

Search for a light charged Higgs boson decaying to $c\bar{s}$ in pp collisions at $\sqrt{s} = 8$ TeV



The CMS collaboration

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

ABSTRACT: A search for a light charged Higgs boson, originating from the decay of a top quark and subsequently decaying into a charm quark and a strange antiquark, is presented. The data used in the analysis correspond to an integrated luminosity of 19.7 fb^{-1} recorded in proton-proton collisions at $\sqrt{s} = 8$ TeV by the CMS experiment at the LHC. The search is performed in the process $t\bar{t} \rightarrow W^{\pm}bH^{\mp}\bar{b}$, where the W boson decays to a lepton (electron or muon) and a neutrino. The decays lead to a final state comprising an isolated lepton, at least four jets and large missing transverse energy. No significant deviation is observed in the data with respect to the standard model predictions, and model-independent upper limits are set on the branching fraction $\mathcal{B}(t \rightarrow H^+b)$, ranging from 1.2 to 6.5% for a charged Higgs boson with mass between 90 and 160 GeV, under the assumption that $\mathcal{B}(H^+ \rightarrow c\bar{s}) = 100\%$.

KEYWORDS: Supersymmetry, Hadron-Hadron scattering, Higgs physics

ARXIV EPRINT: [1510.04252](https://arxiv.org/abs/1510.04252)

Contents

1	Introduction	1
2	The CMS detector, simulation and reconstruction	2
3	Analysis	4
3.1	Event selection	4
3.2	Background estimation	5
3.3	Reconstruction of the W/H mass	6
4	Systematic uncertainties	7
5	Results	10
6	Summary	12
	The CMS collaboration	18

1 Introduction

A Higgs boson has recently been discovered by the ATLAS [1] and CMS [2, 3] Collaborations with a mass around 125 GeV and properties consistent with those expected from the standard model (SM) within the current experimental uncertainties. However, precise measurements of the properties of the new boson are needed to identify or exclude differences with respect to the SM predictions. The mass of the Higgs boson itself is subject to quadratically divergent corrections at high energies [4]. Several extensions beyond the SM (BSM) have been proposed to address such divergences. Supersymmetry [5–7] is one such model that invokes a symmetry between fundamental fermions and bosons. The Higgs sector of the so-called minimal supersymmetric standard model (MSSM) [8, 9] consists of two Higgs doublets, resulting in five physical states: a light and a heavy CP-even h and H , a CP-odd A , and two charged Higgs bosons H^\pm . At lowest order, the MSSM Higgs sector can be expressed in terms of two parameters, usually chosen as the mass of the CP-odd boson (m_A) and the ratio of the vacuum expectation values of the two Higgs doublets ($\tan\beta$). The generic two-Higgs-doublet model (2HDM), of which the MSSM is a special case, encompasses the following four scenarios.

- Type I: all quarks and leptons couple only to the second doublet.
- Type II: all up-type quarks couple to the second doublet while all down-type quarks and charged leptons couple to the first one.

- Type X: both up- and down-type quarks couple to the second doublet and all leptons to the first one.
- Type Y: the roles of the two doublets are reversed with respect to Type II.

The LEP experiments [10] have set a 95% confidence level (CL) lower limit on the charged Higgs boson mass of 80.0 GeV for the Type II scenario and of 72.5 GeV for the Type I scenario for $m_A > 12$ GeV. If the mass of the charged Higgs boson, m_{H^+} , is smaller than the mass difference between the top and the bottom quarks, the top quark can decay via $t \rightarrow H^+ b$ (charge conjugate processes are always implied). For values of $\tan \beta < 1$, the MSSM charged Higgs boson predominantly decays to a charm quark and a strange antiquark ($c\bar{s}$). In 2HDMs of Types I and Y [11], the branching fraction $\mathcal{B}(H^+ \rightarrow c\bar{s})$ is larger than 10% for any value of $\tan \beta$, while in Types II and X it can reach 100% for $\tan \beta < 1$. In this study, we assume $\mathcal{B}(H^+ \rightarrow c\bar{s})$ to be 100%.

The presence of the $t \rightarrow H^+ b$, $H^+ \rightarrow c\bar{s}$ decay mode alters the event yield of $t\bar{t}$ pairs with hadronic jets in the final state, compared to the SM. Upper limits on the branching fraction, $\mathcal{B}(t \rightarrow H^+ b) < 10\text{--}20\%$, have been set by the CDF [12] and D0 [13] experiments at the Tevatron for m_{H^+} between 80 and 155 GeV, assuming $\mathcal{B}(H^+ \rightarrow c\bar{s}) = 100\%$. Based on 4.7 fb^{-1} of data recorded at a centre-of-mass energy of 7 TeV, the ATLAS Collaboration has set an upper limit on $\mathcal{B}(t \rightarrow H^+ b)$ between 1 and 5% for a charged Higgs boson mass in the range 90–150 GeV [14].

In this paper, we report a model-independent search for a charged Higgs boson in the 90–160 GeV mass range using the final state $t\bar{t} \rightarrow bH^+\bar{b}W^-$, where the W boson decays to a lepton ($\ell = e$ or μ) and a neutrino, and the charged Higgs boson decays to $c\bar{s}$. The contribution of the process $t\bar{t} \rightarrow bH^+\bar{b}H^-$ is expected to be negligible in this ℓ +jets final state. Figure 1 shows the dominant Feynman diagrams for the final state both in the SM $t\bar{t}$ process as well as for the model with a charged Higgs boson. We use a data sample recorded by the CMS experiment at the CERN LHC in pp collisions at $\sqrt{s} = 8$ TeV corresponding to an integrated luminosity of 19.7 fb^{-1} .

