Physics Letters B 710 (2012) 26–48

Contents lists available at SciVerse ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Combined results of searches for the standard model Higgs boson in pp collisions at $\sqrt{s} = 7$ TeV ☆

CMS Collaboration ⋆

CERN, Switzerland

ARTICLE INFO

Article history:
Available online 27 February 2012
Editor: W.-D. Schlatter

Keywords:
CMS
Higgs
Physics
Statistics

ABSTRACT

Combined results are reported from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ TeV in five Higgs boson decay modes: $\gamma\gamma$, bb, $\tau\tau$, WW, and ZZ. The explored Higgs boson mass range is 110–600 GeV. The analysed data correspond to an integrated luminosity of 4.6–4.8 fb^{-1}. The expected excluded mass range in the absence of the standard model Higgs boson is 118–543 GeV at 95% CL. The observed results exclude the standard model Higgs boson in the mass range 127–600 GeV at 95% CL, and in the mass range 129–525 GeV at 99% CL. An excess of events above the expected standard model background is observed at the low end of the explored mass range making the observed limits weaker than expected in the absence of a signal. The largest excess, with a local significance of 3.1σ, is observed for a Higgs boson mass hypothesis of 124 GeV. The global significance of observing an excess with a local significance $\geqslant 3.1\sigma$ anywhere in the search range 110–600 (110–145) GeV is estimated to be 1.5σ (2.1σ). More data are required to ascertain the origin of the observed excess.

1. Introduction

The discovery of the mechanism for electroweak symmetry breaking is one of the goals of the physics programme at the Large Hadron Collider (LHC). In the standard model (SM) [1–3], this symmetry breaking is achieved by introducing a complex scalar doublet, leading to the prediction of the Higgs boson (H) [4–9]. To date, experimental searches for this particle have yielded null results. Limits at 95% confidence level (CL) on its mass have been placed by experiments at LEP, $m_H > 114.4$ GeV [10], the Tevatron, $m_H \notin (162–166)$ GeV [11], and ATLAS, $m_H \notin (145–206), (214–224), (340–450)$ GeV [12–14]. Precision electroweak measurements, not taking into account the results from direct searches, indirectly constrain the SM Higgs boson mass to be less than 158 GeV [15].

In this Letter, we report on the combination of Higgs boson searches carried out in proton–proton collisions at $\sqrt{s} = 7$ TeV using the Compact Muon Solenoid (CMS) detector [16] at the LHC. The analysed data recorded in 2010–2011 correspond to an integrated luminosity of 4.6–4.8 fb^{-1}, depending on the search channel. The search is performed for Higgs boson masses in the range 110–600 GeV.

The CMS apparatus consists of a barrel assembly and two endcaps, comprising, in successive layers outwards from the collision region, the silicon pixel and strip tracker, the lead tungstate crystal electromagnetic calorimeter, the brass/scintillator hadron calorimeter, the superconducting solenoid, and gas-ionization chambers embedded in the steel return yoke for the detection of muons.

Early phenomenological work on Higgs boson production and decay can be found in Refs. [17–19]. There are four main mechanisms for Higgs boson production in pp collisions at $\sqrt{s} = 7$ TeV. The gluon–gluon fusion mechanism has the largest cross section, followed in turn by vector boson fusion (VBF), associated WH and ZH production, and production in association with top quarks, $t\bar{t}H$. The cross sections for the Higgs boson production mechanisms and the decay branching fractions, together with their uncertainties, are taken from Ref. [20] and are derived from Refs. [21–66]. The total cross section varies from 20 to 0.3 pb as a function of the Higgs boson mass, over the explored range.

The relevant decay modes of the SM Higgs boson depend strongly on its mass m_H. The results presented here are based on the following five decay modes: $H \to \gamma\gamma$, $H \to \tau\tau$, $H \to bb$, $H \to WW$, followed by $WW \to (\ell\nu)(\ell\nu)$ decays, and $H \to ZZ$, followed by ZZ decays to 4ℓ, $2\ell 2\nu$, $2\ell 2q$, and $2\ell 2\tau$. Here and throughout, ℓ stands for electrons or muons and q for quarks. For simplicity, $H \to \tau^+\tau^-$ is denoted as $H \to \tau\tau$, $H \to b\bar{b}$ as $H \to bb$, etc. The WW and ZZ decay modes are used over the entire explored mass range. The $\gamma\gamma$, $\tau\tau$, and bb decay modes are used only for $m_H < 150$ GeV since their expected sensitivities are not significant compared to WW and ZZ for higher Higgs boson masses.

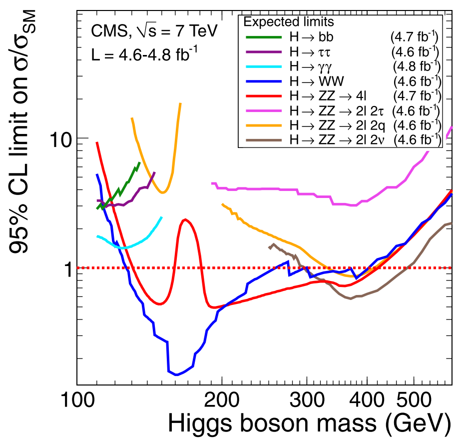
☆ © CERN for the benefit of the CMS Collaboration.

⋆ *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.2012.02.064

Table 1
Summary information on the analyses included in this combination.

Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_H resolution	Reference
$H \to \gamma\gamma$	110–150	4.8	2	1–3%	[67]
$H \to \tau\tau$	110–145	4.6	9	20%	[68]
$H \to bb$	110–135	4.7	5	10%	[69]
$H \to WW^* \to 2\ell 2\nu$	110–600	4.6	5	20%	[70]
$H \to ZZ^{(*)} \to 4\ell$	110–600	4.7	3	1–2%	[71]
$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%	[72]
$H \to ZZ^{(*)} \to 2\ell 2q$	{ 130–164 200–600	4.6	6	3% 3%	[73]
$H \to ZZ \to 2\ell 2\tau$	190–600	4.7	8	10–15%	[74]



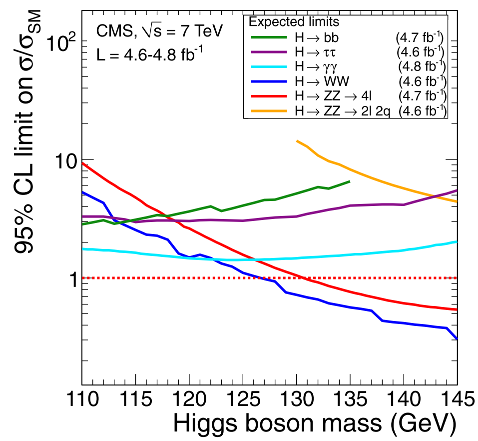


Fig. 1. The median expected 95% CL upper limits on the cross section ratio σ/σ_{SM} as a function of the SM Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right), for the eight Higgs boson decay channels. Here σ_{SM} denotes the cross section predicted for the SM Higgs boson. A channel showing values below unity (dotted red line) would be expected to be able to exclude a Higgs boson of that mass at 95% CL. The jagged structure in the limits for some channels results from the different event selection criteria employed in those channels for different Higgs boson mass sub-ranges. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

For a given Higgs boson mass hypothesis, the search sensitivity depends on the Higgs boson production cross section and decay branching fraction into the chosen final state, the signal selection efficiency, the Higgs boson mass resolution, and the level of standard model backgrounds with the same or a similar final state. In the low-mass range, the bb and $\tau\tau$ decay modes suffer from large backgrounds, which reduces the search sensitivity in these channels. For a Higgs boson with a mass below 120 GeV, the best sensitivity is achieved in the $\gamma\gamma$ decay mode, which has a very small branching fraction, but a more manageable background. In the mass range 120–200 GeV, the best sensitivity is achieved in the $H \to WW$ channel. At higher masses, the $H \to ZZ$ branching fraction is large and the searches for $H \to ZZ \to 4\ell$ and $H \to ZZ \to 2\ell 2\nu$ provide the best sensitivity. Among all decay modes, the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ channels play a special role as they provide a very good mass resolution for the reconstructed diphoton and four-lepton final states, respectively.

