Physics Letters B 710 (2012) 403–425

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Search for the standard model Higgs boson decaying into two photons in pp collisions at $\sqrt{s} = 7$ TeV ☆

CMS Collaboration *

CERN, Switzerland

ARTICLE INFO

Article history:
Received 7 February 2012
Received in revised form 1 March 2012
Accepted 2 March 2012
Available online 6 March 2012
Editor: M. Doser

Keywords:
CMS
Physics
Higgs

ABSTRACT

A search for a Higgs boson decaying into two photons is described. The analysis is performed using a dataset recorded by the CMS experiment at the LHC from pp collisions at a center-of-mass energy of 7 TeV, which corresponds to an integrated luminosity of 4.8 fb^{-1}. Limits are set on the cross section of the standard model Higgs boson decaying to two photons. The expected exclusion limit at 95% confidence level is between 1.4 and 2.4 times the standard model cross section in the mass range between 110 and 150 GeV. The analysis of the data excludes, at 95% confidence level, the standard model Higgs boson decaying into two photons in the mass range 128 to 132 GeV. The largest excess of events above the expected standard model background is observed for a Higgs boson mass hypothesis of 124 GeV with a local significance of 3.1σ. The global significance of observing an excess with a local significance $\geqslant 3.1\sigma$ anywhere in the search range 110–150 GeV is estimated to be 1.8σ. More data are required to ascertain the origin of this excess.

1. Introduction

The standard model (SM) [1–3] of particle physics has been very successful in explaining experimental data. The origin of the masses of the W and Z bosons that arise from electroweak symmetry breaking remains to be identified. In the SM the Higgs mechanism is postulated, which leads to an additional scalar field whose quantum, the Higgs boson, should be experimentally observable [4–9].

Direct searches at the LEP experiments ruled out a SM Higgs boson lighter than 114.4 GeV at 95% confidence level (CL) [10]. Limits at 95% CL on the SM Higgs boson mass have also been placed by experiments at the Tevatron, excluding 162–166 GeV [11], and by the ATLAS Collaboration at the Large Hadron Collider (LHC), excluding the ranges 145–206, 214–224, and 340–450 GeV [12–14]. Precision electroweak measurements indirectly constrain the mass of the SM Higgs boson to be less than 158 GeV at 95% CL [15].

The $\text{H} \to \gamma\gamma$ decay channel provides a clean final-state topology with a mass peak that can be reconstructed with high precision. In the mass range $110 < m_\text{H} < 150$ GeV, $\text{H} \to \gamma\gamma$ is one of the more promising channels for a Higgs search at the LHC. The primary production mechanism of the Higgs boson at the LHC is gluon fusion with additional small contributions from vector boson fusion (VBF) and production in association with a W or Z boson, or a $\text{t}\bar{\text{t}}$ pair [16–27]. In the mass range $110 < m_\text{H} < 150$ GeV the SM $\text{H} \to \gamma\gamma$ branching fraction varies between 0.14% and 0.23% [28]. Previous searches in this channel have been conducted by the CDF and D0 experiments [29,30], and also at the LHC by ATLAS [31].

This Letter describes a search for a Higgs boson decaying into two photons in pp collisions at a center-of-mass energy of 7 TeV, using data taken in 2011 and corresponding to an integrated luminosity of 4.8 fb^{-1}. To improve the sensitivity of the search, selected diphoton events are subdivided into classes according to indicators of mass resolution and signal-to-background ratio. Five mutually exclusive event classes are defined: four in terms of the pseudorapidity and the shower shapes of the photons, and a fifth class into which are put all events containing a pair of jets passing selection requirements which are designed to select Higgs bosons produced by the VBF process.

2. The CMS detector

A detailed description of the CMS detector can be found elsewhere [32]. The main features and those most pertinent to this analysis are described below. The central feature is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with particle detection systems. The steel return yoke outside the solenoid is instrumented with gas detectors used to identify muons. Charged particle trajectories are measured by the silicon pixel and strip tracker, with full azimuthal coverage

☆ © CERN for the benefit of the CMS Collaboration.

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

0370-2693/ © 2012 CERN. Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.physletb.2012.03.003

within $|\eta| < 2.5$, where the pseudorapidity η is defined as $\eta = -\ln[\tan(\theta/2)]$, with θ being the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction. A lead-tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) surround the tracking volume and cover the region $|\eta| < 3$. The ECAL barrel extends to $|\eta| \approx 1.48$. A lead/silicon-strip preshower detector is located in front of the ECAL endcap. A steel/quartz-fibre Cherenkov forward calorimeter extends the calorimetric coverage to $|\eta| < 5.0$. In the region $|\eta| < 1.74$, the HCAL cells have widths of 0.087 in both pseudorapidity and azimuth (ϕ). In the (η, ϕ) plane, and for $|\eta| < 1.48$, the HCAL cells map on to 5×5 ECAL crystal arrays to form calorimeter towers projecting radially outwards from points slightly offset from the nominal interaction point. In the endcap, the ECAL arrays matching the HCAL cells contain fewer crystals. Calibration of the ECAL uses π^0s, $W \to e\nu$, and $Z \to ee$. Deterioration of transparency of the ECAL crystals due to irradiation during the LHC running periods and their subsequent recovery is monitored continuously and corrected for using light injected from a laser and LED system.

3. Data sample and reconstruction

The dataset consists of events collected with diphoton triggers and corresponds to an integrated luminosity of 4.8 fb^{-1}. Diphoton triggers with asymmetric transverse energy, E_T, thresholds and complementary photon selections were used. One selection required a loose calorimetric identification using the shower shape and very loose isolation requirements on photon candidates, and the other required only that the photon candidate had a high value of the R_9 variable. This variable is defined as the energy sum of 3×3 crystals centered on the most energetic crystal in the supercluster (described below) divided by the energy of the supercluster. Its value is used in the analysis to identify photons undergoing a conversion. The E_T thresholds used were at least 10% lower than the final selection thresholds. As the instantaneous luminosity delivered by the LHC increased, it became necessary to tighten the isolation cut applied in the trigger. To maintain high trigger efficiency, all four possible combinations of threshold and selection criterion were deployed (i.e., with both photon candidates having the R_9 condition, with the high threshold candidate having the R_9 condition applied and the low threshold candidate having the loose ID and isolation, and so on). Accepting events that satisfy any of these triggers results in a >99% trigger efficiency for events passing the offline selection.

Photon candidates are reconstructed from clusters of ECAL channels around significant energy deposits, which are merged into superclusters. The clustering algorithms result in almost complete recovery of the energy of photons that convert in the material in front of the ECAL. In the barrel region, superclusters are formed from five-crystal-wide strips in η centered on the locally most energetic crystal (seed) and have a variable extension in ϕ. In the endcaps, where the ECAL crystals do not have an $\eta \times \phi$ geometry, matrices of 5×5 crystals (which may partially overlap) around the most energetic crystals are merged if they lie within a narrow road in η.

The photon energy is computed starting from the raw supercluster energy. In the endcaps the preshower energy is added where the preshower is present ($|\eta| > 1.65$). In order to obtain the best resolution, the raw energy is corrected for the containment of the shower in the clustered crystals, and the shower losses for photons which convert in material upstream of the calorimeter. These corrections are computed using a multivariate regression technique based on the TMVA boosted decision tree implementation [33]. The regression is trained on photons in a sample of simulated events using the ratio of the true photon energy to the raw energy as the target variable. The input variables are the global η and ϕ coordinates of the supercluster, a collection of shower-shape variables, and a set of local cluster coordinates.

Jets, used in the dijet tag, are reconstructed using a particle-flow algorithm [34,35], which uses the information from all CMS sub-detectors to reconstruct different types of particles produced in the event. The basic objects of the particle-flow reconstruction are the tracks of charged particles reconstructed in the central tracker, and energy deposits reconstructed in the calorimetry. These objects are clustered with the anti-k_T algorithm [36] using a distance parameter $\Delta R = 0.5$. The jet energy measurement is calibrated to correct for detector effects using samples of dijet, γ+jet, and Z+jet events [37]. Energy from overlapping pp interactions other than that which produced the diphoton (pile-up), and from the underlying event, is also included in the reconstructed jets. This energy is subtracted using the FastJet technique [38–40], which is based on the calculation of the η-dependent transverse momentum density, evaluated on an event-by-event basis.

Samples of Monte Carlo (MC) events used in the analysis are fully simulated using GEANT4 [41]. The simulated events are reweighted to reproduce the distribution of the number of interactions taking place in each bunch crossing.