2 The CMS detector, simulation and reconstruction

A detailed description of the CMS detector together with a definition of the coordinate system used and the relevant kinematic variables can be found in ref. [15]. The central feature of CMS is a superconducting solenoid of 6 m diameter providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass-scintillator hadron calorimeter are located inside the solenoid. Forward calorimeters extend the pseudorapidity [15] coverage provided by the barrel and endcap detectors. The muon detection system is composed of drift tubes, cathode strip chambers, and resistive plate chambers, embedded in the steel flux-return yoke outside the solenoid.

The CMS first-level trigger system consists of custom hardware processors. It uses information from the calorimeters and muon detector to select the interesting events. The high-level trigger system, based on a computing farm, further reduces the event rate from around 100 kHz to less than 1 kHz, before data storage.

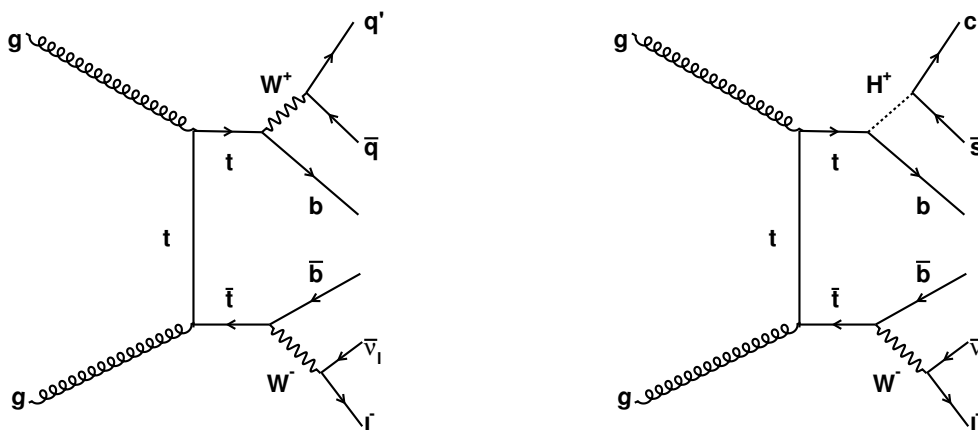


Figure 1. Leading order Feynman diagram for $t\bar{t}$ production at the LHC in the ℓ +jets final state in the SM (left) and additional diagram for the model with a charged Higgs boson (right).

The analysis exploits event reconstruction based on the particle-flow (PF) algorithm [16, 17]. This algorithm reconstructs all stable particles in an event by combining information from all subdetectors. The resulting list of particles is then used to reconstruct higher-level objects such as jets and missing transverse energy (E_T^{miss}). Muons are reconstructed by performing a simultaneous global track fit to hits in the silicon tracker and the muon detector [18]. Electrons are identified by combining information from clusters of energy deposits in the electromagnetic calorimeter and the hits in the tracker [19]. Jets are reconstructed using the anti- k_T algorithm [20] with a distance parameter of 0.5.

Among the large number of pp interactions per LHC bunch crossing (“pileup”) we select the one having the maximum squared sum of the transverse momenta (p_T) of charged-particle tracks as the primary vertex. On average, there were about 20 pileup events in the 2012 data. In order to suppress jets coming from pileup interactions, a jet identification criterion [21] based on a multivariate analysis method is used. We correct for the detector response to obtain a realistic jet energy scale. The E_T^{miss} [22] is defined as the magnitude of the vector sum of p_T of all reconstructed particles.

The method to identify jets from b quark hadronization (called “b jets”) involves the use of secondary vertices together with track based lifetime information [23, 24] to provide an efficient discrimination between b jets and jets from light quarks and gluons. We choose a discriminator value that yields a misidentification probability for light-parton jets of approximately 1% in the p_T range 80 to 120 GeV. The corresponding b tagging efficiency is $\sim 70\%$ for jets with an average p_T of 80 GeV in $t\bar{t}$ events. The probability of misidentifying a c jet as a b jet is $\sim 20\%$.

Background events from $t\bar{t}$ decay processes (other than signal), W+jets and Z+jets are generated with MADGRAPH 5.1 [25], interfaced with PYTHIA 6.4 [26]. The underlying event tuning Z2* [27] and CTEQ6M [28] parton distribution function (PDF) set are used. The number of $t\bar{t}$ events is estimated from the SM next-to-next-to-leading-order (NNLO)

calculation [29] of the $t\bar{t}$ production cross section, which is 252.9 ± 6.0 pb. The single top quark processes are generated using POWHEG 1.0 [30–34]. The expected contribution of the W+jets background is calculated at NNLO with FEWZ 3.1 [35]. The Z+jets and single top quark events are also normalized to NNLO cross section calculations [36, 37]. The $t\bar{t} \rightarrow bH^+\bar{b}W^-$ (HW) signal sample is generated with PYTHIA and normalized using the same production cross section as SM $t\bar{t}$. The diboson backgrounds (WW, WZ, and ZZ) are generated with PYTHIA and their cross sections are computed with MCFM 6.2 [38].

Generated events are processed through a full detector simulation based on GEANT4 [39], followed by a detailed trigger emulation and the CMS event reconstruction. Minimum bias events are superimposed on the hard interactions to simulate pileup. Simulated events are reweighted according to the pileup distribution observed in the data.