2. Search channels

The results presented in this Letter are obtained by combining the eight individual Higgs boson searches listed in Table 1. The table summarizes the main characteristics of these searches, namely: the mass range of the search, the integrated luminosity used, the number of exclusive sub-channels, and the approximate instrumental mass resolution. The presence of a signal or an upward fluctuation of the background in one of the channels, at a certain value of the Higgs boson mass, is expected to manifest itself as an excess extending around that value for a range corresponding to the m_H resolution.

As an illustration of the search sensitivity of the eight channels, Fig. 1 shows the median expected 95% CL upper limit on the ratio of the signal cross section, σ, and the predicted SM Higgs boson cross section, σ_{SM}, as a function of the SM Higgs boson mass hypothesis. A channel showing values below unity (dotted red line) would be expected to be able to exclude a Higgs boson of that mass at 95% CL. The method used for deriving limits is described in Section 3.

The $H \to \gamma\gamma$ analysis [67] is focused on a search for a narrow peak in the diphoton mass distribution. The event sample is split into two mutually exclusive sets: (i) diphoton events with one forward and one backward jet, consistent with the VBF topology, and (ii) all remaining events. This division is motivated by the consideration that there is a much better signal-to-background-ratio in the first set compared to the second. The second set, containing over 99% of data, is further subdivided into four classes based on whether or not both photons produce compact electromagnetic showers, and whether or not both photons are in the central part of the CMS detector. This subdivision is motivated by the fact that the photon energy resolution depends on whether or not a photon converts in the detector volume in front of the electromagnetic calorimeter, and whether it is measured in the barrel or in the endcap section of the calorimeter. The background in the signal region is estimated from a fit to the observed diphoton mass distribution in data.

The $H \to \tau\tau$ search [68] is performed using the final-state signatures $e\mu$, $e\tau_h$, $\mu\tau_h$, where electrons and muons arise from leptonic τ-decays $\tau \to \ell\nu_\ell\nu_\tau$ and τ_h denotes hadronic τ-decays $\tau \to \text{hadrons} + \nu_\tau$. Each of these three categories is further divided into three exclusive sub-categories according to the nature of the associated jets: (i) events with the VBF signature, (ii) events with just one jet with large transverse energy E_T, and (iii) events with either no jets or with one with a small E_T. In each of these nine categories we search for a broad excess in the reconstructed $\tau\tau$ mass distribution. The main irreducible background is from $Z \to \tau\tau$ production, whose $\tau\tau$ mass distribution is derived from data by using $Z \to \mu\mu$ events, in which the reconstructed muons are replaced with reconstructed particles from the decay of simulated τ leptons of the same momenta. The reducible backgrounds ($W+$ jets, multijet production, $Z \to ee$) are also evaluated from control samples in data.

The $H \to bb$ search [69] concentrates on Higgs boson production in association with W or Z bosons, in which the focus is on the following decay modes: $W \to e\nu/\mu\nu$ and $Z \to ee/\mu\mu/\nu\nu$. The $Z \to \nu\nu$ decay is identified by requiring a large missing transverse energy E_T^{miss}. The value E_T^{miss} is defined as the modulus of the vector $\vec{E}_T^{miss}$ computed as the negative of the vector sum of the transverse momenta of all reconstructed objects in the volume of the detector (leptons, photons, and charged/neutral hadrons). The dijet system, with both jets tagged as b-quark jets [75], is also required to have a large transverse momentum, which helps to reduce backgrounds and improves the dijet mass resolution. We use a multivariate analysis (MVA) technique, in which a classifier is trained on simulated signal and background events for a number of Higgs boson masses, and the events above an MVA output threshold are counted as signal-like. The rates of the main backgrounds, consisting of W/Z+jets and top-quark events, are derived from control samples in data. The WZ and ZZ backgrounds with a Z boson decaying to a pair of b-quarks, as well as the single-top background, are estimated from simulation.

The $H \to WW^{(*)} \to 2\ell 2\nu$ analysis [70] searches for an excess of events with two leptons of opposite charge, large E_T^{miss}, and up to two jets. Events are divided into five categories, with different background compositions and signal-to-background ratios. For events with no jets, the main background stems from non-resonant WW production; for events with one jet, the dominant backgrounds are from WW and top-quark production. The events with no jets and one jet are split into same-flavour and different-flavour dilepton sub-channels, since the background from Drell–Yan production is much larger for the same-flavour dilepton events. The two-jet category is optimized to take advantage of the VBF production signature. The main background in this channel is from top-quark production. To improve the separation of signal from backgrounds, MVA classifiers are trained for a number of Higgs boson masses, and a search is made for an excess of events in the output distributions of the classifiers. All background rates, except for very small contributions from WZ, ZZ, and $W\gamma$, are evaluated from data.

In the $H \to ZZ^{(*)} \to 4\ell$ channel [71], we search for a four-lepton mass peak over a small continuum background. The 4e, 4μ, $2e2\mu$ sub-channels are analyzed separately since there are differences in the four-lepton mass resolutions and the background rates arising from jets misidentified as leptons. The dominant irreducible background in this channel is from non-resonant ZZ production (with both Z bosons decaying to either 2e, or 2μ, or 2τ with the taus decaying leptonically) and is estimated from simulation. The smaller reducible backgrounds with jets misidentified as leptons, e.g. $Z+$ jets, are estimated from data.

In the $H \to ZZ \to 2\ell 2\nu$ search [72], we select events with a lepton pair (ee or $\mu\mu$), with invariant mass consistent with that of an on-shell Z boson, and a large E_T^{miss}. We then define a transverse invariant mass m_T from the dilepton momenta and E_T^{miss}, assuming that E_T^{miss} arises from a $Z \to \nu\nu$ decay. We search for a broad excess of events in the m_T distribution. The non-resonant ZZ and WZ backgrounds are taken from simulation, while all other backgrounds are evaluated from control samples in data.

In the $H \to ZZ^{(*)} \to 2\ell 2q$ search [73], we select events with two leptons (ee or $\mu\mu$) and two jets with zero, one, or two b-tags, thus defining a total of six exclusive final states. Requiring b-tagging improves the signal-to-background ratio. The two jets are required to form an invariant mass consistent with that of an on-shell Z boson. The aim is to search for a peak in the invariant mass distribution of the dilepton-dijet system, with the background rate and shape estimated using control regions in data.