4. Vertex location

The mean number of pp interactions per bunch crossing over the full dataset is 9.5. The interaction vertices reconstructed using the tracks of charged particles are distributed in the longitudinal direction, z, with an RMS spread of 6 cm. If the interaction point is known to better than about 10 mm, then the resolution on the opening angle between the photons makes a negligible contribution to the mass resolution, as compared to the ECAL energy resolution. Thus the mass resolution can be preserved by correctly assigning the reconstructed photons to one of the interaction vertices reconstructed from the tracks. The techniques used to achieve this are described below.

The reconstructed primary vertex which most probably corresponds to the interaction vertex of the diphoton event can be identified using the kinematic properties of the tracks associated with the vertex and their correlation with the diphoton kinematics. In addition, if either of the photons converts and the tracks from the conversion are reconstructed and identified, the direction of the converted photon, determined by combining the conversion vertex position and the position of the ECAL supercluster, can be used to point to and so identify the diphoton interaction vertex.

For the determination of the primary vertex position using kinematic properties, three discriminating variables are constructed from the measured scalar, p_T, or vector, $\vec{p}_T$, transverse momenta of the tracks associated with each vertex, and the transverse momentum of the diphoton system, $p_T^{\gamma\gamma}$. These three variables are: $\sum p_T^2$, and two variables which quantify the p_T balance with respect to the diphoton system: $-\sum(\vec{p}_T \cdot \frac{\vec{p}_T^{\gamma\gamma}}{|\vec{p}_T^{\gamma\gamma}|})$ and $(|\sum \vec{p}_T| - p_T^{\gamma\gamma})/(|\sum \vec{p}_T| + p_T^{\gamma\gamma})$. An estimate of the pull to each vertex from the longitudinal location on the beam axis pointed to by any reconstructed tracks (from a photon conversion) associated with the two photon candidates is also computed: $|z_{\text{conversion}} - z_{\text{vertex}}|/\sigma_{\text{conversion}}$. These variables are used in a multivariate system based on boosted decision trees (BDT) to choose the reconstructed vertex to associate with the photons.

The vertex-finding efficiency, defined as the efficiency to locate the vertex to within 10 mm of its true position, has been studied with $Z \to \mu\mu$ events where the algorithm is run after the removal of the muon tracks. The use of tracks from a converted photon to locate the vertex is studied with $\gamma+\text{jet}$ events. In both cases the ratio of the efficiency measured in data to that in MC simulation is close to unity. The value is measured as a function of the boson p_T, as measured by the reconstructed muons, and is used as a correction to the Higgs boson signal model. An uncertainty of 0.4% is ascribed to the knowledge of the vertex finding efficiency coming from the statistical uncertainty in the efficiency measurement from $Z \to \mu\mu$ (0.2%) and the uncertainty related to the Higgs boson p_T spectrum description, which is estimated to be 0.3%. The overall vertex-finding efficiency for a Higgs boson of mass 120 GeV, integrated over its p_T spectrum, is computed to be 83.0 ± 0.2 (stat) ± 0.4 (syst)%.

5. Photon selection

The event selection requires two photon candidates with $p_T^{\gamma}(1) > m_{\gamma\gamma}/3$ and $p_T^{\gamma}(2) > m_{\gamma\gamma}/4$ within the ECAL fiducial region, $|\eta| < 2.5$, and excluding the barrel-endcap transition region $1.44 < |\eta| < 1.57$. The fiducial region requirement is applied to the supercluster position in the ECAL, and the p_T threshold is applied after the vertex assignment. The excluded barrel-endcap transition region removes from the acceptance the last two rings of crystals in the barrel, to ensure complete containment of accepted showers, and the first ring of trigger towers in the endcap which is obscured by cables and services exiting between the barrel and endcap. In the rare case where the event contains more than two photons passing all the selection requirements, the pair with the highest summed (scalar) p_T is chosen.

The dominant backgrounds to $H \to \gamma\gamma$ consist of 1) the irreducible background from the prompt diphoton production, and 2) the reducible backgrounds from $pp \to \gamma+\text{jet}$ and $pp \to \text{jet}+\text{jet}$ where one or more of the "photons" is not a prompt photon. Photon identification requirements are used to greatly reduce the contributions from non-prompt photon background.

Isolation is a powerful tool to reject the non-prompt background due to electromagnetic showers originating in jets – mainly due to single and multiple π^0s. The isolation of the photon candidates is measured by summing the transverse momentum (or energy) found in the tracker, ECAL or HCAL within a distance $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of the candidate (values of $\Delta R = 0.3$ and $\Delta R = 0.4$ are used). The tracks or calorimeter energy deposits very close to the candidates, which might originate from the candidate itself, are excluded from the sum. Pile-up results in two complications. First, the E_T summed in the isolation region in the ECAL and in the HCAL includes a contribution from other collisions in the same bunch crossing. The isolation sums in the ECAL and HCAL, and hence both the efficiency and rejection power of selection based on the sums, are thus dependent on the number of interactions in the bunch crossing. Second, the track isolation requires that the tracks used in the isolation sum are matched to the chosen vertex (so that the sum does not suffer from pile-up). If the vertex is incorrectly assigned, the isolation sum will be unrelated to the true isolation of the candidate. This allows non-prompt candidates which are not, in fact, isolated from tracks originating from their interaction point, to appear isolated.

The first issue is dealt with by calculating the median transverse energy density in the event, ρ, in regions of the detector separated from the jets and photons, and subtracting an appropriate amount, proportional to ρ, from the isolation sums. The second problem is dealt with by applying a selection requirement not only on the isolation sum calculated using the chosen diphoton vertex, but also on the isolation sum calculated using the vertex hypothesis which maximizes the sum. The isolation requirements are applied as a constant fraction of the candidate photon p_T, effectively cutting harder on low p_T photons. It has been shown with $Z \to ee$ events that the resulting variation of selection efficiency with p_T is well modeled in the simulation.

Table 1
Photon identification efficiencies measured in the four photon categories using a tag and probe technique applied to $Z \to ee$ events (for all requirements except the electron veto). Both statistical and systematic errors are given for the data measurement (in that order), and these are combined quadratically to calculate the error on the ratio $\epsilon_{\text{data}}/\epsilon_{\text{MC}}$.

Category	ϵ_{data} (%)	ϵ_{MC} (%)	$\epsilon_{\text{data}}/\epsilon_{\text{MC}}$
Barrel, $R_9 > 0.94$	$89.26 \pm 0.06 \pm 0.04$	90.61 ± 0.05	0.985 ± 0.001
Barrel, $R_9 < 0.94$	$68.31 \pm 0.06 \pm 0.55$	68.16 ± 0.05	1.002 ± 0.008
Endcap, $R_9 > 0.94$	$73.65 \pm 0.14 \pm 0.39$	73.45 ± 0.12	1.002 ± 0.006
Endcap, $R_9 < 0.94$	$51.25 \pm 0.11 \pm 1.25$	48.70 ± 0.08	1.052 ± 0.026

In addition to isolation variables, the following observables are also used for photon selection: the ratio of hadronic energy behind the photon to the photon energy, the transverse width of the electromagnetic shower, and an electron track veto.

Photon candidates with high values of R_9 are mostly unconverted and have less background than those with lower values. Photon candidates in the barrel have less background than those in the endcap. For this reason it has been found useful to divide photon candidates into four categories and apply a different selection in each category, using more stringent requirements in categories with higher background and worse resolution.

The efficiency of the photon identification is measured in data using tag and probe techniques [42]. The efficiency of the complete selection excluding the electron veto requirement is determined using $Z \to ee$ events. Table 1 shows the results for data and MC simulation, and the ratio of efficiency in data to that in the simulation, $\epsilon_{\text{data}}/\epsilon_{\text{MC}}$. The efficiency for photons to pass the electron veto has been measured using $Z \to \mu\mu\gamma$ events, where the photon is produced by final-state radiation, which provide a rather pure source of prompt photons. The efficiency approaches 100% in all except the fourth category, where it is 92.6 ± 0.7%, due to imperfect pixel detector coverage at large η. The ratio $\epsilon_{\text{data}}/\epsilon_{\text{MC}}$ for the electron veto is close to unity in all categories. The quadratic sum of the statistical and systematic uncertainties for the measurements of efficiencies using data are propagated to the uncertainties on the ratios. The ratios are used as corrections to the signal efficiency simulated in the MC model of the signal. The uncertainties on the ratios are taken as a systematic uncertainties in the limit setting.

