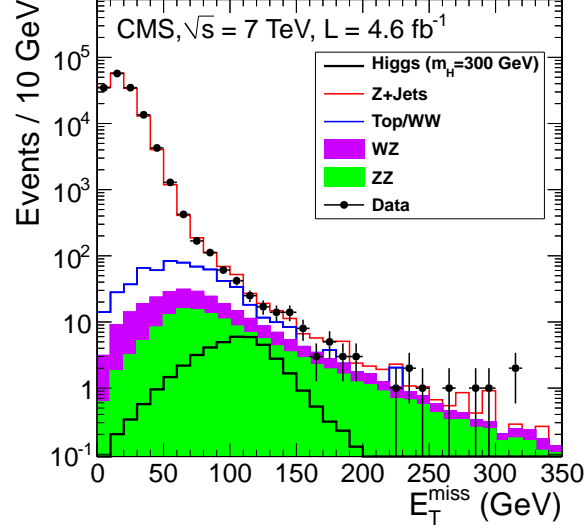


Figure 1: The E_T^{miss} distribution in data compared to the background simulation. The dielectron and dimuon channels are combined. Contributions from ZZ, WZ, non-resonant background and Z+jets background are stacked on top of each other. The E_T^{miss} distribution in signal events for $m_H = 300$ GeV is also shown.

The background processes that do not involve a Z resonance (non-resonant background) are estimated by using a control sample of events with dileptons of different flavor ($e^\pm\mu^\mp$) that pass the full analysis selection. This background consists mainly of leptonic W decays in $t\bar{t}$, tW decays and WW events. Small contributions from single top-quark events produced from s -channel and t -channel processes, W+jets events in which the W boson decays leptonically and a jet is mismeasured as a lepton, and $Z \rightarrow \tau\tau$ events in which τ leptons produce light leptons and E_T^{miss} are included in this estimate of the non-resonant background. This method cannot distinguish between the non-resonant background and a possible contribution from $H \rightarrow WW \rightarrow 2\ell 2\nu$ events, which are treated as part of the non-resonant background estimate.

The non-resonant background in the e^+e^- and $\mu^+\mu^-$ final states is estimated by applying a scale factor (α) to the selected $e^\pm\mu^\mp$ events:

$$N_{\mu\mu} = \alpha_\mu \times N_{e\mu}, \quad N_{ee} = \alpha_e \times N_{e\mu}.$$

This α factor is computed from the sidebands (SB) of the Z peak ($40 < M(\ell\ell) < 70$ GeV and $110 < M(\ell\ell) < 200$ GeV) by using the following relations:

$$\alpha_\mu = \frac{N_{\mu\mu}^{\text{SB}}}{N_{e\mu}^{\text{SB}}}, \quad \alpha_e = \frac{N_{ee}^{\text{SB}}}{N_{e\mu}^{\text{SB}}}$$

where N_{ee}^{SB} , $N_{\mu\mu}^{\text{SB}}$, and $N_{e\mu}^{\text{SB}}$ are the number of events in the Z sidebands in a top-enriched sample of e^+e^- , $\mu^+\mu^-$, and $e^\pm\mu^\mp$ final states, respectively. Such samples are selected by requiring $E_T^{\text{miss}} > 70$ GeV and a b-tagged jet in the events. The measured values of α with the corresponding statistical uncertainties are $\alpha_\mu = 0.58 \pm 0.02$ and $\alpha_e = 0.42 \pm 0.02$.

Since the M_T distribution obtained for the non-resonant background is based on a small sample of $e^\pm\mu^\mp$ events scaled by α , this distribution is smoothed [60] for use in the shape-based analysis.

6 Systematic Uncertainties

Systematic uncertainties include experimental uncertainties on the selection and measurement of the reconstructed objects, theoretical uncertainties on the signal and background processes which are derived from Monte Carlo simulation, and uncertainties on backgrounds determined from control samples in data. These are summarised in Table 2.

The theoretical uncertainties on the predicted signal are evaluated by changing the parton distribution functions and the QCD renormalization and factorization scales [38, 45, 61–64]. The theoretical uncertainties on the NLO cross sections of the ZZ and WZ backgrounds are estimated by the same procedure of changing the parton distribution functions and the QCD renormalization and factorization scales by using the program MCFM 6.0.

The cross section for on-shell Higgs boson production and decay is calculated in the zero-width approximation. Recent studies show that current Monte Carlo simulation does not describe the correct Higgs-boson line shape for $m_H \gtrsim 300$ GeV. These effects are estimated to correspond to an additional uncertainty of 10–30% on the theoretical cross section for $400 < m_H < 600$ GeV [38, 65, 66].