3 Analysis

3.1 Event selection

For the muon+jets final state, events are selected at the trigger level using an isolated single muon with $p_T > 24$ GeV and $|\eta| < 2.1$. In the offline analysis, an event is selected if it has at least one reconstructed muon with $p_T > 25$ GeV and $|\eta| < 2.1$. The muon is required to be isolated from the rest of the event activity by requiring the relative isolation $I_{\text{rel}} < 0.12$, defined as

$$I_{\text{rel}} = \frac{I^{\text{ch}} + \max[(I^\gamma + I^{\text{nh}} - 0.5 \times I_{\text{PU}}^{\text{ch}}), 0]}{p_T}. \quad (3.1)$$

Here, I^{ch} , I^γ , and I^{nh} are the sum of transverse energies for charged hadrons, photons, and neutral hadrons, respectively, in a cone size of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ around the muon direction, and $I_{\text{PU}}^{\text{ch}}$ is the p_T sum of charged hadrons associated to all pileup vertices. The latter term is used to estimate the contribution of neutral particles from the pileup events. The factor 0.5 takes into account the neutral-to-charged particle ratio. The simulated events are reweighted in order to reproduce the muon trigger and selection efficiencies that are measured in data using a “tag-and-probe” technique [40].

For the electron+jets final state, events are selected with one isolated single-electron trigger with $p_T > 27$ GeV and $|\eta| < 2.5$; they are selected offline if the electron has $p_T > 30$ GeV and $|\eta| < 2.5$. Other electron identification criteria are applied based on a multivariate analysis [41]. The electron should be isolated by requiring the relative isolation $I_{\text{rel}}^\rho < 0.1$, given by

$$I_{\text{rel}}^\rho = \frac{I^{\text{ch}} + \max[(I^\gamma + I^{\text{nh}} - \rho A_{\text{eff}}), 0]}{p_T}, \quad (3.2)$$

where I^{ch} , I^γ , and I^{nh} are calculated in a cone size of $\Delta R = 0.3$ around the electron direction, ρ is the energy density in the event that is used to estimate the average pileup contribution within the electron isolation cone, and A_{eff} is a measure of the effective area subtended by the isolation cone. Any event that has an additional muon or electron with

$p_T > 10$ GeV and $|\eta| < 2.5$ passing a loose isolation (<0.3) is rejected. The second-lepton veto rejects most of the events from Z+jets and SM $t\bar{t}$ decays, where both the W bosons decay to leptons.

Events are required to have at least four jets with $p_T > 25$ GeV and $|\eta| < 2.5$, where two jets are expected to originate from top-quark decays and the other two from W/H⁺ boson decays. Since a neutrino is present in the signal final state, the events are required to have $E_T^{\text{miss}} > 20$ GeV. The E_T^{miss} requirement suppresses the QCD multijet and Z($\ell^+\ell^-$)+jets backgrounds. In these events the reconstructed E_T^{miss} is expected to be small, arising mostly from the mismeasurement of energy in the calorimeters. Compared to the dominant SM $t\bar{t}$ background, the possible contribution from $t\bar{t}V$ ($V = W, Z$) events is found to be negligible (less than 1% of the total background).

In both signal and SM $t\bar{t}$ events, there are two b quarks in the final state that originate directly from the top quark decays. Thus, we require the events to have at least two b jets. This requirement strongly suppresses the W+jets and QCD multijet backgrounds, where the b jets come from the misidentification of light-quark including c jets or gluon jets. The simulated events are reweighted to reproduce the efficiencies measured in data in dedicated control regions [24].

The p_T spectra of the top quark and antiquark in data are found to be softer than that predicted by the MADGRAPH and PYTHIA generators [42]. In order to account for this effect, the simulated $t\bar{t}$ events are reweighted according to the generated p_T distribution of the top quarks and antiquarks. Event-by-event scale factors are derived based on the measurement of differential top-quark pair production cross sections in the ℓ +jets channel by CMS at $\sqrt{s} = 8$ TeV [43]. These factors are applied to the simulated SM $t\bar{t}$ and signal samples before any event selection is required.

3.2 Background estimation

Most of the backgrounds coming from $t\bar{t}$, W+jets, Z+jets, single top quark and diboson processes are estimated from simulated samples normalized to NNLO predictions. As the QCD background is not well modeled by simulation, its contribution is estimated from data. A control region where the lepton candidate is non-isolated, given by $0.12 < I_{\text{rel}} < 0.30$ for muons and $0.1 < I_{\text{rel}}^{\rho} < 0.3$ for electrons, is used to estimate the normalization of the QCD multijet background. After subtracting the expected contributions of other processes from data, the result is extrapolated to the signal region by using a scale factor determined from events with low E_T^{miss} . The shape of the QCD background distribution is evaluated from the sample of non-isolated leptons.

In figure 2 we compare the event yields for various background samples and a signal sample, generated assuming $m_{H^+} = 120$ GeV and $\mathcal{B}(t \rightarrow H^+b) = 10\%$, after each selection step. At each step, the number of expected background events is found to match the data within uncertainties. The dotted line in figure 2 shows the total number of expected signal and background events in the presence of H⁺ in the top quark decay. The total number of events including the H⁺ signal is

$$N_{\text{total}} = (1 - x)^2 N_{t\bar{t} \rightarrow bW^+ \bar{b}W^-} + 2x(1 - x) N_{\text{HW}} + N_{\text{other}}, \quad (3.3)$$

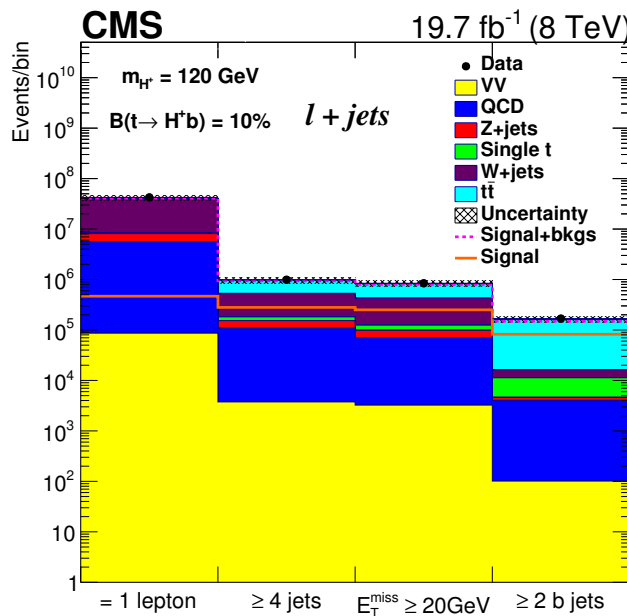


Figure 2. Number of expected and observed data events after different selection requirements. “Uncertainty” in the legend here, and of other plots, includes statistical and systematic uncertainties.