In the $H \to ZZ \to 2\ell 2\tau$ search [74], one Z boson is required to be on-shell and to decay to a lepton pair (ee or $\mu\mu$). The other Z boson is required to decay through a $\tau\tau$ pair to one of the four final-state signatures $e\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$. Thus, eight exclusive sub-channels are defined. We search for a broad excess in the distribution of the dilepton-ditau mass, constructed from the visible products of the tau decays, neglecting the effect of the accompanying neutrinos. The dominant background is non-resonant ZZ production whose rate is estimated from simulation. The main sub-leading backgrounds with jets misidentified as τ leptons stem from $Z+$ jets (including ZW) and top-quark events. These backgrounds are estimated from data.

3. Combination methodology

The combination of the SM Higgs boson searches requires simultaneous analysis of the data from all individual search channels, accounting for all statistical and systematic uncertainties and their correlations. The results presented here are based on a combination of Higgs boson searches in a total of 40 exclusive sub-channels described in Section 2. Depending on the sub-channel, the input to the combination may be a total number of selected events or an event distribution for the final discriminating variable. Either binned or unbinned distributions are used, depending upon the particular search sub-channel.

The number of sources of systematic uncertainties considered in the combination ranges from 156 to 222, depending on the Higgs boson mass. A large fraction of these uncertainties are correlated across different channels and between signal and backgrounds within a given channel. Uncertainties considered include: theoretical uncertainties on the expected cross sections and acceptances for signal and background processes, experimental uncertainties arising from modelling of the detector response (event reconstruction and selection efficiencies, energy scale and resolution), and statistical uncertainties associated with either ancillary measurements of backgrounds in control regions or selection efficiencies obtained using simulated events. Systematic uncertainties can affect either the shape of distributions, or event yields, or both.

The combination is repeated for 183 Higgs boson mass hypotheses in the range 110–600 GeV. The step size in this scan varies [76] across the mass range and is determined by the Higgs boson mass resolution. The minimum step size is 0.5 GeV at lower masses, where it corresponds to the mass resolution of the $\gamma\gamma$ and 4ℓ channels. The maximum step size is 20 GeV at large masses, where the intrinsic Higgs boson width is the limiting factor.

3.1. General framework

The overall statistical methodology used in this combination was developed by the CMS and ATLAS Collaborations in the context of the LHC Higgs Combination Group. The detailed description of the methodology can be found in Ref. [76]. Below we outline the basic steps in the combination procedure.

Firstly, a signal strength modifier μ is introduced that multiplies the expected SM Higgs boson cross section such that $\sigma = \mu \cdot \sigma_{SM}$.

Secondly, each independent source of systematic uncertainty is assigned a nuisance parameter θ_i. The expected Higgs boson and background yields are functions of these nuisance parameters, and are written as $\mu \cdot s(\theta)$ and $b(\theta)$, respectively. Most nuisance parameters are constrained by other measurements. They are encoded in the probability density functions $p_i(\tilde{\theta}_i \mid \theta_i)$ describing the probability to measure a value $\tilde{\theta}_i$ of the i-th nuisance parameter, given its true value θ_i.

Next, we define the likelihood $\mathcal{L}$, given the data and the measurements $\tilde{\theta}$:

$$\mathcal{L}\big(\text{data} \mid \mu \cdot s(\theta) + b(\theta)\big) = \mathcal{P}\big(\text{data} \mid \mu \cdot s(\theta) + b(\theta)\big) \cdot p(\tilde{\theta} \mid \theta), \tag{1}$$

where $\mathcal{P}(\text{data} \mid \mu \cdot s(\theta) + b(\theta))$ is a product of probabilities over all bins of discriminant variable distributions in all channels (or over all events for sub-channels with unbinned distributions), and $p(\tilde{\theta} \mid \theta)$ is the probability density function for all nuisance parameter measurements.

In order to test a Higgs boson production hypothesis for a given mass, we construct an appropriate test statistic. The test statistic is a single number encompassing information on the observed data, expected signal, expected background, and all uncertainties associated with these expectations. It allows one to rank all possible experimental observations according to whether they are more consistent with the background-only or with the signal + background hypotheses.

Finally, in order to infer the presence or absence of a signal in the data, we compare the observed value of the test statistic with the distribution of values expected under the background-only and under the signal + background hypotheses. The expected distributions are obtained by generating pseudo-datasets from the probability density functions $\mathcal{P}(\text{data} \mid \mu \cdot s(\theta) + b(\theta))$ and $p(\tilde{\theta} \mid \theta)$. The values of the nuisance parameters θ used for generating pseudo-datasets are obtained by maximizing the likelihood $\mathcal{L}$ under the background-only or under the signal + background hypotheses.

3.2. *Quantifying an excess*

In order to quantify the statistical significance of an excess over the background-only expectation, we define a test statistic q_0 as:

$$q_0 = -2 \ln \frac{\mathcal{L}(\text{data} \mid b(\hat{\theta}_0))}{\mathcal{L}(\text{data} \mid \hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))}, \quad \hat{\mu} \geqslant 0, \tag{2}$$

where $\hat{\theta}_0$, $\hat{\theta}$, and $\hat{\mu}$ are the values of the parameters θ and μ that maximise the likelihoods in the numerator and denominator, and the subscript in $\hat{\theta}_0$ indicates that the maximization in the numerator is done under the background-only hypothesis ($\mu = 0$). Since the Higgs boson signal cannot be negative, the allowed range for $\hat{\mu}$ is $\hat{\mu} \geqslant 0$. With this definition, a signal-like excess, $\hat{\mu} > 0$, corresponds to a positive value of q_0. In the absence of an excess, $\hat{\mu}$ is zero (the lowest allowed value), the likelihood ratio becomes equal to one, and $q_0 = 0$.

An excess can be quantified in terms of the p-value p_0, which is the probability to obtain a value of q_0 at least as large as the one observed in data, q_0^{obs}, under the background-only (b) hypothesis:

$$p_0 = P\big(q_0 \geqslant q_0^{\text{obs}} \mid b\big). \tag{3}$$

We choose to relate the significance Z of an excess to the p-value via the Gaussian one-sided tail integral:

$$p_0 = \int_Z^\infty \frac{1}{\sqrt{2\pi}} \exp\big(-x^2/2\big)\,dx. \tag{4}$$

The test statistic q_0 has one degree of freedom (μ) and, in the limit of a large number of events, its distribution under the background-only hypothesis converges to a half of the χ^2 distribution for one degree of freedom plus $0.5 \cdot \delta(q_0)$ [77]. The term with the delta function $\delta(q_0)$ corresponds to the 50% probability not to observe an excess under the background-only hypothesis. This asymptotic property allows the significance to be evaluated directly from the observed test statistic q_0^{obs} as $Z = \sqrt{q_0^{\text{obs}}}$ [77].

The local p-value p_0 characterises the probability of a background fluctuation resembling a signal-like excess for a given value of the Higgs boson mass. The probability for a background fluctuation to be at least as large as the observed maximum excess anywhere in a specified mass range is given by the global probability or global p-value. This probability can be evaluated by generating pseudo-datasets incorporating all correlations between analyses optimized for different Higgs boson masses. It can also be estimated from the data by counting the number of transitions from deficit to excess in a specified Higgs boson mass range [76, 78]. The global significance is computed from the global p-value using Eq. (4).