Various factors contribute to the experimental uncertainties that apply to processes derived from Monte Carlo simulation. These include uncertainties on the trigger efficiency and lepton selection efficiencies. The effect of lepton momentum scale and jet energy scale is also taken into account and is propagated to the evaluation of E_T^{miss} . The uncertainty on the b jet veto is estimated by measuring the b-tagging efficiency in data from fully leptonic $t\bar{t}$ decays [58]. The uncertainty due to the modeling of pile-up is evaluated by shifting the mean of the distribution of the number of pile-up interactions up and down by one.

The uncertainty on the estimate of the non-resonant background is dominated by the statistical uncertainty of the $e^\pm\mu^\mp$ control sample. The uncertainty on the prediction of the Z+jets background is affected by any residual contamination of the γ +jets control sample from processes involving a photon and genuine E_T^{miss} . Consequently, this method provides only an upper bound on the prediction. To account for this contamination, the Z+jets background prediction is changed from zero to the estimate obtained from the γ +jets control sample in the limit-setting procedure. This is achieved by taking half of the estimate from the γ +jets control sample as the central value for the Z+jets background and assigning a 100% systematic uncertainty to this value. Since Z+jets contributes to only 10–15% of the total background, the large uncertainty on this background does not have a significant impact on the overall performance of the analysis.

In the shape-based analysis, the difference in the M_T distribution with respect to an alternate Monte Carlo generator (MADGRAPH versus PYTHIA) is used as an uncertainty in the modeling of the ZZ, WZ backgrounds. The uncertainty on the M_T distributions arising from the limited number of Monte Carlo simulated events is taken into account by scaling all the bins up and

down by the respective statistical uncertainties. This is done in a correlated manner to obtain two bounding distributions, within which the nominal distribution is changed. For the non-resonant background, where the nominal M_T distribution is obtained by smoothing the M_T distribution of $e^\pm\mu^\mp$ events, the bounding distributions are taken from simulation to account for any possible bias introduced by smoothing. The uncertainty for signal is assigned by reweighting the p_T spectrum of the Higgs boson to the one obtained from changing the renormalization and factorization scales in the NNLO+NNLL calculation [36, 37].

Table 2: Summary of systematic uncertainties on event yields of signal and background processes. Ranges refer to uncertainties that depend on the hypothesised value of m_H .

Source	Uncertainty [%]
Luminosity	4.5
PDF for Higgs production (gluon-fusion)	8.2–10.4
PDF for Higgs production (VBF)	3.8–7.6
PDF for $qq \rightarrow ZZ$	4.8
PDF for $qq \rightarrow WZ$	5.5
QCD scale for Higgs production (gluon-fusion)	7.6–11.1
QCD scale for Higgs production (VBF)	0.4–2
QCD scale for $gg \rightarrow ZZ$	20
QCD scale for $qq \rightarrow ZZ$	6.2
QCD scale for $qq \rightarrow WZ$	8.5
Higgs boson line shape	10–30
Trigger	1 (for ee), 2 (for $\mu\mu$)
Lepton identification and isolation	2
Lepton momentum scale	5 (for ee), 2 (for $\mu\mu$)
Jet energy scale	1–1.5
bjet Veto	1–1.2
Pile-up	1–3
Non-resonant background	15–100
Z+jets	100

7 Results

The event yields for the cut-based analysis, as a function of m_H , and the estimated backgrounds for the 4.6 fb^{-1} dataset are listed in Table 3. The M_T distributions for the shape-based analysis based on the selections described in Table 1 for $m_H = 300$ and 400 GeV hypotheses are shown in Fig. 2. No significant excess of events is observed over the expectation from the SM background and limits are set on the production cross section of the standard model Higgs boson as a function of m_H .

The median expected and observed 95% CL upper limits on the cross section $\sigma \times BR(H \rightarrow ZZ \rightarrow 2\ell 2\nu)$ for $250 < m_H < 600 \text{ GeV}$ by using the cut- and the shape-based approaches are shown in Fig. 3. The measured ratio R of the 95% CL upper limit cross section σ to the SM Higgs boson production cross section σ_{SM} as a function of m_H is shown in Fig. 4. These results are obtained by using the CL_s method [67–69]. For the cut-based analysis the SM Higgs boson is excluded in the mass range $310\text{--}465 \text{ GeV}$ at 95% confidence level, while the expected exclusion limit in the background-only hypothesis is $305\text{--}470 \text{ GeV}$. For the shape-based analysis the SM

Table 3: Background estimates, signal predictions, and observed number of events for an integrated luminosity of 4.6 fb^{-1} after the cut-based selection. The uncertainties include the statistical and systematic components (in that order). The results for signal contain only the systematic uncertainties as the statistical uncertainties are negligible. For the non-resonant background, the 68% upper limit is quoted in the case where the background prediction is zero.