The efficiency of the trigger has also been measured using $Z \to ee$ events, with the events classified as described below. For events passing the analysis selection the trigger efficiency is found to be 100% in the high R_9 event classes, and about 99% in the other two classes.

6. Event classes

The sensitivity of the search can be enhanced by subdividing the selected events into classes according to indicators of mass resolution and signal-to-background ratio and combining the results of a search in each class.

Two photon classifiers are used: the minimum R_9 of the two photons, R_9^{min}, and the maximum pseudorapidity (absolute value) of the two photons, giving four classes based on photon properties. The class boundary values for R_9 and pseudorapidity are the same as those used to categorize photon candidates for the photon identification cuts. These photon classifiers are effective in separating diphotons whose mass is reconstructed with good resolution from those whose mass is less well measured and in separating events for which the signal-to-background probability is higher from those for which it is lower.

A further class of events includes any event passing a dijet tag defined to select Higgs bosons produced by the VBF process. Events in which a Higgs boson is produced by VBF have two forward jets, originating from the two scattered quarks. Higgs bosons produced by this mechanism have a harder transverse momentum spectrum than those produced by the gluon–gluon fusion process or the photon pairs produced by the background processes [43]. By using a dijet tag it is possible to define a small class of events which have an expected signal-to-background ratio more than an order of magnitude greater than events in the four classes defined by photon properties. The additional classification of events into a dijet-tagged class improves the sensitivity of the analysis by about 10%.

Candidate diphoton events for the dijet-tagged class have the same selection requirements imposed on the photons as for the other classes with the exception of the p_T thresholds, which are modified so as to be more appropriate for the boosted VBF Higgs bosons and so increasing the signal acceptance. The threshold requirements for this class are $p_T^{\gamma}(1) > 55 \times m_{\gamma\gamma}/120$, and $p_T^{\gamma}(2) > 25$ GeV.

The selection variables for the jets use the two highest transverse energy (E_T) jets in the event with pseudorapidity $|\eta| < 4.7$. The pseudorapidity restriction with respect to the full calorimeter acceptance ($|\eta| < 5$), avoids the use of jets for which the energy corrections are less reliable and is found to have only a small effect (<2% change) on the signal efficiency. The following selection requirements have been optimized using simulated events, of VBF signal and diphoton background, to improve the expected limit at 95% CL on the VBF signal cross section, using this class of events alone. The E_T thresholds for the two jets are 30 and 20 GeV, and the pseudorapidity separation between them is required to be greater than 3.5. Their invariant mass is required to be greater than 350 GeV. Two additional selection criteria, relating the dijet to the diphoton system, have been applied: the difference between the average pseudorapidity of the two jets and the pseudorapidity of the diphoton system is required to be less than 2.5 [44], and the difference in azimuthal angle between the diphoton system and the dijet system is required to be greater than 2.6 radians (≈150°).

For a Higgs boson having a mass, m_H, of 120 GeV the overall acceptance times selection efficiency of the dijet tag for Higgs boson events is 15% (0.5%) for those produced by VBF (gluon–gluon fusion). This corresponds to about 2.01 (0.76) expected events. Events passing this tag are excluded from the four classes defined by R_9 and pseudorapidity, but enter the fifth class. About 3% of Higgs boson signal events are expected to be removed from the four classes defined by diphoton properties. In the mass range $100 < m_{\gamma\gamma} < 180$ GeV the fractions of diphoton events in the selected data, which pass the dijet VBF tag and enter the fifth class, and which would otherwise have entered one of the four classes defined in Table 2, are 0.8%, 0.5%, 0.3% and 0.4%, respectively.

The number of events in each of the five classes is shown in Table 2, for signal events from all Higgs boson production processes (as predicted by MC simulation), and for data. A Higgs boson with $m_H = 120$ GeV is chosen for the signal, and the data are counted in a bin (±10 GeV) centered at 120 GeV. The table also shows the mass resolution, parameterized both as σ_{eff}, half-the-width of the narrowest window containing 68.3% of the distribution, and as the full width at half maximum (FWHM) of the invariant mass distribution divided by 2.35. The resolution in the endcaps is noticeably worse than in the barrel due to several factors, which include the amount of material in front of the calorimeter and less precise single channel calibration.

Significant systematic uncertainties on the efficiency of dijet tagging of signal events arise from the uncertainty on the MC modeling of jet-energy corrections and jet-energy resolution, and from uncertainties in predicting the presence of the jets and their kinematics. These uncertainties arise from the effect of different underlying event tunes, and from the uncertainty on parton distribution functions and QCD scale factor. Overall, an uncertainty of 10% is assigned to the efficiency for VBF signal events to enter the dijet tag class, and an uncertainty of 70%, which is dominated by the uncertainty on the underlying event tune is assigned to the efficiency for signal events produced by gluon–gluon fusion to enter the dijet-tag class. The uncertainty on the underlying event tunes was investigated by comparing the DT6 [45], P0 [46], PROPT0 and PROQ20 [47] tunes to the Z2 tune [48] in PYTHIA [49].

7. Background and signal modeling

The MC simulation of the background processes is not used in the analysis. However, the diphoton mass spectrum that is observed after the full event selection is found to agree with the distribution predicted by MC simulation, within the uncertainties on the cross sections of the contributing processes which is estimated to be about 15%. The background components have been scaled by K-factors obtained from CMS measurements [50–52]. The contribution to the background in the diphoton mass range $110 < m_{\gamma\gamma} < 150$ GeV from processes giving non-prompt photons is about 30%.

The background model is obtained by fitting the observed diphoton mass distributions in each of the five event classes over the range $100 < m_{\gamma\gamma} < 180$ GeV. The choice of function used to fit the background, and the choice of the range, was made based on a study of the possible bias introduced by the choice on both the limit, in the case of no signal, and the measured signal strength, in the case of a signal.

The bias studies were performed using background-only and signal-plus-background MC simulation samples and showed that for the first four classes, the bias in either excluding or finding a Higgs boson signal in the mass range $110 < m_{\gamma\gamma} < 150$ GeV can be ignored, if a 5th order polynomial fit to the range $100 < m_{\gamma\gamma} < 180$ GeV is used. In both cases the maximum bias was found to be at least five times smaller than the statistical uncertainties of the fit. For the dijet-tagged event class, which contains much fewer

Table 2
Number of selected events in different event classes, for a SM Higgs boson signal ($m_H = 120$ GeV), and for data at 120 GeV. The value given for data, expressed as events/GeV, is obtained by dividing the number of events in a bin of ±10 GeV, centered at 120 GeV, by 20 GeV. The mass resolution for a SM Higgs boson signal in each event class is also given.

	Both photons in barrel		One or both in endcap		Dijet tag
	$R_9^{\min} > 0.94$	$R_9^{\min} < 0.94$	$R_9^{\min} > 0.94$	$R_9^{\min} < 0.94$	
SM signal expected	25.2 (33.5%)	26.6 (35.3%)	9.5 (12.6%)	11.4 (14.9%)	2.8 (3.7%)
Data (events/GeV)	97.5 (22.8%)	143.4 (33.6%)	76.7 (17.9%)	107.4 (25.1%)	2.3 (0.5%)
σ_{eff} (GeV)	1.39	1.84	2.76	3.19	1.71
FWHM/2.35 (GeV)	1.19	1.53	2.81	3.18	1.37