3.3. *Quantifying the absence of a signal*

In order to set exclusion limits on a Higgs boson hypothesis, we define a test statistic q_μ, which depends on the hypothesised signal rate μ. The definition of q_μ makes use of a likelihood ratio similar to the one for q_0, but uses instead the signal + background model in the numerator:

$$q_\mu = -2 \ln \frac{\mathcal{L}(\text{data} \mid \mu \cdot s(\hat{\theta}_\mu) + b(\hat{\theta}_\mu))}{\mathcal{L}(\text{data} \mid \hat{\mu} \cdot s(\hat{\theta}) + b(\hat{\theta}))}, \quad 0 \leqslant \hat{\mu} < \mu, \tag{5}$$

where the subscript μ in $\hat{\theta}_\mu$ indicates that, in this case, the maximisation of the likelihood in the numerator is done under the hypothesis of a signal of strength μ. In order to force one-sided limits on the Higgs boson production rate, we constrain $\hat{\mu} < \mu$.

This definition of the test statistic differs slightly from the one used in searches at LEP and the Tevatron, where the background-only hypothesis was used in the denominator. With the definition of the test statistic given in Eq. (5), in the asymptotic limit of a large number of background events, the expected distributions of q_μ under the signal + background and under the background-only hypotheses are known analytically [77].

For the calculation of the exclusion limit, we adopt the modified frequentist construction CL_s [79,80]. We define two tail probabilities associated with the observed data; namely, the probability to obtain a value for the test statistic q_μ larger than the observed value q_μ^{obs} for the signal + background ($\mu \cdot s + b$) and for the background-only (b) hypotheses:

$$\text{CL}_{\text{s+b}} = P\big(q_\mu \geqslant q_\mu^{\text{obs}} \mid \mu \cdot s + b\big), \tag{6}$$

$$\text{CL}_\text{b} = P\big(q_\mu \geqslant q_\mu^{\text{obs}} \mid b\big), \tag{7}$$

and obtain the CL_s value from the ratio

$$\text{CL}_\text{s} = \frac{\text{CL}_{\text{s+b}}}{\text{CL}_\text{b}}. \tag{8}$$

If $\text{CL}_\text{s} \leqslant \alpha$ for $\mu = 1$, we determine that the SM Higgs boson is excluded at the $1 - \alpha$ confidence level. To quote the upper limit on

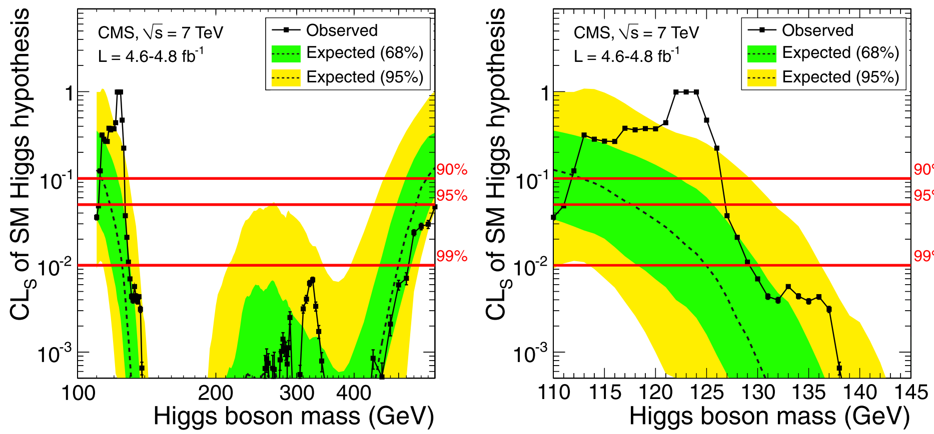


Fig. 2. The $\mathrm{CL_s}$ values for the SM Higgs boson hypothesis as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right). The observed values are shown by the solid line. The dashed line indicates the expected median of results for the background-only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively. The three horizontal lines on the $\mathrm{CL_s}$ plot show confidence levels of 90%, 95%, and 99%, defined as $(1 - \mathrm{CL_s})$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

μ at the 95% confidence level, we adjust μ until we reach $\mathrm{CL_s} = 0.05$.

4. Results

The $\mathrm{CL_s}$ value for the SM Higgs boson hypothesis as a function of its mass is shown in Fig. 2. The observed values are shown by the solid line. The dashed black line indicates the median of the expected results for the background-only hypothesis, with the green (dark) and yellow (light) bands indicating the ranges in which the $\mathrm{CL_s}$ values are expected to reside in 68% and 95% of the experiments under the background-only hypothesis. The probabilities for an observation to lie above or below the 68% (95%) band are 16% (2.5%) each. The observed and median expected values of $\mathrm{CL_s}$ as well as the 68% and 95% bands are obtained by generating ensembles of pseudo-datasets.

The thick red horizontal lines indicate $\mathrm{CL_s}$ values of 0.10, 0.05, and 0.01. The mass regions where the observed $\mathrm{CL_s}$ values are below these lines are excluded with the corresponding $(1 - \mathrm{CL_s})$ confidence levels of 90%, 95%, and 99%, respectively. We exclude a SM Higgs boson at 95% CL in the mass range 127–600 GeV. At 99% CL, we exclude it in the mass range 129–525 GeV.

In the mass range 122–124 GeV, the observed results lie above the expectation for the SM signal + background hypothesis. In this case, $\hat{\mu}$ is at its maximum allowed value μ, the test statistic $q_\mu^{\mathrm{obs}} = 0$ (Eq. (5)), and $\mathrm{CL_{s+b}}$, $\mathrm{CL_b}$ and hence $\mathrm{CL_s}$ equal unity (Eqs. (6)–(8)).

Fig. 3 shows the 95% CL upper limits on the signal strength modifier, $\mu = \sigma/\sigma_{\mathrm{SM}}$, obtained by generating ensembles of pseudo-datasets, as a function of m_{H}. The ordinate thus shows the Higgs boson cross section that is excluded at 95% CL, expressed as a multiple of the SM Higgs boson cross section.

The median expected exclusion range of m_{H} at 95% CL in the absence of a signal is 118–543 GeV. The differences between the observed and expected limits are consistent with statistical fluctuations since the observed limits are generally within the green (68%) or yellow (95%) bands of the expected limit values. For the largest values of m_{H}, we observe fewer events than the median expected number for the background-only hypothesis, which makes the observed limits in that range stronger than expected. However, at small m_{H} we observe an excess of events. This makes the observed limits weaker than expected in the absence of a SM Higgs boson.

Fig. 4 shows the separate observed limits for the eight individual decay channels studied, and their combination. For masses beyond 200 GeV, the limits are driven mostly by the $\mathrm{H} \to \mathrm{ZZ}$ decay channels, while in the range 125–200 GeV, the limits are largely defined by the $\mathrm{H} \to \mathrm{WW}$ decay mode. For the mass range below 120 GeV, the dominant contributor to the sensitivity is the $\mathrm{H} \to \gamma\gamma$ channel. The observed limits presented in Fig. 4 can be compared to the expected ones shown in Fig. 1. The results shown in both figures are calculated using the asymptotic formula for the $\mathrm{CL_s}$ method.