m_H (GeV)	ZZ	WZ	Top/WW/ W+jets/ $Z \rightarrow \tau\tau$	Z+Jets	Total Background	Expected Signal	Data
250	$36.0 \pm 0.2 \pm 2.6$	$24.0 \pm 0.3 \pm 2.0$	$65.0 \pm 3.8 \pm 5.8$	15.0 ± 15.0	$140.0 \pm 3.8 \pm 16.0$	22.0 ± 2.2	142
300	$23.0 \pm 0.2 \pm 1.7$	$13.0 \pm 0.2 \pm 1.1$	$18.0 \pm 1.1 \pm 3.0$	6.3 ± 6.3	$60.0 \pm 1.1 \pm 7.3$	21.0 ± 2.1	64
350	$16.0 \pm 0.1 \pm 1.1$	$7.0 \pm 0.2 \pm 0.6$	$2.0 \pm 0.1 \pm 1.0$	4.1 ± 4.1	$29.0 \pm 0.3 \pm 4.4$	21.0 ± 2.5	26
400	$12.0 \pm 0.1 \pm 0.9$	$4.6 \pm 0.1 \pm 0.4$	< 1.1	2.7 ± 2.7	$19.0 \pm 0.2 \pm 2.9$	17.0 ± 2.0	18
500	$7.5 \pm 0.1 \pm 0.5$	$2.0 \pm 0.1 \pm 0.2$	< 1.1	1.4 ± 1.4	$11.0 \pm 0.1 \pm 1.5$	7.4 ± 1.3	14
600	$3.9 \pm 0.1 \pm 0.3$	$0.8 \pm 0.1 \pm 0.1$	< 1.1	0.6 ± 0.6	$5.3 \pm 0.1 \pm 0.7$	2.9 ± 0.7	5

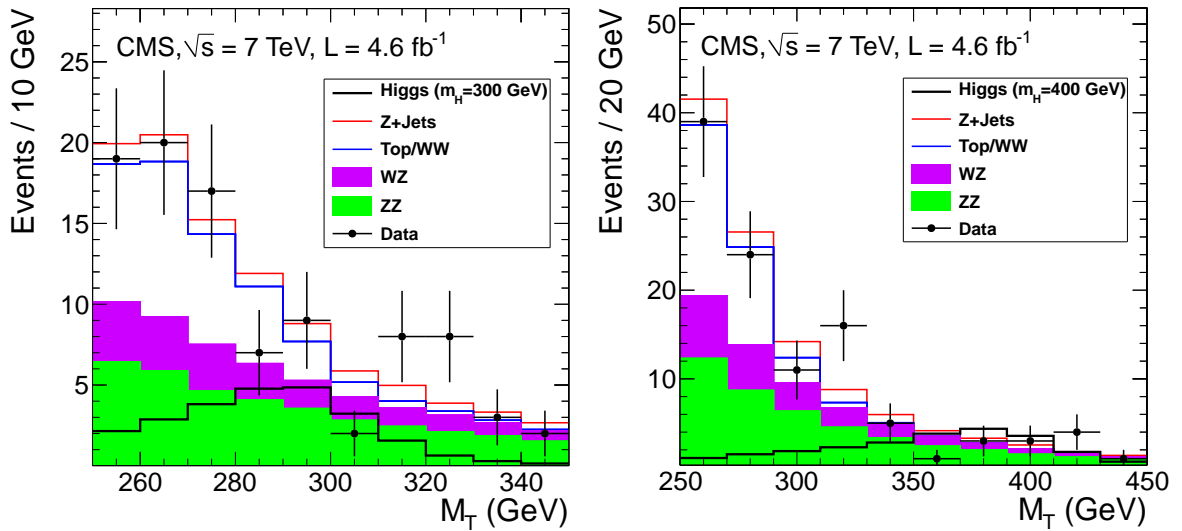


Figure 2: The M_T distribution for events passing m_H selections for 300 GeV (left) and 400 GeV (right). The dielectron and dimuon channels are combined.

Higgs boson is excluded in the mass range 270–440 GeV at 95% confidence level while the expected exclusion limit for the background-only hypothesis is 290–490 GeV.

8 Summary

A search for the standard model Higgs boson has been performed in the decay channel $H \rightarrow ZZ \rightarrow 2\ell 2\nu$ in pp collisions at $\sqrt{s} = 7 \text{ TeV}$, using a data sample corresponding to an integrated luminosity of 4.6 fb^{-1} . No significant excess is found above the background expectation. The presence of the SM Higgs boson is excluded for $270 \text{ GeV} < m_H < 440 \text{ GeV}$ at 95% CL.