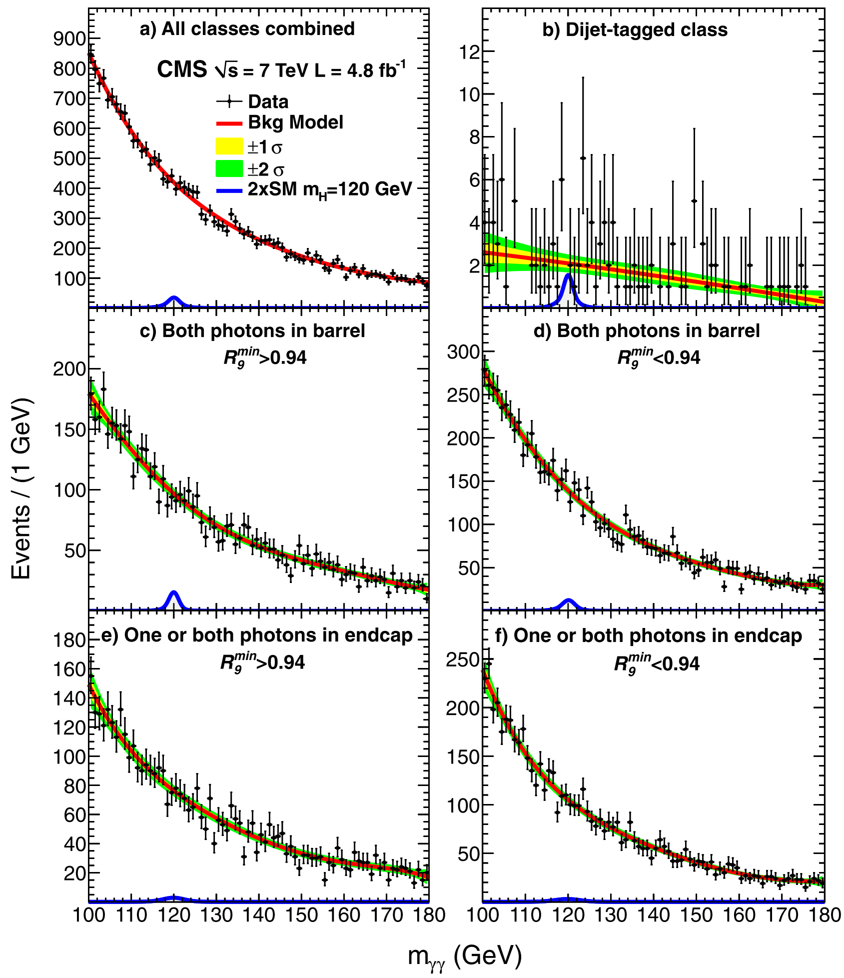

Fig. 1. Background model fit to the $m_{\gamma\gamma}$ distribution for the five event classes, together with a simulated signal ($m_{\mathrm{H}} = 120$ GeV). The magnitude of the simulated signal is what would be expected if its cross section were twice the SM expectation. The sum of the event classes together with the sum of the five fits is also shown. a) The sum of the five event classes. b) The dijet-tagged class. c) Both photons in the barrel, $R_9^{\min} > 0.94$. d) Both photons in the barrel, $R_9^{\min} < 0.94$. e) At least one photon in the endcaps, $R_9^{\min} > 0.94$. f) At least one photon in the endcaps, $R_9^{\min} < 0.94$.

events, the use of a 2nd order polynomial was shown to be sufficient and unbiased.

The description of the Higgs boson signal used in the search is obtained from MC simulation using the next-to-leading order (NLO) matrix-element generator POWHEG [53,54] interfaced with PYTHIA [49], using the Z2 underlying event tune. For the dominant gluon–gluon fusion process, the Higgs boson transverse momentum spectrum has been reweighted to the next-to-next-to-leading logarithmic (NNLL) + NLO distribution computed by the HQT program [55–57]. The uncertainty on the signal cross section due to PDF uncertainties has been determined using the PDF4LHC prescription [58–62]. The uncertainty on the cross section due to scale uncertainty has been estimated by varying independently the renormalization and factorization scales used by HQT, between $m_{\mathrm{H}}/2$ and $2m_{\mathrm{H}}$. We have verified that the effect of this variation on the rapidity of the Higgs boson is very small and can be neglected.

Corrections are made to the measured energy of the photons based on detailed study of the mass distribution of $Z \to ee$ events and comparison with MC simulation. After the application of these corrections the $Z \to ee$ events are re-examined and values are derived for the random smearing that needs to be made to the MC simulation to account for the energy resolution observed in the data. These smearings are derived for photons separated into four η regions (two in the barrel and two in the endcap) and two categories of R_9. The uncertainties on the measurements of the photon scale and resolution are taken as systematic uncertainties in the limit setting. The overall uncertainty on the diphoton mass scale is less than 1%.

The $m_{\gamma\gamma}$ distributions for the data in the five event classes, together with the background fits, are shown in Fig. 1. The uncertainty bands shown are computed from the fit uncertainty on the background yield within each bin used for the data points. The expected signal shapes for $m_{\mathrm{H}} = 120$ GeV are also shown. The magnitude of the simulated signal is what would be expected if its cross section were twice the SM expectation. The sum of the five event classes is also shown, where the line representing the background model is the sum of the five fits to the individual event classes.

8. Results

The confidence level for exclusion or discovery of a SM Higgs boson signal is evaluated using the diphoton invariant mass distribution for each of the event classes. The results in the five classes are combined in the CL calculation to obtain the final result.

The limits are evaluated using a modified frequentist approach, $\mathrm{CL_s}$, taking the profile likelihood as a test statistic [63–65]. Both a

Table 3
Separate sources of systematic uncertainties accounted for in this analysis. The magnitude of the variation of the source that has been applied to the signal model is shown in the second column.

Sources of systematic uncertainty		Uncertainty	
Per photon		Barrel	Endcap
Photon identification efficiency		1.0%	2.6%
$R_9 > 0.94$ classification (class migration)		4.0%	6.5%
Energy resolution ($\Delta\sigma/E_{MC}$)	$R_9 > 0.94$ (low η, high η)	0.22%, 0.61%	0.91%, 0.34%
	$R_9 < 0.94$ (low η, high η)	0.24%, 0.59%	0.30%, 0.53%
Energy scale ($(E_{data} - E_{MC})/E_{MC}$)	$R_9 > 0.94$ (low η, high η)	0.19%, 0.71%	0.88%, 0.19%
	$R_9 < 0.94$ (low η, high η)	0.13%, 0.51%	0.18%, 0.28%
Per event			
Integrated luminosity		4.5%	
Vertex finding efficiency		0.4%	
Trigger efficiency	One or both photons $R_9 < 0.94$ in endcap	0.4%	
	Other events	0.1%	
Dijet selection			
Dijet-tagging efficiency	VBF process	10%	
	Gluon–gluon fusion process	70%	
Production cross sections		Scale	PDF
Gluon–gluon fusion		+12.5% −8.2%	+7.9% −7.7%
Vector boson fusion		+0.5% −0.3%	+2.7% −2.1%
Associated production with W/Z		1.8%	4.2%
Associated production with $t\bar{t}$		+3.6% −9.5%	8.5%

binned and an unbinned evaluation of the likelihood are considered. While most of the analysis and determination of systematic uncertainties are common for these two approaches, there are differences at the final stages which make a comparison useful. The signal model is taken from MC simulation after applying the corrections determined from data/simulation comparisons of $Z \to ee$ and $Z \to \mu\mu\gamma$ events mentioned above, and the reweighting of the Higgs boson transverse momentum spectrum. The background is evaluated from a fit to the data without reference to the MC simulation.

Since a Higgs boson signal would be reconstructed with a mass resolution approaching 1 GeV in the classes with best resolution, the limit and signal significance evaluation is carried out in steps of 0.5 GeV. The SM Higgs boson cross sections and branchings ratios used are taken from Ref. [66].

Table 3 lists the sources of systematic uncertainty considered in the analysis, together with the magnitude of the variation of the source that has been applied.

The limit set on the cross section of a Higgs boson decaying to two photons using the frequentist CL_S computation and an unbinned evaluation of the likelihood, is shown in Fig. 2. Also shown is the limit relative to the SM expectation, where the theoretical uncertainties on the expected cross sections from the different production mechanisms are individually included as systematic uncertainties in the limit setting procedure. The observed limit excludes at 95% CL the standard model Higgs boson decaying into two photons in the mass range 128 to 132 GeV. The fluctuations of the observed limit about the expected limit are consistent with statistical fluctuations to be expected in scanning the mass range. The largest deviation, at $m_{\gamma\gamma} = 124$ GeV, is discussed in more detail below. It has also been verified that the shape of the observed limit is insensitive to the choice of background model fitting function. The results obtained from the binned evaluation of the likelihood are in excellent agreement with the results shown in Fig. 2.