Fig. 5 shows two separate combinations in the low mass range: one for the $\gamma\gamma$ and $\mathrm{ZZ} \to 4\ell$ channels, which have good mass resolution, and another for the three channels with poor mass resolution (bb, $\tau\tau$, WW). The expected sensitivities of these two combinations are very similar. Both indicate an excess of events: the excess in the $\mathrm{bb} + \tau\tau + \mathrm{WW}$ combination has, as expected, little mass dependence in this range, while the excess in the $\gamma\gamma$ and $\mathrm{ZZ} \to 4\ell$ combination is clearly more localized. The results shown in Fig. 5 are calculated using the asymptotic formula.

To quantify the consistency of the observed excesses with the background-only hypothesis, we show in Fig. 6 (left) a scan of the combined local p-value p_0 in the low-mass region. A broad offset of about one standard deviation, caused by excesses in the channels with poor mass resolution (bb, $\tau\tau$, WW), is complemented by localized excesses observed in the $\mathrm{ZZ} \to 4\ell$ and $\gamma\gamma$ channels. This causes a decrease in the p-values for $118 < m_{\mathrm{H}} < 126$ GeV, with two narrow features: one at 119.5 GeV, associated with three $\mathrm{ZZ} \to 4\ell$ events, and the other at 124 GeV, arising mostly from the observed excess in the $\gamma\gamma$ channel. The p-values shown in Fig. 6 are obtained with the asymptotic formula and were validated by generating ensembles of background-only pseudo-datasets.

The minimum local p-value $p_{\min} = 0.001$ at $m_{\mathrm{H}} \simeq 124$ GeV corresponds to a local significance $Z_{\max}$ of 3.1σ. The global significance of the observed excess for the entire search range of 110–600 GeV is estimated directly from the data following the method described in Ref. [76] and corresponds to 1.5σ. For a restricted range of interest, the global p-value is evaluated using pseudo-datasets. For the mass range 110–145 GeV, it yields a significance of 2.1σ.

The p-value characterises the probability of background producing an observed excess of events, but it does not give information about the compatibility of an excess with an expected signal. The latter is provided by the best fit $\hat{\mu}$ value, shown in Fig. 6 (right).

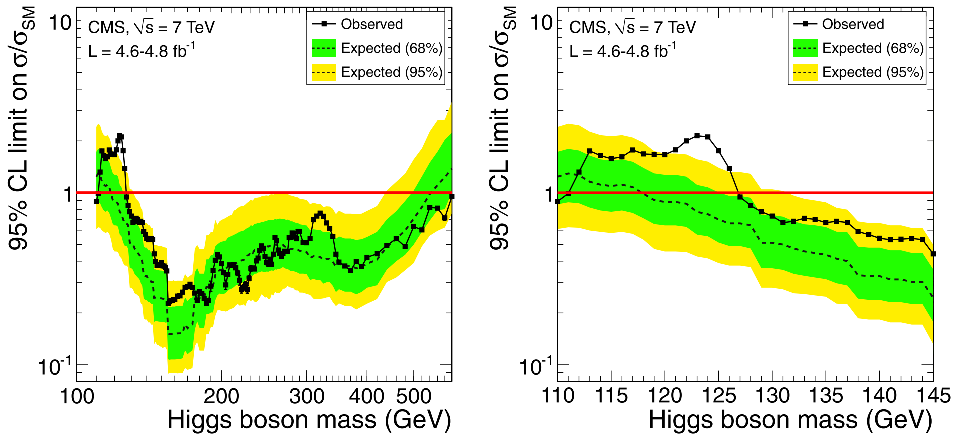


Fig. 3. The 95% CL upper limits on the signal strength parameter $\mu = \sigma/\sigma_{SM}$ for the SM Higgs boson hypothesis as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right). The observed values as a function of mass are shown by the solid line. The dashed line indicates the expected median of results for the background-only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

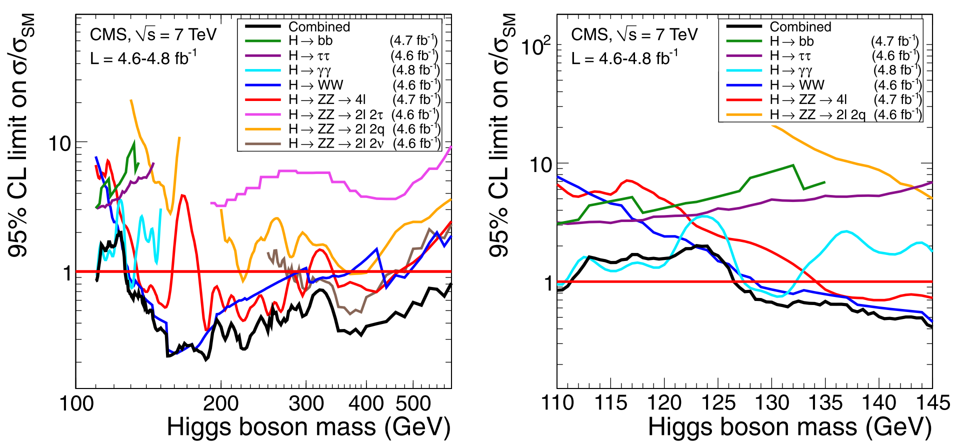


Fig. 4. The observed 95% CL upper limits on the signal strength parameter $\mu = \sigma/\sigma_{SM}$ as a function of the Higgs boson mass in the range 110–600 GeV (left) and 110–145 GeV (right) for the eight Higgs boson decay channels and their combination.

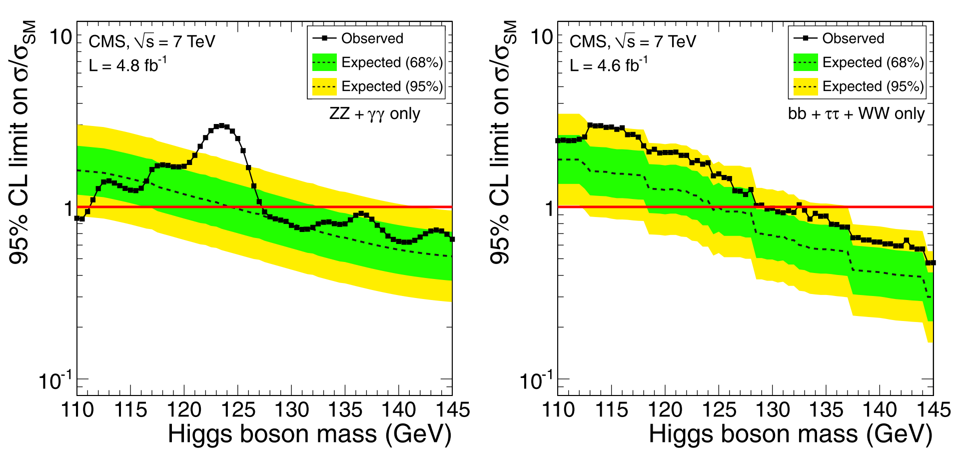


Fig. 5. The 95% CL upper limits on the signal strength parameter $\mu = \sigma/\sigma_{SM}$ for the SM Higgs boson hypothesis as a function of m_H, separately for the combination of the $ZZ + \gamma\gamma$ (left) and $bb + \tau\tau + WW$ (right) searches. The observed values as a function of mass are shown by the solid line. The dashed line indicates the expected median of results for the background-only hypothesis, while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this Letter.)