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC machine. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC

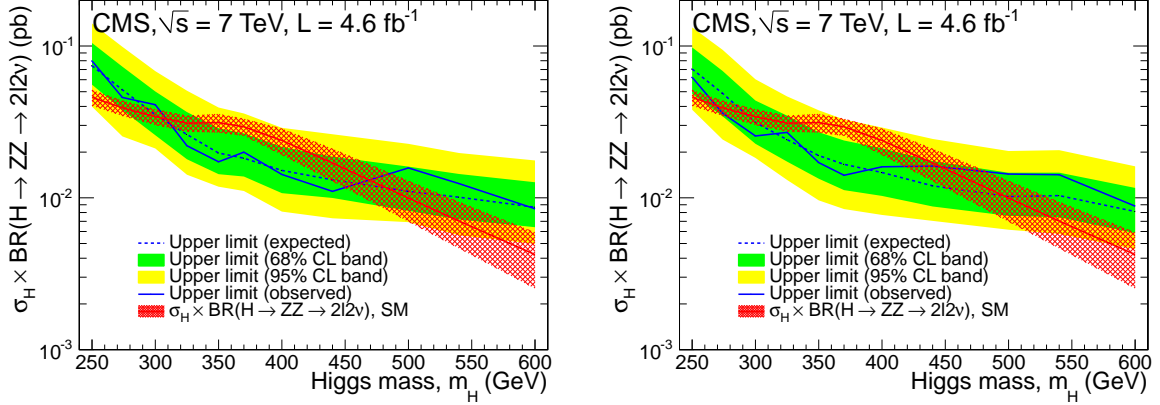


Figure 3: The median expected and observed 95% CL upper limits on the cross section $\sigma \times BR(H \rightarrow ZZ \rightarrow 2\ell 2\nu)$ for the Higgs boson masses in the range 250 – 600 GeV for the cut-based (left) and shape-based (right) analyses.

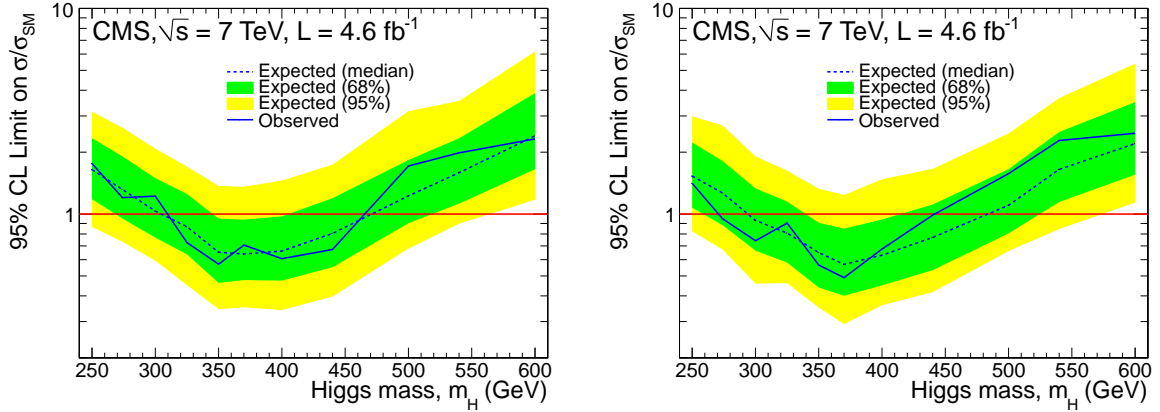


Figure 4: The ratio R of the 95% CL cross section upper limit σ to the SM Higgs boson production cross section σ_{SM} as a function of the Higgs boson mass m_H for the cut-based (left) and shape-based (right) analyses.

(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 (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); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA). Individuals have received support from the Marie-Curie programme and the European Research Council (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 Council of Science and Industrial Research, India; and the HOMING PLUS programme of Foundation for Polish Science, cofinanced from European Union, Regional Development Fund.

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A The CMS Collaboration

Yerevan Physics Institute, Yerevan, Armenia

S. Chatrchyan, V. Khachatryan, A.M. Sirunyan, A. Tumasyan

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer¹, M. Hoch, N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöffbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

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

V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium

S. Bansal, L. Benucci, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haeevermaet, 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

O. Charaf, B. Clerboux, G. De Lentdecker, V. Dero, A.P.R. Gay, G.H. Hammad, T. Hreus, A. Léonard, P.E. Marage, L. Thomas, C. Vander Velde, P. Vanlaer, J. Wickens

Ghent University, Ghent, Belgium

V. Adler, K. Bernaert, 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, L. Vanelderen, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

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

S. Basegmez, G. Bruno, L. Ceard, J. De Favereau De Jeneret, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco², G. Grégoire, J. Hollar, V. Lemaître, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, N. Schul