where $x = \mathcal{B}(t \rightarrow H^+b)$ and N_i is the number of expected events for the process i . Based on simulations we have found that the expected contribution of the signal $t\bar{t} \rightarrow bH^+\bar{b}H^-$ component is negligible.

3.3 Reconstruction of the W/H mass

A kinematic fit is used to fully reconstruct $t\bar{t}$ events resulting in an improved mass resolution of the hadronically decaying boson. The fit constrains the event to the hypothesis for the production of two top quarks. As described above, one of the W bosons from top quarks decays into a lepton-neutrino pair, while the other boson (a W in SM $t\bar{t}$ and the H^+ in the case of signal) decays into a quark-antiquark pair. Since we are interested in reconstructing the W/ H^+ boson mass, we relax the constraint on the light dijet mass to be consistent with the W mass. On the other hand, both the top-quark masses are constrained to 172.5 GeV. The detailed description of the algorithm and constraints on the fit are available in ref. [44].

The kinematic fit receives the four-momenta of the lepton and all jets passing the selection requirements, E_T^{miss} , and their respective resolutions. The jet energy resolution (JER) in data varies between 5 to 20% over the p_T range 30 to 1000 GeV. The jet energy in the simulation is thus smeared to appropriately reproduce the resolution measured in the data [45].

Only jets that pass the b tagging requirement are considered as b-jet candidates in the $t\bar{t}$ hypothesis, while all other jets are taken to be the light-quark candidates for hadronic boson decays. For each event, the assignment that gives the maximum fit probability is retained. The fit modifies the measured value of the jet p_T within its resolution to a value

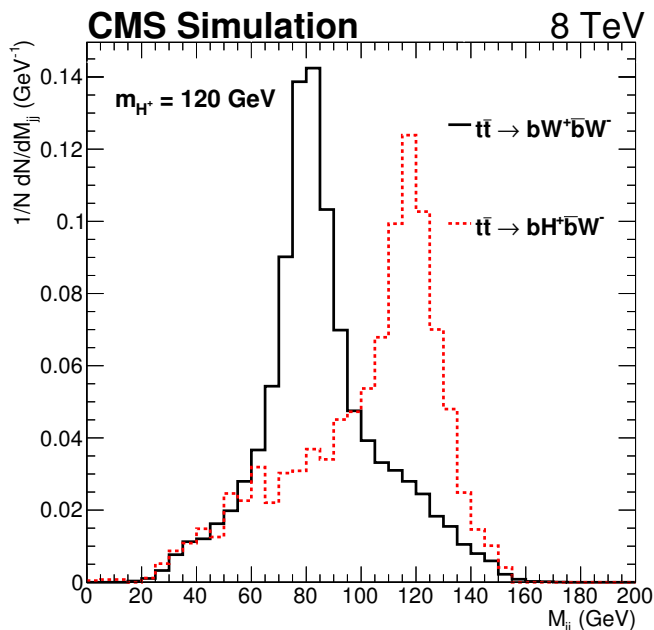


Figure 3. Invariant mass distributions of the dijet system, assumed to come from $c\bar{s}$ hadronization, obtained with a kinematic fit after all selections. The solid black histogram represents the SM $t\bar{t}$ events and the dashed red histogram denotes the same in the presence of a H^+ boson.

corresponding to the minimum χ^2 . Figure 3 shows the W and H^+ boson mass distributions obtained from the kinematic fit after final event selections. The kinematic fit significantly improves the dijet mass resolution, which is vital in separating the H^+ boson from the W boson peak.

As a control plot, figure 4 shows the transverse mass (m_T) of the system formed from the lepton candidate and E_T^{miss} . The dotted line represents the total number of expected signal and background events in the presence of H^+ obtained using eq. (3.3) for an assumed branching fraction of $\mathcal{B}(t \rightarrow H^+b) = 10\%$. This line is below the total background expectation, because the reduction in the SM $t\bar{t}$ yield is not fully compensated by the HW component and we are missing the $t\bar{t} \rightarrow bH^+\bar{b}H^-$ component as we select the events with a high p_T lepton. Other distributions such as p_T and η of the lepton, jets, and b jets as well as the jet multiplicity and b-jet multiplicity were studied. The χ^2 distribution of the kinematic fit was also checked. All these distributions show a good agreement between data and expected SM background.

4 Systematic uncertainties

The following sources of systematic uncertainty are considered in this analysis.