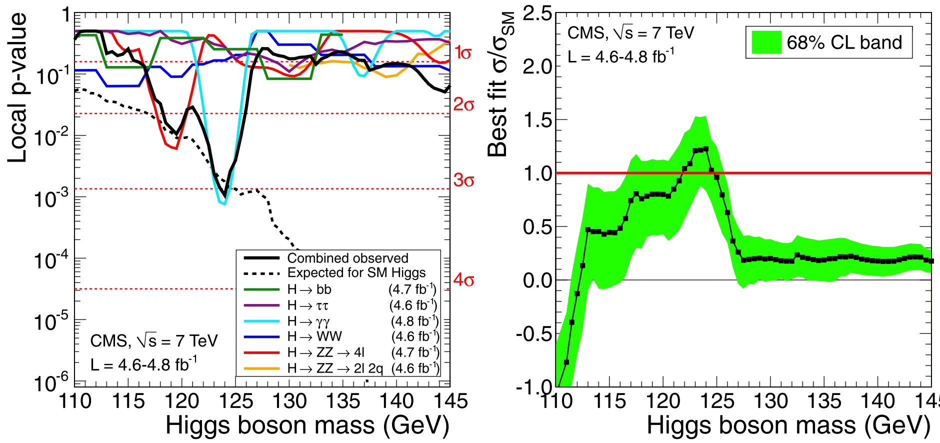


Fig. 6. The observed local p-value p_0 (left) and best-fit $\hat{\mu} = \sigma/\sigma_{SM}$ (right) as a function of the SM Higgs boson mass in the range 110–145 GeV. The global significance of the observed maximum excess (minimum local p-value) in this mass range is about 2.1σ, estimated using pseudo-experiments. The dashed line on the left plot shows the expected local p-values $p_0(m_H)$, should a Higgs boson with a mass m_H exist. The band in the right plot corresponds to the $\pm 1\sigma$ uncertainties on the $\hat{\mu}$ values.

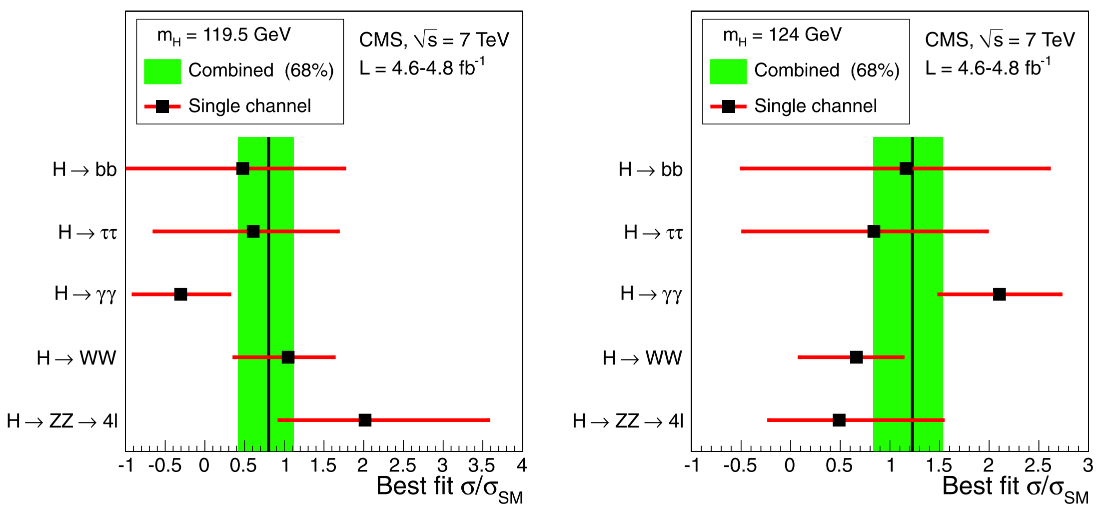


Fig. 7. Values of $\hat{\mu} = \sigma/\sigma_{SM}$ for the combination (solid vertical line) and for contributing channels (points) for two hypothesized Higgs boson masses. The band corresponds to $\pm 1\sigma$ uncertainties on the overall $\hat{\mu}$ value. The horizontal bars indicate $\pm 1\sigma$ uncertainties on the $\hat{\mu}$ values for individual channels.

In this fit the constraint $\hat{\mu} \geq 0$ is not applied, so that a negative value of $\hat{\mu}$ indicates an observation below the expectation from the background-only hypothesis. The band corresponds to the $\pm 1\sigma$ uncertainty (statistical + systematic) on the value of $\hat{\mu}$ obtained from a change in q_μ by one unit ($\Delta q_\mu = 1$), after removing the $\hat{\mu}$ constraint in Eq. (5). The observed $\hat{\mu}$ values are within 1σ of unity in the mass range from 117–126 GeV.

Fig. 7 shows the interplay of contributing channels for the two Higgs boson mass hypotheses $m_H = 119.5$ and 124 GeV. The choice of these mass points is motivated by the features seen in Fig. 6 (left). The plots show the level of statistical compatibility between the channels contributing to the combination.

5. Conclusions

Combined results are reported from searches for the SM Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ TeV in five Higgs boson decay modes: $\gamma\gamma$, bb, $\tau\tau$, WW, and ZZ. The explored Higgs boson mass range is 110–600 GeV. The analysed data correspond to an integrated luminosity of 4.6–4.8 fb^{-1}. The expected excluded mass range in the absence of the standard model Higgs boson is 118–543 GeV at 95% CL. The observed results exclude the standard model Higgs boson in the mass range 127–600 GeV at 95% CL, and in the mass range 129–525 GeV at 99% CL. An excess of events above the expected standard model background is observed at the low end of the explored mass range making the observed limits weaker than expected in the absence of a signal. The largest excess, with a local significance of 3.1σ, is observed for a Higgs boson mass hypothesis of 124 GeV. The global significance of observing an excess with a local significance $\geqslant 3.1\sigma$ anywhere in the search range 110–600 (110–145) GeV is estimated to be 1.5σ (2.1σ). More data are required to ascertain the origin of the observed 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); 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).