Université de Mons, Mons, Belgium

N. Bely, T. Caebergs, E. Daubie

Centro Brasileiro de Pesquisas Físicas, 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, S.M. Silva Do Amaral, L. Soares Jorge, A. Sznajder

Instituto de Física Teórica, Universidade Estadual Paulista, Sao Paulo, Brazil

T.S. Anjos³, C.A. Bernardes³, F.A. Dias⁴, T.R. Fernandez Perez Tomei, E. M. Gregores³, C. Lagana, F. Marinho, P.G. Mercadante³, S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

V. Genchev¹, P. Iaydjiev¹, S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, R. Hadjiiska, A. Karadzhinova, 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, 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, S. Wang, B. Zhu, W. Zou

Universidad de Los Andes, Bogota, Colombia

A. Cabrera, B. Gomez Moreno, A.F. Osorio Oliveros, J.C. Sanabria

Technical University of Split, Split, Croatia

N. Godinovic, D. Lelas, R. Plestina⁵, D. Polic, I. Puljak¹

University of Split, Split, Croatia

Z. Antunovic, M. Dzelalija, 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, 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. Assran⁶, A. Ellithi Kamel⁷, S. Khalil⁸, M.A. Mahmoud⁹, A. Radi^{8,10}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

A. Hektor, M. Kadastik, M. Müntel, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland

V. Azzolini, P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

S. Czellar, 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. Korpela, T. Tuuva

Laboratoire d'Annecy-le-Vieux de Physique des Particules, IN2P3-CNRS, Annecy-le-Vieux, France

D. Sillou

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, 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. Bluj¹¹, C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, S. Elgammal, R. Granier de Cassagnac, M. Haguenaer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaut, C. Veelken, A. Zabi

Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

J.-L. Agram¹², J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte¹², F. Drouhin¹², C. Ferro, J.-C. Fontaine¹², D. Gelé, U. Goerlach, P. Juillot, M. Karim¹², A.-C. Le Bihan, P. Van Hove

Centre de Calcul de l'Institut National de Physique Nucleaire et de Physique des Particules (IN2P3), Villeurbanne, France

F. Fassi, D. Mercier

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

C. Baty, S. Beauceron, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, J. Chasserat, R. Chierici¹, D. Contardo, P. Depasse, H. El Mamouni, A. Falkiewicz, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, T. Le Grand, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, S. Viret

Institute of High Energy Physics and Informatization, Tbilisi State University, Tbilisi, Georgia

D. Lomidze

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. Zhukov¹³

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

M. Ata, J. Caudron, E. Dietz-Laursonn, M. Erdmann, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], 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, M. Davids, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Linn, A. Nowack, L. Perchalla, O. Pooth, J. Rennefeld, P. Sauerland, A. Stahl, M.H. Zoeller

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz¹⁴, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, D. Dammann, G. Eckerlin, D. Eckstein, A. Flossdorf, G. Flucke, A. Geiser, J. Hauk, H. Jung¹, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann¹⁴, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, J. Olzem, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, M. Rosin, J. Salfeld-Nebgen, R. Schmidt¹⁴, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, J. Tomaszewska, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

C. Autermann, V. Blobel, S. Bobrovskiy, 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, N. Pietsch, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, H. Stadie, G. Steinbrück, J. Thomsen

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, M. Guthoff¹, C. Hackstein, F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, I. Katkov¹³, J.R. Komaragiri, T. Kuhr, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, M. Renz, S. Röcker, C. Saout, A. Scheurer, P. Schieferdecker, F.-P. Schilling, M. Schmanau, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, J. Wagner-Kuhr, T. Weiler, M. Zeise, E.B. Ziebarth

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, E. Stiliaris

University of Ioánnina, Ioánnina, Greece

I. Evangelou, C. Foudas¹, P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras, F.A. Triantis

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

A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu¹, P. Hidas, D. Horvath¹⁵, A. Kapusi, K. Krajczar¹⁶, F. Sikler¹, V. Veszpremi, G. Vesztergombi¹⁶

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, J. Molnar, J. Palinkas, Z. Szillasi

University of Debrecen, Debrecen, Hungary

J. Karancsi, P. Raics, Z.L. Trocsanyi, B. Ujvari

Panjab University, Chandigarh, India

S.B. Beri, V. Bhatnagar, N. Dhingra, R. Gupta, M. Jindal, M. Kaur, J.M. Kohli, M.Z. Mehta, N. Nishu, L.K. Saini, A. Sharma, A.P. Singh, J. Singh, S.P. Singh

University of Delhi, Delhi, India

S. Ahuja, B.C. Choudhary, A. Kumar, A. Kumar, 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, S. Jain, S. Jain, R. Khurana, S. Sarkar

Bhabha Atomic Research Centre, Mumbai, India

R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty¹, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India