- **Jet energy scale, resolution, and E_T^{miss} scale:** the uncertainty in the jet energy scale (JES) is the leading source of uncertainty in the analysis. It is evaluated as a function of jet p_T and η according to ref. [45], and is then propagated to E_T^{miss} . The

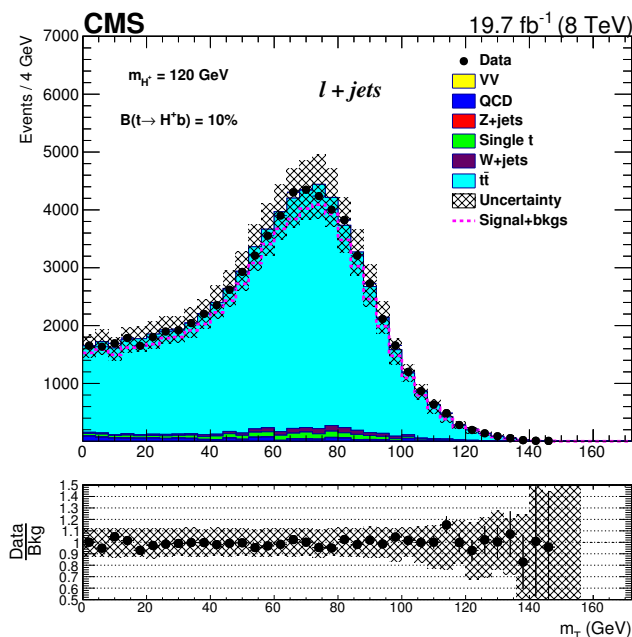


Figure 4. Transverse mass distribution of the lepton plus E_T^{miss} system after all selections.

uncertainty in JES affects both the event yield and the shape of the dijet (W or H⁺) mass distribution. To evaluate the uncertainty in the dijet mass distribution, the momenta of the jets are scaled according to the JES uncertainty by $\pm 1\sigma$. The scaled jet momenta are then passed on as inputs to the kinematic fit and the corresponding dijet mass is returned by the fit. We take the difference in the dijet mass spectrum with respect to the nominal one as a shape uncertainty in the reference distribution used in the statistical analysis (described in section 5). In order to take the uncertainty due to the JER scale factor into account, two alternative dijet invariant mass distributions are obtained after smearing the jets with the JER scale factor varied by $\pm 1\sigma$. The difference with respect to the nominal value is assigned as a shape uncertainty.

- **b tagging uncertainty:** the uncertainty in the b tagging efficiency and misidentification probability is another leading source of uncertainty as the selection requires two b jets. The data-simulation scale factor and the corresponding uncertainty due to the b tagging efficiency as well as the misidentification probability are taken from ref. [24]. The scale factor is applied to simulated events by randomly removing or promoting the events according to the scale factor in the b tagging efficiency and misidentification probability. The uncertainty is estimated as the difference in the event yield when the scale factors are varied by their uncertainties. The data-simulation scale factor on the $c \rightarrow b$ misidentification probability is taken to be the same as that of the b tagging efficiency and the error in the scale factor is taken as twice the corresponding uncertainty for the b jets.

- **Normalization uncertainty:** the error in the $t\bar{t}$ production cross section, which is common for both SM $t\bar{t}$ and signal events, is a leading source of uncertainty. We consider the uncertainties on the normalization of the W+jets and Z+jets processes as fully correlated since their PDF uncertainties are known to be approximately 95% correlated. The normalization uncertainties due to the single top quark and diboson processes are also considered.
- **Lepton trigger, identification, and isolation efficiency:** the uncertainty in the combined data-simulation scale factor for the muon trigger, identification, and isolation efficiencies is taken to be 3%, as estimated using a tag-and-probe method. Similarly in the electron case the uncertainty on the associated combined data-simulation scale factor is taken to be 3%.
- **Uncertainty due to top quark p_T reweighting:** as the top quark p_T reweighting is expected to change the dijet mass shape, the uncertainty corresponding to this reweighting is considered as a shape uncertainty [43].
- **$t\bar{t}$ modeling uncertainty:** the uncertainty due to the variation of the renormalization and factorization scales used in the $t\bar{t}$ simulation is estimated by simultaneously changing their common nominal value by factors of 0.5 and 2. The nominal value is set to the momentum transfer (Q) in the hard process, given by $Q^2 = m_t^2 + \sum p_T^2$ in MADGRAPH, where the sum is over all additional final state partons in the matrix element calculations. An additional shape uncertainty is used to take into account the error due to matching thresholds used for interfacing the matrix elements generated with MADGRAPH and PYTHIA parton showering. The thresholds are changed from the default value of 20 GeV to 10 and 40 GeV.
- **Top mass uncertainty:** the uncertainty due to a possible variation of the top quark mass from its nominal value of 172.5 GeV used in the simulation is studied by changing the latter by ± 1 GeV. An additional shape uncertainty is used to take this effect into account.
- **QCD normalization uncertainty:** as the QCD multijet contribution is obtained from data, we estimate the systematic uncertainty due to the error in the QCD scale factors from the non-isolated to isolated region by varying them by approximately 40% and 60% for the electron+jets and muon+jets channel, respectively. This is calculated using data as described in section 3.2.
- **Size of the simulated samples:** due to the limited size of some of the simulated samples, the bin-by-bin statistical uncertainties in the dijet mass distribution are taken into account for each of those samples.
- **Integrated luminosity uncertainty:** the uncertainty on the integrated luminosity measurement is estimated to be 2.6% [46].

All systematic uncertainties considered for the muon+jets and electron+jets channel are listed in tables 1 and 2, respectively.

	HW	$t\bar{t}_{\mu+jets}$	W+jets	Z+jets	Single t	Diboson	QCD
JES+JER+ E_T^{miss}	6.0	3.2	24.9	19.6	6.4	11.5	—
b tagging	5.6	4.3	—	—	5.3	—	—
Jet \rightarrow b misidentification	—	—	5.1	3.1	—	3.7	—
Lepton selection	3.0	3.0	3.0	3.0	3.0	3.0	—
Normalization	6.0	6.0	5.0	4.0	6.0	10.0	60.0
Simulation statistics	2.1	0.4	4.4	3.5	2.0	5.8	17.5
Top quark p_T reweighting	3.6	1.3	—	—	—	—	—
Integrated luminosity	2.6	2.6	2.6	2.6	2.6	2.6	—

Table 1. Systematic uncertainties (in percent) for the yield of signal and background processes after all selections in the muon+jets channel.