Fig. 3 shows the local p-value calculated, using the asymptotic approximation [67], at 0.5 GeV intervals in the mass range $110 < m_H < 150$ GeV. The local p-values for the dijet-tag event class, and for the combination of the four other classes, are also shown (dash-dotted and dashed lines respectively). The local p-value

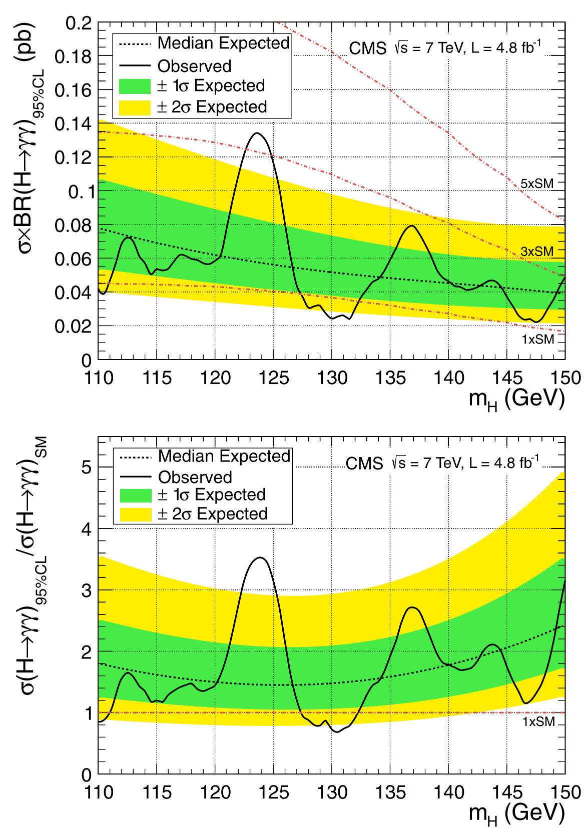

Fig. 2. Exclusion limit on the cross section of a SM Higgs boson decaying into two photons as a function of the boson mass (upper plot). Below is the same exclusion limit relative to the SM Higgs boson cross section, where the theoretical uncertainties on the cross section have been included in the limit setting.

quantifies the probability for the background to produce a fluctuation at least as large as observed, and assumes that the relative signal strength between the event classes follows the MC signal model for the standard model Higgs boson. The local p-value

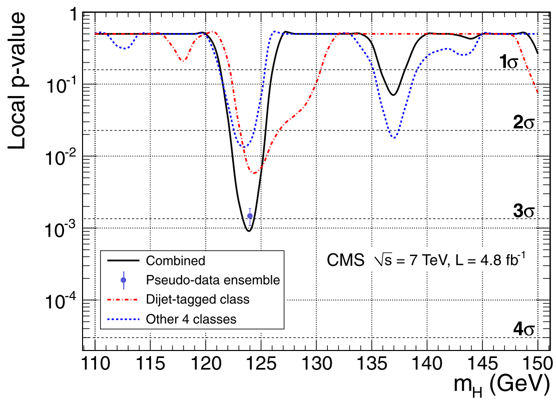

Fig. 3. The local p-value as a function of Higgs boson mass, calculated in the asymptotic approximation. The point at 124 GeV shows the value obtained with a pseudo-data ensemble.

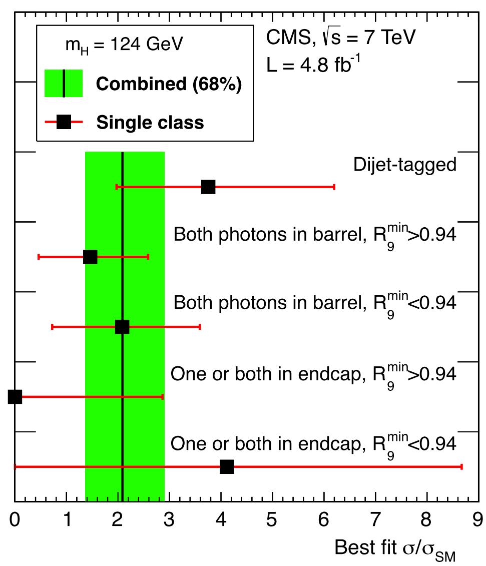

Fig. 4. The best fit signal strength, in terms of the standard model Higgs boson cross section, for the combined fit to the five classes (vertical line) and for the individual contributing classes (points) for the hypothesis of a SM Higgs boson mass of 124 GeV. The band corresponds to $\pm 1\sigma$ uncertainties on the overall value. The horizontal bars indicate $\pm 1\sigma$ uncertainties on the values for individual classes.

corresponding to the largest upwards fluctuation of the observed limit, at 124 GeV, has been computed to be 9.2×10^{-4} (3.1σ) in the asymptotic approximation, and $1.5 \pm 0.4 \times 10^{-3}$ (3.0σ) when the calculation uses pseudo-data (the value for the pseudo-data ensemble at 124 GeV is shown in Fig. 3). The combined best fit signal strength, for a SM Higgs boson mass hypothesis of 124 GeV, is 2.1 ± 0.6 times the SM Higgs boson cross section. In Fig. 4 this combined best fit signal strength is compared to the best fit signal strengths in each of the event classes. Since a fluctuation of the background could occur at any point in the mass range there is a look-elsewhere effect [68]. When this is taken into account the probability, under the background only hypothesis, of observing a similar or larger excess in the full analysis mass range ($110 < m_H < 150$ GeV) is 3.9×10^{-2}, corresponding to a global significance of 1.8σ.

9. Conclusions

A search has been performed for the standard model Higgs boson decaying into two photons using data obtained from pp collisions at $\sqrt{s} = 7$ TeV corresponding to an integrated luminosity of 4.8 fb^{-1}. The selected events are subdivided into classes according to indicators of mass resolution and signal-to-background ratio, and the results of a search in each class are combined. The expected exclusion limit at 95% confidence level is between 1.4 and 2.4 times the standard model cross section in the mass range between 110 and 150 GeV. The analysis of the data excludes at 95% confidence level the standard model Higgs boson decaying into two photons in the mass range 128 to 132 GeV. The largest excess of events above the expected standard model background is observed for a Higgs boson mass hypothesis of 124 GeV with a local significance of 3.1σ. The global significance of observing an excess with a local significance $\geqslant 3.1\sigma$ anywhere in the search range 110–150 GeV is estimated to be 1.8σ. More data are required to ascertain the origin of this excess.

Acknowledgements

We wish to 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 (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (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); SCSR (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); and the Council of Science and Industrial Research, India.

References

[1] S.L. Glashow, Nucl. Phys. 22 (1961) 579, doi:10.1016/0029-5582(61)90469-2.
[2] S. Weinberg, Phys. Rev. Lett. 19 (1967) 1264, doi:10.1103/PhysRevLett.19.1264.
[3] A. Salam, in: N. Svartholm (Ed.), Elementary Particle Physics: Relativistic Groups and Analyticity, Proceedings of the Eighth Nobel Symposium, Almquvist & Wiskell, 1968, p. 367.
[4] F. Englert, R. Brout, Phys. Rev. Lett. 13 (1964) 321, doi:10.1103/PhysRevLett.13.321.
[5] P.W. Higgs, Phys. Lett. 12 (1964) 132, doi:10.1016/0031-9163(64)91136-9.
[6] P.W. Higgs, Phys. Rev. Lett. 13 (1964) 508, doi:10.1103/PhysRevLett.13.508.
[7] G.S. Guralnik, C.R. Hagen, T.W.B. Kibble, Phys. Rev. Lett. 13 (1964) 585, doi:10.1103/PhysRevLett.13.585.