T. Aziz, S. Ganguly, M. Guchait¹⁷, A. Gurtu¹⁸, M. Maity¹⁹, G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, A. Saha, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad, N.K. Mondal

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

H. Arfaei, H. Bakhshiansohi²⁰, S.M. Etesami²¹, A. Fahim²⁰, M. Hashemi, H. Hesari, A. Jafari²⁰, M. Khakzad, A. Mohammadi²², M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh²³, M. Zeinali²¹

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,1}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, L. Lusito^{a,b}, G. Maggi^{a,c}, M. Maggi^a, N. Manna^{a,b}, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, F. Romano^{a,c}, G. Selvaggi^{a,b}, L. Silvestris^a, G. Singh^{a,b}, S. Tupputi^{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, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^a, 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,1}, P. Giacomelli^a, C. Grandi^a, S. Marcellini^a, G. Masetti^a, M. Meneghelli^{a,b}, A. Montanari^a, F.L. Navarria^{a,b}, F. Odorici^a, A. Perrotta^a, F. Primavera^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G. 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,1}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, S. Colafranceschi²⁴, F. Fabbri, D. Piccolo

INFN Sezione di Genova, Genova, Italy

P. Fabbri, R. Musenich

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

A. Benaglia^{a,b,1}, F. De Guio^{a,b}, L. Di Matteo^{a,b}, S. Fiorendi^{a,b}, S. Gennai^{a,1}, A. Ghezzi^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b,1}, 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,1}, N. Cavallo^{a,25}, A. De Cosa^{a,b}, O. Dogangun^{a,b}, F. Fabozzi^{a,25}, A.O.M. Iorio^{a,1}, L. Lista^a, M. Merola^{a,b}, P. Paolucci^a

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

P. Azzi^a, N. Bacchetta^{a,1}, P. Bellan^{a,b}, D. Bisello^{a,b}, A. Branca^a, R. Carlin^{a,b}, P. Checchia^a, T. Dorigo^a, U. Dosselli^a, F. Fanzago^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, K. Kanishchev, S. Lacaprara^{a,26}, I. Lazzizzera^{a,c}, M. Margoni^{a,b}, M. Mazzucato^a, A.T. Meneguzzo^{a,b}, M. Nespolo^{a,1}, L. Perrozzi^a, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b,1}, S. Vanini^{a,b}, P. Zotto^{a,b}, G. Zumerle^{a,b}

INFN Sezione di Pavia ^a, Università di Pavia ^b, Pavia, Italy

U. Berzano^a, 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, B. Caponeri^{a,b}, L. Fano^{a,b}, P. Lariccia^{a,b}, A. Lucaroni^{a,b,1}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b}, F. Romeo^{a,b}, A. Santocchia^{a,b}, S. Taroni^{a,b,1}, M. Valdata^{a,b}

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

P. Azzurri^{a,c}, G. Bagliesi^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c}, R. Dell'Orso^a, F. Fiori^{a,b}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,27}, A. Messineo^{a,b}, F. Palla^a, F. Palmonari^a, A. Rizzi, A.T. Serban^a, P. Spagnolo^a, R. Tenchini^a, G. Tonelli^{a,b,1}, A. Venturi^{a,1}, 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,1}, M. Diemoz^a, C. Fanelli, M. Grassi^{a,1}, E. Longo^{a,b}, P. Meridiani^a, F. Micheli, S. Nourbakhsh^a, G. Organtini^{a,b}, F. Pandolfi^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, M. Sigamani^a, L. Soffi

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, C. Botta^{a,b}, N. Cartiglia^a, R. Castello^{a,b}, M. Costa^{a,b}, N. Demaria^a, A. Graziano^{a,b}, C. Mariotti^{a,1}, 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, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspà^{a,c}, R. Sacchi^{a,b}, V. Sola^{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, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, M. Marone^{a,b}, D. Montanino^{a,b,1}, A. Penzo^a

Kangwon National University, Chunchon, Korea

S.G. Heo, S.K. Nam

Kyungpook National University, Daegu, Korea

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

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

J.Y. Kim, Zero J. Kim, S. Song

Konkuk University, Seoul, Korea

H.Y. Jo

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, E. Seo, K.S. Sim

University of Seoul, Seoul, Korea

M. Choi, S. Kang, H. Kim, 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, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Vilnius University, Vilnius, Lithuania

M.J. Bilinskas, I. Grigelionis, M. Janulis

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

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

G. Brona, M. Cwiok, W. Dominik, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski

Soltan Institute for Nuclear Studies, Warsaw, Poland

H. Bialkowska, B. Boimska, T. Frueboes, R. Gokieli, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

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

N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, A. Nayak, J. Pela¹, P.Q. Ribeiro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, I. Belotelov, P. Bunin, I. Golutvin, A. Kamenev, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, 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, A. Toropin, S. Troitsky