	HW	$t\bar{t}_{e+jets}$	W+jets	Z+jets	Single t	Diboson	QCD
JES+JER+ E_T^{miss}	4.6	4.0	18.3	17.5	6.0	12.5	—
b tagging	5.6	4.3	—	—	5.9	—	—
Jet \rightarrow b misidentification	—	—	4.8	4.5	—	7.5	—
Lepton selection	3.0	3.0	3.0	3.0	3.0	3.0	—
Normalization	6.0	6.0	5.0	4.0	6.0	10.0	40.0
Simulation statistics	2.5	0.5	5.4	5.1	2.5	6.3	13.8
Top quark p_T reweighting	3.8	2.2	—	—	—	—	—
Integrated luminosity	2.6	2.6	2.6	2.6	2.6	2.6	—

Table 2. Systematic uncertainties (in percent) for the yield of signal and background processes after all selections in the electron+jets channel.

5 Results

The event yields after all selections are listed in table 3 along with their combined statistical and systematic uncertainties. The number of signal events from the HW process is also listed for $\mathcal{B}(t \rightarrow H^+b) = 10\%$. The signal event yield is obtained using the SM $t\bar{t}$ cross section. The total number of expected background events matches well the number of observed data events within uncertainties. The dijet mass distribution after all selections is shown in figure 5. The dotted line represents the expected distribution of signal and background events for $\mathcal{B}(t \rightarrow H^+b) = 10\%$. Again, the data are in agreement with the SM background expectation. An upper limit is obtained on $\mathcal{B}(t \rightarrow H^+b)$ as discussed later in this section.

Assuming that any excess or deficit of events in data, when compared with the expected background contribution, is due to the $t \rightarrow H^+b$, $H^+ \rightarrow c\bar{s}$ decay, the difference ΔN between the observed number of data events and the predicted background contribution is given as a function of $x = \mathcal{B}(t \rightarrow H^+b)$ via the following relation:

$$\Delta N = N_{t\bar{t}}^{\text{BSM}} - N_{t\bar{t}}^{\text{SM}} = 2x(1-x)N^{\text{HW}} + [(1-x)^2 - 1]N_{t\bar{t}}^{\text{SM}}. \quad (5.1)$$

Process	muon+jets channel	electron+jets channel
HW, $m_{H^+} = 120$ GeV $\mathcal{B}(t \rightarrow H^+b) = 10\%$	4420 ± 580	2943 ± 371
SM $t\bar{t}$	41712 ± 4735	25884 ± 3009
W+jets	755 ± 199	500 ± 101
Z+jets	91 ± 19	83 ± 16
QCD	381 ± 67	655 ± 91
Single t	1096 ± 114	687 ± 73
Diboson	15 ± 3	12 ± 2
Total background	44050 ± 4741	27820 ± 3013
Data	42785	28447

Table 3. The number of expected signal and background events in 19.7 fb^{-1} of data, along with their combined statistical and systematic uncertainties.

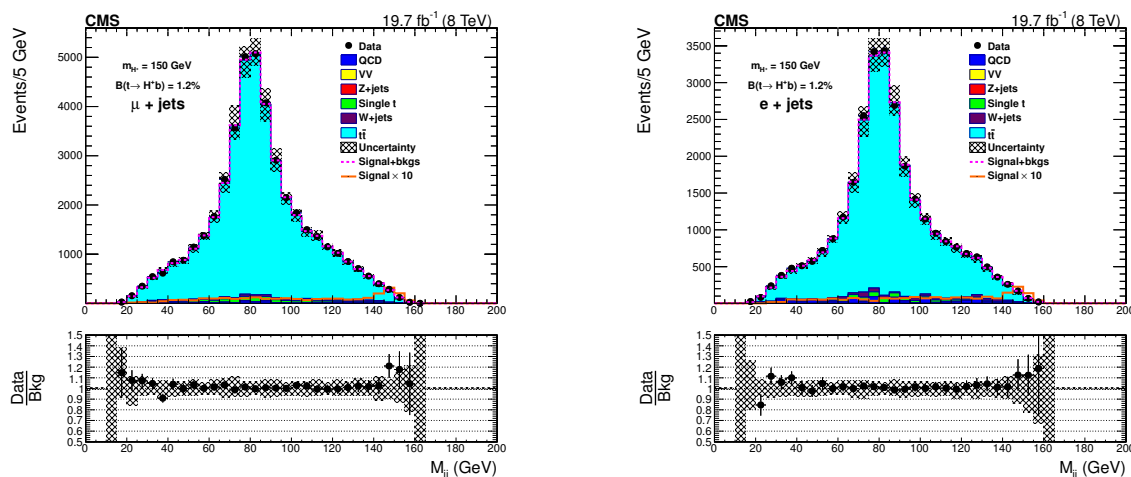


Figure 5. Dijet mass distributions of the hadronically decaying boson after all selections, using background templates and constrained uncertainties obtained from the maximum likelihood fit, for the muon+jets (left) and electron+jets (right) channel. The dotted line represents the expected yield in the presence of signal.

Here, N^{HW} is estimated from simulation forcing the first top quark to decay to bH^+ and the second to $\bar{b}W^-$, and $N_{t\bar{t}}^{\text{SM}}$ is also calculated from simulation, as given by the $t\bar{t}$ background in table 3. Eq. (5.1) does not depend on any MSSM parameters. Therefore, the obtained limit in the absence of a significant excess or deficit of events is model-independent.