Open access

References

[1] S. 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, Weak and electromagnetic interactions, in: N. Svartholm (Ed.), Elementary Particle Physics: Relativistic Groups and Analyticity, Proceedings of the Eighth Nobel Symposium, Almqvist and 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. Guralnik, C. 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] ALEPH Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration, LEP Working Group for Higgs Boson Searches, Phys. Lett. B 565 (2003) 61, doi:10.1016/S0370-2693(03)00614-2.
[11] CDF Collaboration, D0 Collaboration, Phys. Rev. Lett. 104 (2010) 061802, doi:10.1103/PhysRevLett.104.061802, a more recent, unpublished, limit is given in preprint arXiv:1107.5518.
[12] ATLAS Collaboration, Search for the Higgs boson in the $\mathrm{H} \to \mathrm{WW}(*) \to \ell^+\nu\ell^-\bar{\nu}$ decay channel in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector, 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 Collaboration, CDF Collaboration, D0 Collaboration, DELPHI Collaboration, L3 Collaboration, OPAL Collaboration, SLD Collaboration, LEP Electroweak Working Group, Tevatron Electroweak Working Group, SLD Electroweak and Heavy Flavour Groups, Precision electroweak measurements and constraints on the standard model, CERN PH-EP-2010-095 (2010), arXiv:1012.2367, http://cdsweb.cern.ch/record/1313716.
[16] S. Chatrchyan, et al., JINST 03 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
[17] J.R. Ellis, M.K. Gaillard, D.V. Nanopoulos, Nucl. Phys. B 106 (1976) 292, doi:10.1016/0550-3213(76)90382-5.
[18] H. Georgi, S. Glashow, M. Machacek, D.V. Nanopoulos, Phys. Rev. Lett. 40 (1978) 692, doi:10.1103/PhysRevLett.40.692.
[19] S. Glashow, D.V. Nanopoulos, A. Yildiz, Phys. Rev. D 18 (1978) 1724, doi:10.1103/PhysRevD.18.1724.
[20] S. Dittmaier, C. Mariotti, G. Passarino, R. Tanaka (Eds.), Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables, CERN CERN-2011-002 (2011), arXiv:1101.0593, http://cdsweb.cern.ch/record/1318996.
[21] A. Djouadi, M. Spira, P.M. Zerwas, Phys. Lett. B 264 (1991) 440, doi:10.1016/0370-2693(91)90375-Z.
[22] S. Dawson, Nucl. Phys. B 359 (1991) 283, doi:10.1016/0550-3213(91)90061-2.
[23] M. Spira, A. Djouadi, D. Graudenz, P.M. Zerwas, Nucl. Phys. B 453 (1995) 17, doi:10.1016/0550-3213(95)00379-7, arXiv:hep-ph/9504378.
[24] R.V. Harlander, W.B. Kilgore, Phys. Rev. Lett. 88 (2002) 201801, doi:10.1103/PhysRevLett.88.201801, arXiv:hep-ph/0201206.
[25] C. Anastasiou, K. Melnikov, Nucl. Phys. B 646 (2002) 220, doi:10.1016/S0550-3213(02)00837-4, arXiv:hep-ph/0207004.
[26] V. Ravindran, J. Smith, W.L. van Neerven, Nucl. Phys. B 665 (2003) 325, doi:10.1016/S0550-3213(03)00457-7, arXiv:hep-ph/0302135.
[27] S. Catani, D. de Florian, M. Grazzini, P. Nason, JHEP 0307 (2003) 028, doi:10.1088/1126-6708/2003/07/028.
[28] U. Aglietti, R. Bonciani, G. Degrassi, A. Vicini, Phys. Lett. B 595 (2004) 432, doi:10.1016/j.physletb.2004.06.063, arXiv:hep-ph/0404071.
[29] G. Degrassi, F. Maltoni, Phys. Lett. B 600 (2004) 255, doi:10.1016/j.physletb.2004.09.008, arXiv:hep-ph/0407249.
[30] S. Actis, G. Passarino, C. Sturm, S. Uccirati, Phys. Lett. B 670 (2008) 12, doi:10.1016/j.physletb.2008.10.018, arXiv:0809.1301.
[31] C. Anastasiou, R. Boughezal, F. Petriello, JHEP 0904 (2009) 003, doi:10.1088/1126-6708/2009/04/003, arXiv:0811.3458.
[32] D. de Florian, M. Grazzini, Phys. Lett. B 674 (2009) 291, doi:10.1016/j.physletb.2009.03.033, arXiv:0901.2427.
[33] G. Bozzi, S. Catani, D. de Florian, M. Grazzini, Nucl. Phys. B 737 (2006) 73, doi:10.1016/j.nuclphysb.2005.12.022, arXiv:hep-ph/0508068.
[34] D. de Florian, G. Ferrera, M. Grazzini, D. Tommasini, JHEP 1111 (2011) 064, doi:10.1007/JHEP11(2011)064.
[35] G. Passarino, C. Sturm, S. Uccirati, Nucl. Phys. B 834 (2010) 77, doi:10.1016/j.nuclphysb.2010.03.013, arXiv:1001.3360.
[36] C. Anastasiou, S. Buehler, F. Herzog, A. Lazopoulos, Total cross-section for Higgs boson hadroproduction with anomalous Standard Model interactions, 2011, arXiv:1107.0683.
[37] I.W. Stewart, F.J. Tackmann, Theory uncertainties for Higgs and other searches using jet bins, 2011, arXiv:1107.2117.
[38] A. Djouadi, J. Kalinowski, M. Spira, Comput. Phys. Commun. 108 (1998) 56, doi:10.1016/S0010-4655(97)00123-9, arXiv:hep-ph/9704448.
[39] A. Djouadi, J. Kalinowski, M. Muhlleitner, M. Spira, An update of the program HDECAY, in: The Les Houches 2009 Workshop on TeV Colliders: The Tools and Monte Carlo Working Group Summary Report, 2010, arXiv:1003.1643.
[40] A. Bredenstein, A. Denner, S. Dittmaier, M.M. Weber, Phys. Rev. D 74 (2006) 013004, doi:10.1103/PhysRevD.74.013004, arXiv:hep-ph/0604011.
[41] A. Bredenstein, A. Denner, S. Dittmaier, M. Weber, JHEP 0702 (2007) 080, doi:10.1088/1126-6708/2007/02/080, arXiv:hep-ph/0611234.
[42] 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.
[43] A. Denner, S. Heinemeyer, I. Puljak, D. Rebuzzi, M. Spira, Eur. Phys. J. C 71 (2011) 1753, doi:10.1140/epjc/s10052-011-1753-8, arXiv:1107.5909.
[44] M. Ciccolini, A. Denner, S. Dittmaier, Phys. Rev. Lett. 99 (2007) 161803, doi:10.1103/PhysRevLett.99.161803, arXiv:0707.0381.
[45] M. Ciccolini, A. Denner, S. Dittmaier, Phys. Rev. D 77 (2008) 013002, doi:10.1103/PhysRevD.77.013002, arXiv:0710.4749.
[46] T. Figy, C. Oleari, D. Zeppenfeld, Phys. Rev. D 68 (2003) 073005, doi:10.1103/PhysRevD.68.073005, arXiv:hep-ph/0306109.
[47] K. Arnold, et al., Comput. Phys. Commun. 180 (2009) 1661, doi:10.1016/j.cpc.2009.03.006, arXiv:0811.4559.
[48] P. Bolzoni, F. Maltoni, S.-O. Moch, M. Zaro, Phys. Rev. Lett. 105 (2010) 011801, doi:10.1103/PhysRevLett.105.011801, arXiv:1003.4451.
[49] T. Han, S. Willenbrock, Phys. Lett. B 273 (1991) 167, doi:10.1016/0370-2693(91)90572-8.
[50] O. Brein, A. Djouadi, R. Harlander, Phys. Lett. B 579 (2004) 149, doi:10.1016/j.physletb.2003.10.112, arXiv:hep-ph/0307206.
[51] M.L. Ciccolini, S. Dittmaier, M. Krämer, Phys. Rev. D 68 (2003) 073003, doi:10.1103/PhysRevD.68.073003, arXiv:hep-ph/0306234.
[52] R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. B 359 (1991) 343, doi:10.1016/0550-3213(91)90064-5.
[53] A. Denner, S. Dittmaier, S. Kallweit, A. Muck, EW corrections to Higgs strahlung at the Tevatron and the LHC with HAWK, 2011, arXiv:1112.5258.
[54] G. Ferrera, M. Grazzini, F. Tramontano, Phys. Rev. Lett. 107 (2011) 152003, doi:10.1103/PhysRevLett.107.152003, arXiv:1107.1164.
[55] W. Beenakker, et al., Phys. Rev. Lett. 87 (2001) 201805, doi:10.1103/PhysRevLett.87.201805, arXiv:hep-ph/0107081.
[56] W. Beenakker, et al., Nucl. Phys. B 653 (2003) 151, doi:10.1016/S0550-3213(03)00044-0, arXiv:hep-ph/0211352.
[57] L. Reina, S. Dawson, Phys. Rev. Lett. 87 (2001) 201804, doi:10.1103/PhysRevLett.87.201804, arXiv:hep-ph/0107101.
[58] L. Reina, S. Dawson, D. Wackeroth, Phys. Rev. D 65 (2002) 053017, doi:10.1103/PhysRevD.65.053017, arXiv:hep-ph/0109066.
[59] S. Dawson, L.H. Orr, L. Reina, D. Wackeroth, Phys. Rev. D 67 (2003) 071503, doi:10.1103/PhysRevD.67.071503, arXiv:hep-ph/0211438.
[60] S. Dawson, C. Jackson, L.H. Orr, L. Reina, D. Wackeroth, Phys. Rev. D 68 (2003) 034022, doi:10.1103/PhysRevD.68.034022, arXiv:hep-ph/0305087.
[61] M. Botje, et al., The PDF4LHC Working Group interim recommendations, 2011, arXiv:1101.0538.
[62] S. Alekhin, et al., The PDF4LHC Working Group interim report, 2011, arXiv:1101.0536.
[63] 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, arXiv:1007.2241.
[64] A. Martin, W. Stirling, R. Thorne, G. Watt, Eur. Phys. J. C 63 (2009) 189, doi:10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002.
[65] R.D. Ball, et al., Nucl. Phys. B 849 (2011), doi:10.1016/j.nuclphysb.2011.03.021, arXiv:1101.1300.