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov¹, A. Krokhotin, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Moscow State University, Moscow, Russia

A. Belyaev, E. Boos, M. Dubinin⁴, L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, L. Sarycheva[†], V. Savrin, A. Snigirev

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. Grishin¹, V. Kachanov, D. Konstantinov, A. Korablev,

V. Krychkin, 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. Adzic²⁸, M. Djordjevic, M. Ekmedzic, D. Krpic²⁸, 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, C. Diez Pardos, 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, 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

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez²⁹, J.M. Vizan Garcia

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. Felcini³⁰, M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, 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, C. Bernet⁵, W. Bialas, G. Bianchi, P. Bloch, A. Bocci, H. Breuker, K. Bunkowski, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, B. Curé, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, A. Gaddi, G. Georgiou, H. Gerwig, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, L. Guiducci, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, H.F. Hoffmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, G. Mavromanolakis, F. Meijers, S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold, M. Nguyen, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi³¹, T. Rommerskirchen, C. Rovelli³², M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³³, D. Spiga, M. Spiropulu⁴, M. Stoye, A. Tsirou, G.I. Veres¹⁶, P. Vichoudis, H.K. Wöhri, S.D. Worm³⁴, 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. Sibille³⁵

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann,

P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli³⁶, P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, M.-C. Sawley, A. Starodumov³⁷, B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli, J. Weng

Universität Zürich, Zurich, Switzerland

E. Aguilo, C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, 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, 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

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci³⁸, S. Cerci³⁹, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, I. Hos, E.E. Kangal, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk⁴⁰, A. Polatoz, K. Sogut⁴¹, D. Sunar Cerci³⁹, B. Tali³⁹, H. Topakli³⁸, D. Uzun, 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

M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya⁴², O. Kaya⁴², S. Ozkorucuklu⁴³, N. Sonmez⁴⁴

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. Newbold³⁴, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso⁴⁵, K.W. Bell, A. Belyaev⁴⁵, 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. Nikitenko³⁷, A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi⁴⁶, D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, A. Sparrow, A. Tapper, S. Tourneur, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, D. Wardrope, T. Whyntie

Brunel University, Uxbridge, United Kingdom

M. Barrett, M. Chadwick, J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, 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

C. Henderson

Boston University, Boston, USA

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

Brown University, Providence, USA

S. Bhattacharya, D. Cutts, A. Ferapontov, U. Heintz, S. Jabeen, G. Kukartsev, 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, M. Caulfield, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko, A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, J. Robles, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, Los Angeles, USA

V. Andreev, K. Arisaka, 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, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng, 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, H. Pi, M. Pieri, R. Ranieri, M. Sani, I. Sfiligoi, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁴⁷, 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. Kovalskyi¹, V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, J.R. Vlimant, C. West

California Institute of Technology, Pasadena, USA

A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, E. Di Marco, J. Duarte, M. Gataullin, Y. Ma, A. Mott, H.B. Newman, C. Rogan, V. Timciuc, P. Traczyk, J. Veverka, R. Wilkinson, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA

B. Akgun, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, S.Y. Jun, Y.F. Liu, M. Paulini, J. Russ, H. Vogel, I. Vorobiev

University of Colorado at Boulder, Boulder, USA

J.P. Cumalat, M.E. Dinardo, B.R. Drell, C.J. Edelmaier, W.T. Ford, A. Gaz, B. Heyburn, E. Luiggi Lopez, U. Nauenberg, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner, S.L. Zang

Cornell University, Ithaca, USA

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

Fairfield University, Fairfield, USA

A. Biselli, D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, M. Atac, J.A. Bakken, 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, S. Cihangir, W. Cooper, D.P. Eartly, V.D. Elvira, S. Esen, I. Fisk, J. Freeman, Y. Gao, E. Gottschalk, D. Green, O. Gutsche, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, H. Jensen, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, T. Miao, K. Mishra, S. Mrenna, Y. Musienko⁴⁸, C. Newman-Holmes, V. O'Dell, J. Pivarski, R. Pordes, O. Prokofyev, T. Schwarz, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, 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, 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, S. Goldberg, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic⁴⁹, G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, M. Snowball, D. Wang, J. Yelton, M. Zakaria

Florida International University, Miami, USA

V. Gaultney, 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, S. Sekmen, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

M.M. Baarmand, B. Dorney, M. Hohlmann, H. Kalakhety, I. Vodopyanov

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

M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, J. Callner, R. Cavanaugh, C. Dragoiu, L. Gauthier, C.E. Gerber, D.J. Hofman, S. Khalatyan, G.J. Kunde⁵⁰, F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, C. Silvestre, D. Strom, N. Varelas