Based on the CL_S method [47, 48], we perform a binned maximum-likelihood fit to the dijet mass distributions shown in figure 5 in order to search for a possible signal. The background and signal uncertainties described in section 4 are modeled with log-normal probability distribution functions. These uncertainties are represented by nuisance parameters that are varied in the fit. Correlations of all possible uncertainties between signal and backgrounds as well as among the two channels are taken into account. An upper limit at

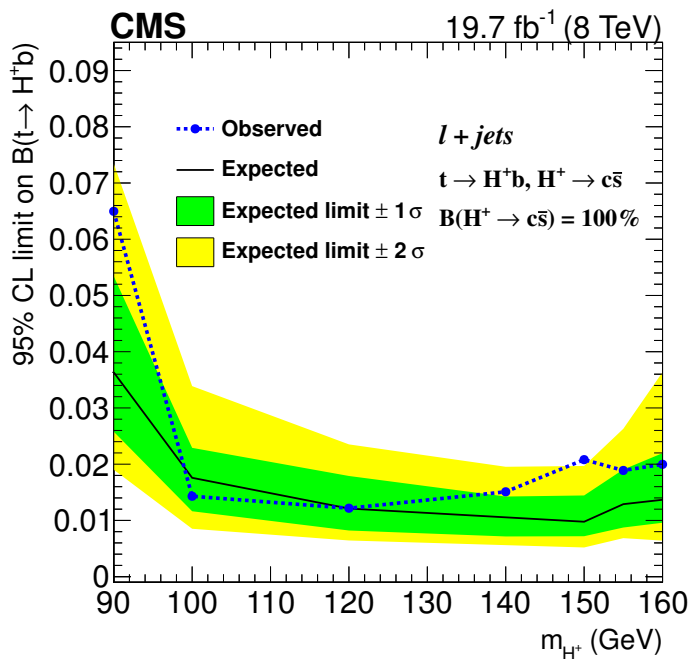


Figure 6. Exclusion limit on the branching fraction $\mathcal{B}(t \rightarrow H^+b)$ as a function of m_{H^+} assuming $\mathcal{B}(H^+ \rightarrow c\bar{s}) = 100\%$.

the 95% CL is set on $\mathcal{B}(t \rightarrow H^+b)$ using eq. (5.1). Both the expected and observed limit as a function of m_{H^+} are shown in figure 6, while table 4 provides their numerical values. The expected upper limit ranges between 1.0 and 3.6% for the mass range probed. The observed limit agrees with the expected one within two standard deviations (σ), except for the region around 150 GeV where we see some excess. To better understand this excess, in figure 7 we present an expanded view of the dijet mass distribution for the muon+jets and electron+jets channel. We find the data points to be consistent with the signal-plus-background hypothesis for a charged Higgs boson mass $m_{H^+} = 150$ GeV for a best-fit branching fraction value $(1.2 \pm 0.2)\%$. The quoted uncertainty here includes both statistical and systematic errors. The local observed significance is 2.4σ , which becomes 1.5σ after incorporating the look-elsewhere effect [49], calculated over the mass region probed in a finer binning of 1 GeV.

6 Summary

A search has been performed for a light charged Higgs boson produced in the top quark decay, subsequently decaying into a charm quark and a strange antiquark. The data sample used in the analysis corresponds to an integrated luminosity of 19.7fb^{-1} recorded by the CMS experiment at $\sqrt{s} = 8$ TeV in pp collisions. After analyzing the dijet mass distribution of the $H^+ \rightarrow c\bar{s}$ candidate events that comprise an isolated lepton, at least four hadronic jets, two of which are identified as b jets, and large missing transverse energy, we have set model-independent upper limits on the branching fraction $\mathcal{B}(t \rightarrow H^+b)$ assuming $\mathcal{B}(H^+ \rightarrow c\bar{s}) = 100\%$. The 95% confidence level upper limits are in the range 1.2–6.5% for a charged Higgs boson mass between 90 and 160 GeV.

95% CL upper limit on $\mathcal{B}(t \rightarrow H^+b)$ in percent						
m_{H^+} (GeV)	Expected limit					Observed limit
	-2σ	-1σ	median	$+1\sigma$	$+2\sigma$	
90	1.9	2.6	3.6	5.3	7.3	6.5
100	0.9	1.2	1.8	2.3	3.4	1.4
120	0.6	0.8	1.2	1.8	2.4	1.2
140	0.6	0.7	1.1	1.4	2.0	1.5
150	0.5	0.7	1.0	1.4	2.0	2.1
155	0.7	0.9	1.3	1.9	2.6	1.9
160	0.6	1.0	1.4	2.2	3.6	2.0

Table 4. Expected and observed limits on $\mathcal{B}(t \rightarrow H^+b)$ (in percent) at 95% CL in the mass range of 90 to 160 GeV.