[66] J. Baglio, A. Djouadi, JHEP 1103 (2011) 055, doi:10.1007/JHEP03(2011)055, arXiv:1012.0530.
[67] CMS Collaboration, Search for the standard model Higgs boson decaying into two photons in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. (2012), in press, arXiv:1202.1487.
[68] CMS Collaboration, Search for neutral Higgs bosons decaying to τ pairs in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. (2012), submitted for publication, arXiv:1202.4083.
[69] CMS Collaboration, Search for the standard model Higgs boson decaying to bottom quarks in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. (2012), in press, arXiv:1202.4195.
[70] CMS Collaboration, Search for the standard model Higgs boson decaying to W^+W^- in the fully leptonic final state in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. (2012), in press, arXiv:1202.1489.
[71] CMS Collaboration, Search for the standard model Higgs boson in the decay channel $H \to ZZ \to 4\ell$ in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Rev. Lett. (2012), in press, arXiv:1202.1997.
[72] CMS Collaboration, Search for the standard model Higgs boson in the $H \to ZZ \to 2\ell 2\nu$ channel in pp collisions at $\sqrt{s} = 7$ TeV, JHEP (2012), in press, arXiv:1202.3478.
[73] CMS Collaboration, Search for a Higgs boson in the decay channel $H \to ZZ^{(*)} \to q\bar{q}\ell^-\ell^+$ in pp collisions at $\sqrt{s} = 7$ TeV, JHEP (2012), submitted for publication, arXiv:1202.1416.
[74] CMS Collaboration, Search for the standard model Higgs boson in the $H \to ZZ \to \ell^+\ell^-\tau^+\tau^-$ decay channel in pp collisions at $\sqrt{s} = 7$ TeV, JHEP (2012), submitted for publication, arXiv:1202.3617.
[75] CMS Collaboration, Algorithms for b jet identification in CMS, CMS Physics Analysis Summary CMS-PAS-BTV-09-001, 2009, http://cdsweb.cern.ch/record/1194494.
[76] ATLAS Collaboration, CMS Collaboration, LHC Higgs Combination Group, Procedure for the LHC higgs boson search combination in Summer 2011, ATL-PHYS-PUB 2011-11/CMS NOTE, 2011/005 (2011), http://cdsweb.cern.ch/record/1379837.
[77] G. Cowan, et al., Eur. Phys. J. C 71 (2011) 1, doi:10.1140/epjc/s10052-011-1554-0, arXiv:1007.1727.
[78] E. Gross, O. Vitells, Eur. Phys. J. C 70 (2010) 525, doi:10.1140/epjc/s10052-010-1470-8, arXiv:1005.1891.
[79] T. Junk, Nucl. Instrum. Meth. A 434 (1999) 435, doi:10.1016/S0168-9002(99)00498-2.
[80] A.L. Read, J. Phys. G 28 (2002) 2693, doi:10.1088/0954-3899/28/10/313.

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

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

National Centre for Particle and High Energy Physics, 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 Martin 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 [c], 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*

L. Barone [a,b], F. Cavallari [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, 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, Korea

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

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

H.Y. Jo

Konkuk 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

Korea University, Seoul, Korea

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

University of Seoul, Seoul, 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, 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

I. Belotelov, P. Bunin, I. Golutvin, A. Kamenev, V. Karjavin, V. Konoplyanikov, G. Kozlov, A. Lanev, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, M. Savina, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

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 [28], M. Djordjevic, M. Ekmedzic, D. Krpic [28], 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 [29], 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 [30], 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 [31], T. Rommerskirchen, C. Rovelli [32], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas [*,33], D. Spiga, M. Spiropulu [4], M. Stoye, A. Tsirou, G.I. Veres [16], P. Vichoudis, H.K. Wöhri, S.D. Worm [34], 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 [35]

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 [36], 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 [37], 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 [38], S. Cerci [39], 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 [40], A. Polatoz, K. Sogut [41], D. Sunar Cerci [39], B. Tali [39], H. Topakli [38], 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 [42], O. Kaya [42], S. Ozkorucuklu [43], N. Sonmez [44]

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

University of Bristol, Bristol, United Kingdom

L. Basso [45], K.W. Bell, A. Belyaev [45], 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, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko [37], A. Papageorgiou, M. Pesaresi, K. Petridis, M. Pioppi [46], 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, 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, 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, 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[47], 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, 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. Kilminster, 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[48], 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 [49], 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 [50], 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 [51], W. Clarida, F. Duru, S. Griffiths, C.K. Lae, E. McCliment, J.-P. Merlo, H. Mermerkaya [52], 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, IA, 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, 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 [53], 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 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, Republic of Korea.