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki⁵¹, W. Clarida, F. Duru, S. Griffiths, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya⁵², A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, 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, A. Bonato, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, N.V. Tran, 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, A. Peterman, K. Rossato, P. Rumerio, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA

B. Alver, 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, Y.-J. Lee, 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, P. Cushman, B. Dahmes, A. De Benedetti, G. Franzoni, A. Gude, J. Haupt, S.C. Kao, K. Klapoetke, Y. Kubota, J. Mans, N. Pastika, V. Rekovic, R. Rusack, M. Sasseville, A. Singovsky, N. Tambe, J. Turkewitz

University of Mississippi, University, USA

L.M. Cremaldi, R. Godang, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders, D. Summers

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, P. Jindal, 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, Z. Wan

Northeastern University, Boston, USA

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, 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, J. Ziegler

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

N. Adam, E. Berry, P. Elmer, D. Gerbaudo, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, E. Laird, 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, A. Zuranski

University of Puerto Rico, Mayaguez, USA

J.G. Acosta, 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, L. Gutay, 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, V. Cuplov, 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, Y. Gotra, J. Han, A. Harel, D.C. Miner, G. Petrillo, W. Sakumoto, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

A. Bhatti, R. Ciesielski, L. Demortier, K. Goulios, G. Lungu, S. Malik, C. Mesropian

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

S. Arora, O. Atramentov, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, M. Park, R. Patel, A. Richards, 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. Kamon⁵³, 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, C. Bardak, J. Damgov, P.R. Duderov, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, P. Mane, Y. Roh, A. Sill, I. Volobouev, R. Wigmans

Vanderbilt University, Nashville, USA

E. Appelt, E. Brownson, D. Engh, C. Florez, W. Gabella, A. Gurrola, M. Issah, W. Johns, P. Kurt, C. Maguire, A. Melo, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

University of Virginia, Charlottesville, USA

M.W. Arenton, M. Balazs, S. Boutle, S. Conetti, B. Cox, B. Francis, S. Goadhouse, 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, M. Mattson, C. Milstène, A. Sakharov

University of Wisconsin, Madison, USA

M. Anderson, M. Bachtis, D. Belknap, J.N. Bellinger, J. Bernardini, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, J. Efron, 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, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased

- 1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
- 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 Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
- 6: Also at Suez Canal University, Suez, Egypt
- 7: Also at Cairo University, Cairo, Egypt
- 8: Also at British University, Cairo, Egypt
- 9: Also at Fayoum University, El-Fayoum, Egypt
- 10: Now at Ain Shams University, Cairo, Egypt
- 11: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
- 12: Also at Université de Haute-Alsace, Mulhouse, France
- 13: Also at Moscow State University, Moscow, Russia
- 14: Also at Brandenburg University of Technology, Cottbus, Germany
- 15: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 16: Also at Eötvös Loránd University, Budapest, Hungary
- 17: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
- 18: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 19: Also at University of Visva-Bharati, Santiniketan, India
- 20: Also at Sharif University of Technology, Tehran, Iran
- 21: Also at Isfahan University of Technology, Isfahan, Iran
- 22: Also at Shiraz University, Shiraz, Iran
- 23: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
- 24: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
- 25: Also at Università della Basilicata, Potenza, Italy
- 26: Also at Laboratori Nazionali di Legnaro dell' INFN, Legnaro, Italy
- 27: Also at Università degli studi di Siena, Siena, Italy
- 28: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
- 29: Also at University of Florida, Gainesville, USA
- 30: Also at University of California, Los Angeles, Los Angeles, USA
- 31: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
- 32: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
- 33: Also at University of Athens, Athens, Greece
- 34: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 35: Also at The University of Kansas, Lawrence, USA
- 36: Also at Paul Scherrer Institut, Villigen, Switzerland
- 37: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 38: Also at Gaziosmanpasa University, Tokat, Turkey

- 39: Also at Adiyaman University, Adiyaman, Turkey
- 40: Also at The University of Iowa, Iowa City, USA
- 41: Also at Mersin University, Mersin, Turkey
- 42: Also at Kafkas University, Kars, Turkey
- 43: Also at Suleyman Demirel University, Isparta, Turkey
- 44: Also at Ege University, Izmir, Turkey
- 45: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
- 46: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
- 47: Also at Utah Valley University, Orem, USA
- 48: Also at Institute for Nuclear Research, Moscow, Russia
- 49: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 50: Also at Los Alamos National Laboratory, Los Alamos, USA
- 51: Also at Argonne National Laboratory, Argonne, USA
- 52: Also at Erzincan University, Erzincan, Turkey
- 53: Also at Kyungpook National University, Daegu, Korea