[8] P.W. Higgs, Phys. Rev. 145 (1966) 1156, doi:10.1103/PhysRev.145.1156.
[9] T.W.B. Kibble, Phys. Rev. 155 (1967) 1554, doi:10.1103/PhysRev.155.1554.
[10] DELPHI, ALEPH, L3, OPAL Collaborations, the LEP Working Group for Higgs Boson Searches, Phys. Lett. B 565 (2003) 61, doi:10.1016/S0370-2693(03)00614-2.
[11] CDF, D0 Collaborations, Phys. Rev. Lett. 104 (2010) 061802, doi:10.1103/PhysRevLett.104.061802, a more recent, unpublished, limit is given in preprint, arXiv:1103.3233.
[12] ATLAS Collaboration, Phys. Rev. Lett. (2011), in press, arXiv:1112.2577.
[13] G. Aad, et al., Phys. Lett. B 705 (2011) 435, doi:10.1016/j.physletb.2011.10.034, arXiv:1109.5945.
[14] G. Aad, et al., Phys. Rev. Lett. 107 (2011) 221802, doi:10.1103/PhysRevLett.107.221802, arXiv:1109.3357.
[15] ALEPH, CDF, D0, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the Tevatron Electroweak Working Group, the SLD Electroweak, the Heavy Flavour Groups, Precision electroweak measurements and constraints on the Standard Model, arXiv:1012.2367, 2010, http://lepewwg.web.cern.ch/LEPEWWG.
[16] S. Dawson, Nucl. Phys. B 359 (1991) 283, doi:10.1016/0550-3213(91)90061-2.
[17] M. Spira, A. Djouadi, D. Graudenz, P.M. Zerwas, Nucl. Phys. B 453 (1995) 17, doi:10.1016/0550-3213(95)00379-7.
[18] R.V. Harlander, W.B. Kilgore, Phys. Rev. Lett. 88 (2002) 201801, doi:10.1103/PhysRevLett.88.201801.
[19] C. Anastasiou, K. Melnikov, Nucl. Phys. B 646 (2002) 220, doi:10.1016/S0550-3213(02)00837-4.
[20] V. Ravindran, J. Smith, W.L. van Neerven, Nucl. Phys. B 665 (2003) 325, doi:10.1016/S0550-3213(03)00457-7.
[21] S. Actis, G. Passarino, C. Sturm, S. Uccirati, Phys. Lett. B 670 (2008) 12, doi:10.1016/j.physletb.2008.10.018.
[22] C. Anastasiou, R. Boughezal, F. Petriello, JHEP 0904 (2009) 003, doi:10.1088/1126-6708/2009/04/003.
[23] P. Bolzoni, F. Maltoni, S.-O. Moch, M. Zaro, Phys. Rev. Lett. 105 (2010) 011801, doi:10.1103/PhysRevLett.105.011801.
[24] D. de Florian, M. Grazzini, Phys. Lett. B 674 (2009) 291, doi:10.1016/j.physletb.2009.03.033.
[25] M. Ciccolini, A. Denner, S. Dittmaier, Phys. Rev. Lett. 99 (2007) 161803, doi:10.1103/PhysRevLett.99.161803.
[26] M. Ciccolini, A. Denner, S. Dittmaier, Phys. Rev. D 77 (2008) 013002, doi:10.1103/PhysRevD.77.013002.
[27] T. Han, S. Willenbrock, Phys. Lett. B 273 (1991) 167, doi:10.1016/0370-2693(91)90572-8.
[28] S. Actis, G. Passarino, C. Sturm, S. Uccirati, Nucl. Phys. B 811 (2009) 182, doi:10.1016/j.nuclphysb.2008.11.024, arXiv:0809.3667.
[29] T. Aaltonen, et al., Phys. Rev. Lett. 103 (2009) 061803, doi:10.1103/PhysRevLett.103.061803.
[30] V.M. Abazov, et al., Phys. Rev. Lett. 102 (2009) 231801, doi:10.1103/PhysRevLett.102.231801.
[31] G. Aad, et al., Phys. Lett. B 705 (2011) 452, doi:10.1016/j.physletb.2011.10.051.
[32] S. Chatrchyan, et al., JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
[33] A. Hoecker, P. Speckmayer, J. Stelzer, J. Therhaag, E. von Toerne, H. Voss, PoS ACAT (2007) 040, arXiv:physics/0703039.
[34] CMS Collaboration, Particle-flow event reconstruction in CMS and performance for jets, taus, and E_T^{miss}, CMS Physics Analysis Summary CMS-PAS-PFT-09-001, http://cdsweb.cern.ch/record/1194487, 2009.
[35] CMS Collaboration, Commissioning of the particle-flow reconstruction in minimum-bias and jet events from pp collisions at 7 TeV, CMS Physics Analysis Summary CMS-PAS-PFT-10-002, http://cdsweb.cern.ch/record/1279341, 2010.
[36] M. Cacciari, G.P. Salam, G. Soyez, JHEP 0804 (2008) 063, doi:10.1088/1126-6708/2008/04/063.
[37] S. Chatrchyan, et al., JINST 06 (2011) P11002, doi:10.1088/1748-0221/6/11/P11002.
[38] M. Cacciari, G.P. Salam, Phys. Lett. B 659 (2008) 119, doi:10.1016/j.physletb.2007.09.077.
[39] M. Cacciari, G.P. Salam, G. Soyez, JHEP 0804 (2008) 005, doi:10.1088/1126-6708/2008/04/005.
[40] M. Cacciari, G.P. Salam, G. Soyez, FastJet user manual, arXiv:1111.6097.
[41] S. Agostinelli, et al., Nucl. Instrum. Meth. A 506 (2003) 250, doi:10.1016/S0168-9002(03)01368-8.
[42] S. Chatrchyan, et al., JHEP 1110 (2011) 132, doi:10.1007/JHEP10(2011)132.
[43] A. Ballestrero, G. Bevilacqua, E. Maina, JHEP 0905 (2009) 015, doi:10.1088/1126-6708/2009/05/015.
[44] D.L. Rainwater, R. Szalapski, D. Zeppenfeld, Phys. Rev. D 54 (1996) 6680, doi:10.1103/PhysRevD.54.6680.
[45] Paolo Bartalini, R. Field, R. Chierici, M. Cacciari, A. Moraes, et al., Multiple partonic interactions at the LHC, in: Proceedings, 1st International Workshop, MPI'08, Perugia, Italy, arXiv:1003.4220, October 27–31, 2008.
[46] P.Z. Skands, Phys. Rev. D 82 (2010) 074018, doi:10.1103/PhysRevD.82.074018, arXiv:1005.3457.
[47] A. Buckley, H. Hoeth, H. Lacker, H. Schulz, J.E. von Seggern, Eur. Phys. J. C 65 (2010) 331, doi:10.1140/epjc/s10052-009-1196-7, arXiv:0907.2973.
[48] R. Field, Early LHC underlying event data – findings and surprises, arXiv:1010.3558.
[49] T. Sjöstrand, S. Mrenna, P.Z. Skands, JHEP 0605 (2006) 026, doi:10.1088/1126-6708/2006/05/026.
[50] S. Chatrchyan, et al., JHEP 1110 (2011) 7, doi:10.1007/JHEP10(2011)007.
[51] S. Chatrchyan, et al., JHEP 1101 (2011) 133, doi:10.1007/JHEP01(2012)133.
[52] S. Chatrchyan, et al., Phys. Lett. B 700 (2011) 187, doi:10.1016/j.physletb.2011.05.027.
[53] S. Alioli, P. Nason, C. Oleari, E. Re, JHEP 0904 (2009) 002, doi:10.1088/1126-6708/2009/04/002.
[54] P. Nason, C. Oleari, JHEP 1002 (2010) 037, doi:10.1007/JHEP02(2010)037.
[55] G. Bozzi, S. Catani, D. de Florian, M. Grazzini, Phys. Lett. B 564 (2003) 65, doi:10.1016/S0370-2693(03)00656-7.
[56] G. Bozzi, S. Catani, D. de Florian, M. Grazzini, Nucl. Phys. B 737 (2006) 73, doi:10.1016/j.nuclphysb.2005.12.022.
[57] D. de Florian, G. Ferrera, M. Grazzini, D. Tommasini, JHEP 1111 (2011) 064, doi:10.1007/JHEP11(2011)064.
[58] M. Botje, J. Butterworth, A. Cooper-Sarkar, A. de Roeck, J. Feltesse, et al., The PDF4LHC Working Group, Interim recommendations, arXiv:1101.0538, 2011.
[59] S. Alekhin, S. Alioli, R.D. Ball, V. Bertone, J. Blumlein, et al., The PDF4LHC Working Group, Interim report, arXiv:1101.0536, 2011.
[60] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P.M. Nadolsky, et al., Phys. Rev. D 82 (2010) 074024, doi:10.1103/PhysRevD.82.074024.
[61] A. Martin, W. Stirling, R. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189, doi:10.1140/epjc/s10052-009-1072-5.
[62] R.D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, et al., Impact of heavy quark masses on parton distributions and LHC phenomenology, arXiv:1101.1300, 2011.
[63] T. Junk, Nucl. Instrum. Meth. A 434 (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.
[64] A. Read, Modified frequentist analysis of search results (the CL_s method), Tech. Rep. CERN-OPEN-2000-005, CERN, http://cdsweb.cern.ch/record/451614, 2000.
[65] ATLAS, CMS Collaborations, LHC Higgs Combination Group, Procedure for the LHC Higgs boson search combination in Summer 2011, ATL-PHYS-PUB/CMS NOTE 2011-11, 2011/005, http://cdsweb.cern.ch/record/1379837, 2011.
[66] S. Dittmaier, C. Mariotti, G. Passarino, R. Tanaka (Eds.), Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables, CERN Report CERN-2011-002, arXiv:1101.0593, http://cdsweb.cern.ch/record/1318996, 2011.
[67] G. Cowan, et al., Eur. Phys. J. C 71 (2011) 1, doi:10.1140/epjc/s10052-011-1554-0, arXiv:1007.1727.
[68] E. Gross, O. Vitells, Eur. Phys. J. C 70 (2010) 525, doi:10.1140/epjc/s10052-010-1470-8, arXiv:1005.1891.

CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer [1], 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. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

Institut für Hochenergiephysik der OeAW, Wien, Austria

N. Shumeiko, J. Suarez Gonzalez

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

M. Korzhik

Research Institute for Nuclear Problems, Minsk, Belarus

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 Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Universiteit Antwerpen, Antwerpen, 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

Vrije Universiteit Brussel, Brussel, Belgium

O. Charaf, B. Clerbaux, 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

Université Libre de Bruxelles, Bruxelles, 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, L. Vanelderen, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

Ghent University, Ghent, Belgium

S. Basegmez, G. Bruno, L. Ceard, J. De Favereau De Jeneret, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco [2], G. Grégoire, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, N. Schul

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

N. Beliy, T. Caebergs, E. Daubie

Université de Mons, Mons, Belgium

G.A. Alves, M. Correa Martins Junior, D. De Jesus Damiao, T. Martins, M.E. Pol, M.H.G. Souza

Centro Brasileiro de Pesquisas Fisicas, 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

Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

T.S. Anjos [3], 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

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

V. Genchev [1], P. Iaydjiev [1], S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Dimitrov, R. Hadjiiska, A. Karadzhinova, V. Kozhuharov, L. Litov, B. Pavlov, P. Petkov

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, 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

State Key Lab. of Nucl. Phys. and Tech., Peking University, Beijing, China

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

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, R. Plestina [5], D. Polic, I. Puljak [1]

Technical University of Split, Split, Croatia

Z. Antunovic, M. Dzelalija, M. Kovac

University of Split, Split, Croatia

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

Institute Rudjer Boskovic, Zagreb, Croatia

A. Attikis, M. Galanti, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis

University of Cyprus, Nicosia, Cyprus

M. Finger, M. Finger Jr.

Charles University, Prague, Czech Republic

Y. Assran [6], A. Ellithi Kamel [7], S. Khalil [8], M.A. Mahmoud [9], A. Radi [10]

Academy of Scientific Research and Technology of the Arab Republic of Egypt, Egyptian Network of High Energy Physics, Cairo, Egypt

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

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

Department of Physics, University of Helsinki, 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

Helsinki Institute of Physics, Helsinki, Finland

K. Banzuzi, A. Korpela, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

D. Sillou

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

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj [11], C. Broutin, P. Busson, C. Charlot, N. Daci, T. Dahms, L. Dobrzynski, S. Elgammal, R. Granier de Cassagnac, M. Haguenauer, P. Miné, C. Mironov, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Thiebaux, C. Veelken, A. Zabi

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

J.-L. Agram [12], J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte [12], F. Drouhin [12], C. Ferro, J.-C. Fontaine [12], D. Gelé, U. Goerlach, P. Juillot, M. Karim [12], A.-C. Le Bihan, P. Van Hove

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

F. Fassi, D. Mercier

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

C. Baty, S. Beauceron, N. Beaupere, M. Bedjidian, O. Bondu, G. Boudoul, D. Boumediene, H. Brun, J. Chasserat, R. Chierici [1], 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

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

D. Lomidze

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

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 [13]

RWTH Aachen University, I. Physikalisches Institut, 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 A, 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

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

M. Aldaya Martin, W. Behrenhoff, U. Behrens, M. Bergholz [14], 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. Jung [1], M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann [14], 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. Schmidt [14], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, J. Tomaszewska, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

C. Autermann, V. Blobel, S. Bobrovskyi, 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

University of Hamburg, Hamburg, Germany

C. Barth, J. Berger, T. Chwalek, W. De Boer, A. Dierlamm, G. Dirkes, M. Feindt, J. Gruschke, M. Guthoff [1], C. Hackstein, F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, I. Katkov [13], 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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

G. Daskalakis, T. Geralis, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, C. Mavrommatis, E. Ntomari

Institute of Nuclear Physics "Demokritos", Aghia Paraskevi, Greece

L. Gouskos, T.J. Mertzimekis, A. Panagiotou, N. Saoulidou, E. Stiliaris

University of Athens, Athens, Greece

I. Evangelou, C. Foudas [1], P. Kokkas, N. Manthos, I. Papadopoulos, V. Patras, F.A. Triantis

University of Ioánnina, Ioánnina, Greece

A. Aranyi, G. Bencze, L. Boldizsar, C. Hajdu [1], P. Hidas, D. Horvath [15], A. Kapusi, K. Krajczar [16], F. Sikler [1], V. Veszpremi, G. Vesztergombi [16]

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

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

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

S. Ahuja, B.C. Choudhary, A. Kumar, A. Kumar, S. Malhotra, M. Naimuddin, K. Ranjan, V. Sharma, R.K. Shivpuri

University of Delhi, Delhi, India

S. Banerjee, S. Bhattacharya, S. Dutta, B. Gomber, S. Jain, S. Jain, R. Khurana, S. Sarkar

Saha Institute of Nuclear Physics, Kolkata, India

R.K. Choudhury, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty [1], L.M. Pant, P. Shukla

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, S. Ganguly, M. Guchait [17], A. Gurtu [18], M. Maity [19], G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, A. Saha, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research – EHEP, Mumbai, India

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

Tata Institute of Fundamental Research – HECR, Mumbai, India

H. Arfaei, H. Bakhshiansohi [20], S.M. Etesami [21], A. Fahim [20], M. Hashemi, H. Hesari, A. Jafari [20], M. Khakzad, A. Mohammadi [22], M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh [23], M. Zeinali [21]

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

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]

[a] *INFN Sezione di Bari, Bari, Italy*
[b] *Università di Bari, Bari, Italy*
[c] *Politecnico di Bari, Bari, 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]

[a] *INFN Sezione di Bologna, Bologna, Italy*
[b] *Università di Bologna, Bologna, 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]

[a] *INFN Sezione di Catania, Catania, Italy*
[b] *Università di Catania, Catania, 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]

[a] *INFN Sezione di Firenze, Firenze, Italy*
[b] *Università di Firenze, Firenze, Italy*

L. Benussi, S. Bianco, S. Colafranceschi [24], F. Fabbri, D. Piccolo

INFN Laboratori Nazionali di Frascati, Frascati, Italy

P. Fabbricatore, R. Musenich

INFN Sezione di Genova, Genova, 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]

[a] *INFN Sezione di Milano-Bicocca, Milano, Italy*
[b] *Università di Milano-Bicocca, Milano, 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]

[a] *INFN Sezione di Napoli, Napoli, Italy*
[b] *Università di Napoli "Federico II", Napoli, 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]

[a] *INFN Sezione di Padova, Padova, Italy*
[b] *Università di Padova, Padova, Italy*
[c] *Università di Trento (Trento), Padova, 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]

[a] INFN Sezione di Pavia, Pavia, Italy
[b] Università di Pavia, Pavia, Italy

M. Biasini [a,b], G.M. Bilei [a], B. Caponeri [a,b], L. Fanò [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]

[a] INFN Sezione di Perugia, Perugia, Italy
[b] Università di Perugia, Perugia, 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,b], A.T. Serban [a], P. Spagnolo [a], R. Tenchini [a], G. Tonelli [a,b,1], A. Venturi [a,1], P.G. Verdini [a]

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

S. Baccaro [a,28], L. Barone [a,b], F. Cavallari [a], I. Dafinei [a], D. Del Re [a,b,1], M. Diemoz [a], C. Fanelli [a,b], M. Grassi [a,1], E. Longo [a,b], P. Meridiani [a], F. Micheli [a,b], S. Nourbakhsh [a], G. Organtini [a,b], F. Pandolfi [a,b], R. Paramatti [a], S. Rahatlou [a,b], M. Sigamani [a], L. Soffi [a,b]

[a] INFN Sezione di Roma, Roma, Italy
[b] Università di Roma "La Sapienza", Roma, 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. Ruspa [a,c], R. Sacchi [a,b], V. Sola [a,b], A. Solano [a,b], A. Staiano [a], A. Vilela Pereira [a]

[a] INFN Sezione di Torino, Torino, Italy
[b] Università di Torino, Torino, Italy
[c] Università del Piemonte Orientale (Novara), Torino, 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]

[a] INFN Sezione di Trieste, Trieste, Italy
[b] Università di Trieste, Trieste, Italy

S.G. Heo, S.K. Nam

Kangwon National University, Chunchon, Republic of 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

Kyungpook National University, Daegu, Republic of Korea

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

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

H.Y. Jo

Konkuk University, Seoul, Republic of 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

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

Y. Cho, Y. Choi, Y.K. Choi, J. Goh, M.S. Kim, B. Lee, J. Lee, S. Lee, H. Seo, I. Yu

Sungkyunkwan University, Suwon, Republic of Korea

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

Vilnius University, Vilnius, Lithuania

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

Centro de Investigacion y de Estudios Avanzados del IPN, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

H.A. Salazar Ibarguen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

E. Casimiro Linares, A. Morelos Pineda, M.A. Reyes-Santos

Universidad Autónoma de San Luis Potosí, San Luis Potosí, Mexico

D. Krofcheck

University of Auckland, Auckland, New Zealand

A.J. Bell, P.H. Butler, R. Doesburg, S. Reucroft, H. Silverwood

University of Canterbury, Christchurch, New Zealand

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 Physics, Quaid-I-Azam University, Islamabad, Pakistan

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

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

Soltan Institute for Nuclear Studies, Warsaw, Poland

N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, P. Musella, A. Nayak, J. Pela [1], P.Q. Ribeiro, J. Seixas, J. Varela, P. Vischia

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

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

Joint Institute for Nuclear Research, Dubna, 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

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, A. Toropin, S. Troitsky

Institute for Nuclear Research, Moscow, Russia

V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov [1], A. Krokhotin, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, V. Stolin, E. Vlasov, A. Zhokin

Institute for Theoretical and Experimental Physics, Moscow, Russia

A. Belyaev, E. Boos, M. Dubinin [4], L. Dudko, A. Ershov, A. Gribushin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushanko, L. Sarycheva [†], V. Savrin, A. Snigirev

Moscow State University, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin [1], V. Kachanov, D. Konstantinov, A. Korablev, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic [29], M. Djordjevic, M. Ekmedzic, D. Krpic [29], J. Milosevic

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia

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

Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Madrid, Spain

C. Albajar, G. Codispoti, J.F. de Trocóniz

Universidad Autónoma de Madrid, Madrid, Spain

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez [30], J.M. Vizan Garcia

Universidad de Oviedo, Oviedo, 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, 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

Instituto de Física de Cantabria (IFCA), CSIC–Universidad de Cantabria, Santander, Spain

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, C. Bernet [5], 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. Rolandi [32], T. Rommerskirchen, C. Rovelli [33], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas [*,34],

D. Spiga, M. Spiropulu [4], M. Stoye, A. Tsirou, G.I. Veres [16], P. Vichoudis, H.K. Wöhri, S.D. Worm [35], W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, 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]

Paul Scherrer Institut, Villigen, 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. Nägeli [37], 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. Starodumov [38], B. Stieger, M. Takahashi, L. Tauscher [†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli, J. Weng

Institute for Particle Physics, ETH Zurich, 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

Universität Zürich, Zurich, Switzerland

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 Central University, Chung-Li, 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

National Taiwan University (NTU), Taipei, Taiwan

A. Adiguzel, M.N. Bakirci [39], S. Cerci [40], 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. Ozturk [41], A. Polatoz, K. Sogut [42], D. Sunar Cerci [40], B. Tali [40], H. Topakli [39], D. Uzun, L.N. Vergili, M. Vergili

Cukurova University, Adana, 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

Middle East Technical University, Physics Department, Ankara, Turkey

M. Deliomeroglu, E. Gülmez, B. Isildak, M. Kaya [43], O. Kaya [43], S. Ozkorucuklu [44], N. Sonmez [45]

Bogazici University, Istanbul, Turkey

L. Levchuk

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

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

University of Bristol, Bristol, United Kingdom

L. Basso [46], K.W. Bell, A. Belyaev [46], 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

Rutherford Appleton Laboratory, Didcot, United Kingdom

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, M. Kenzie, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko [38], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi [47], 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

Imperial College, London, 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

Brunel University, Uxbridge, United Kingdom

K. Hatakeyama, H. Liu, T. Scarborough

Baylor University, Waco, USA

C. Henderson

The University of Alabama, Tuscaloosa, 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

Boston University, Boston, 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

Brown University, Providence, 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, Davis, Davis, 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, Los Angeles, Los Angeles, 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, Riverside, Riverside, 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. Wasserbaech [48], F. Würthwein, A. Yagil, J. Yoo

University of California, San Diego, La Jolla, 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 [1], 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

University of California, Santa Barbara, Santa Barbara, 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

California Institute of Technology, Pasadena, 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

Carnegie Mellon University, Pittsburgh, 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

University of Colorado at Boulder, Boulder, 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

Cornell University, Ithaca, USA

A. Biselli, D. Winn

Fairfield University, Fairfield, 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. Musienko [49], 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

Fermi National Accelerator Laboratory, Batavia, 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. Milenovic [50], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, M. Schmitt, B. Scurlock, P. Sellers, N. Skhirtladze, M. Snowball, D. Wang, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

V. Gaultney, L.M. Lebolo, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida International University, Miami, 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 State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, 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. Kunde [51], F. Lacroix, M. Malek, C. O'Brien, C. Silkworth, C. Silvestre, D. Strom, N. Varelas

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

U. Akgun, E.A. Albayrak, B. Bilki [52], W. Clarida, F. Duru, S. Griffiths, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya [53], 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

The University of Iowa, Iowa City, 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

Johns Hopkins University, Baltimore, 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

The University of Kansas, Lawrence, USA

A.F. Barfuss, T. Bolton, I. Chakaberia, A. Ivanov, S. Khalil, M. Makouski, Y. Maravin, S. Shrestha, I. Svintradze

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, D. Wright

Lawrence Livermore National Laboratory, Livermore, 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

University of Maryland, College Park, 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

Massachusetts Institute of Technology, Cambridge, 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 Minnesota, Minneapolis, USA

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

University of Mississippi, University, 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

University of Nebraska-Lincoln, Lincoln, USA

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

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

A. Anastassov, A. Kubik, N. Mucia, N. Odell, R.A. Ofierzynski, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, M. Velasco, S. Won

Northwestern University, Evanston, 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

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, 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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, 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, West Lafayette, USA

S. Guragain, N. Parashar

Purdue University Calumet, Hammond, USA

A. Adair, C. Boulahouache, V. Cuplov, K.M. Ecklund, F.J.M. Geurts, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

Rice University, Houston, 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

University of Rochester, Rochester, USA

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

The Rockefeller University, New York, 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

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

G. Cerizza, M. Hollingsworth, S. Spanier, Z.C. Yang, A. York

University of Tennessee, Knoxville, USA

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[54], 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 A&M University, College Station, USA

N. Akchurin, J. Damgov, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, Y. Roh, A. Sill, I. Volobouev, R. Wigmans

Texas Tech University, Lubbock, 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

Vanderbilt University, Nashville, 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

University of Virginia, Charlottesville, USA

S. Gollapinni, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, M. Mattson, C. Milstène, A. Sakharov

Wayne State University, Detroit, 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

University of Wisconsin, Madison, USA

[*] Corresponding author.
E-mail address: cms-publication-committee-chair@cern.ch (P. Sphicas).

[†] 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] Also 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 ENEA – Casaccia Research Center, S. Maria di Galeria, Italy.
[29] Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.
[30] Also at University of Florida, Gainesville, USA.
[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 The University of Iowa, Iowa City, USA.
[42] Also at Mersin University, Mersin, Turkey.
[43] Also at Kafkas University, Kars, Turkey.
[44] Also at Suleyman Demirel University, Isparta, Turkey.
[45] Also at Ege University, Izmir, Turkey.
[46] Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
[47] Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy.
[48] Also at Utah Valley University, Orem, USA.
[49] Also at Institute for Nuclear Research, Moscow, Russia.
[50] Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
[51] Also at Los Alamos National Laboratory, Los Alamos, USA.
[52] Also at Argonne National Laboratory, Argonne, USA.
[53] Also at Erzincan University, Erzincan, Turkey.
[54] Also at Kyungpook National University, Daegu, Republic of Korea.