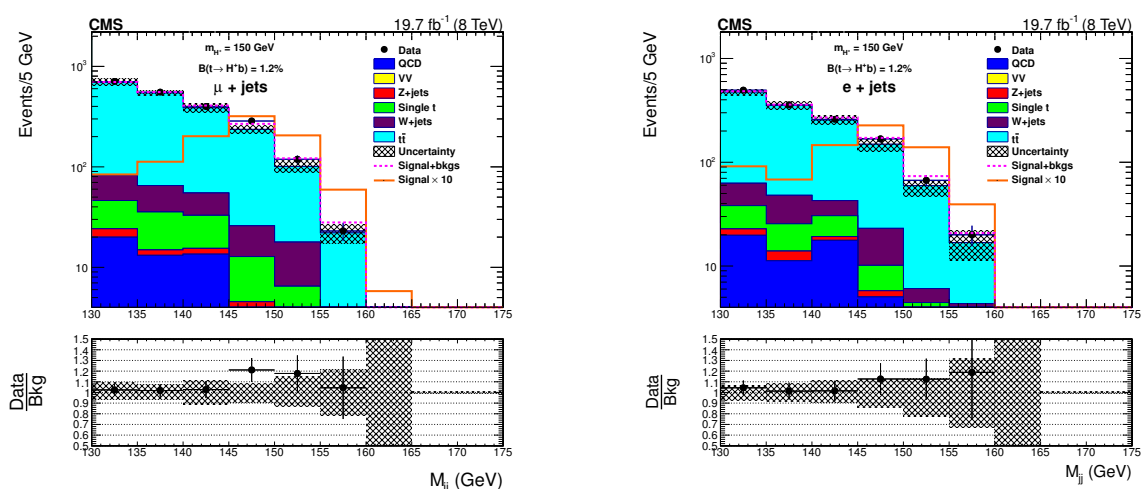


Figure 7. An expanded view of the dijet mass distribution of the hadronically decaying boson after all selections, using background templates and constrained uncertainties obtained from the maximum likelihood fit, for the muon+jets (left) and electron+jets (right) channel. The dotted line represents the expected yield in the presence of signal.

Acknowledgments

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: the Austrian Federal Ministry of Science, Research and Economy and the Austrian Science Fund; the Belgian Fonds de la Recherche Scientifique, and Fonds voor Wetenschappelijk Onderzoek; the Brazilian Funding Agencies (CNPq, CAPES, FAPERJ, and FAPESP); the

Bulgarian Ministry of Education and Science; CERN; the Chinese Academy of Sciences, Ministry of Science and Technology, and National Natural Science Foundation of China; the Colombian Funding Agency (COLCIENCIAS); the Croatian Ministry of Science, Education and Sport, and the Croatian Science Foundation; the Research Promotion Foundation, Cyprus; the Ministry of Education and Research, Estonian Research Council via IUT23-4 and IUT23-6 and European Regional Development Fund, Estonia; the Academy of Finland, Finnish Ministry of Education and Culture, and Helsinki Institute of Physics; the Institut National de Physique Nucléaire et de Physique des Particules / CNRS, and Commissariat à l'Énergie Atomique et aux Énergies Alternatives / CEA, France; the Bundesministerium für Bildung und Forschung, Deutsche Forschungsgemeinschaft, and Helmholtz-Gemeinschaft Deutscher Forschungszentren, Germany; the General Secretariat for Research and Technology, Greece; the National Scientific Research Foundation, and National Innovation Office, Hungary; the Department of Atomic Energy and the Department of Science and Technology, India; the Institute for Studies in Theoretical Physics and Mathematics, Iran; the Science Foundation, Ireland; the Istituto Nazionale di Fisica Nucleare, Italy; the Ministry of Science, ICT and Future Planning, and National Research Foundation (NRF), Republic of Korea; the Lithuanian Academy of Sciences; the Ministry of Education, and University of Malaya (Malaysia); the Mexican Funding Agencies (CINVESTAV, CONACYT, SEP, and UASLP-FAI); the Ministry of Business, Innovation and Employment, New Zealand; the Pakistan Atomic Energy Commission; the Ministry of Science and Higher Education and the National Science Centre, Poland; the Fundação para a Ciência e a Tecnologia, Portugal; JINR, Dubna; the Ministry of Education and Science of the Russian Federation, the Federal Agency of Atomic Energy of the Russian Federation, Russian Academy of Sciences, and the Russian Foundation for Basic Research; the Ministry of Education, Science and Technological Development of Serbia; the Secretaría de Estado de Investigación, Desarrollo e Innovación and Programa Consolider-Ingenio 2010, Spain; the Swiss Funding Agencies (ETH Board, ETH Zurich, PSI, SNF, UniZH, Canton Zurich, and SER); the Ministry of Science and Technology, Taipei; the Thailand Center of Excellence in Physics, the Institute for the Promotion of Teaching Science and Technology of Thailand, Special Task Force for Activating Research and the National Science and Technology Development Agency of Thailand; the Scientific and Technical Research Council of Turkey, and Turkish Atomic Energy Authority; the National Academy of Sciences of Ukraine, and State Fund for Fundamental Researches, Ukraine; the Science and Technology Facilities Council, U.K.; the U.S. Department of Energy, and the U.S. National Science Foundation.

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

Compagnia di San Paolo (Torino); the Consorzio per la Fisica (Trieste); MIUR project 20108T4XTM (Italy); the Thalys and Aristeia programmes cofinanced by EU-ESF and the Greek NSRF; the National Priorities Research Program by Qatar National Research Fund; the Rachadapisek Sompot Fund for Postdoctoral Fellowship, Chulalongkorn University (Thailand); and the Welch Foundation, contract C-1845.

Open Access. This article is distributed under the terms of the Creative Commons Attribution License ([CC-BY 4.0](https://creativecommons.org/licenses/by/4.0/)), which permits any use, distribution and reproduction in any medium, provided the original author(s) and source are credited.

References

- [1] ATLAS collaboration, *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, *Phys. Lett. B* **716** (2012) 1 [[arXiv:1207.7214](https://arxiv.org/abs/1207.7214)] [[INSPIRE](#)].
- [2] CMS collaboration, *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, *Phys. Lett. B* **716** (2012) 30 [[arXiv:1207.7235](https://arxiv.org/abs/1207.7235)] [[INSPIRE](#)].
- [3] CMS collaboration, *Observation of a new boson with mass near 125 GeV in pp collisions at $\sqrt{s} = 7$ and 8 TeV*, *JHEP* **06** (2013) 081 [[arXiv:1303.4571](https://arxiv.org/abs/1303.4571)] [[INSPIRE](#)].
- [4] M.J.G. Veltman, *Second threshold in weak interactions*, *Acta Phys. Polon.* **B 8** (1977) 475 [[INSPIRE](#)].
- [5] Yu. A. Golfand and E.P. Likhtman, *Extension of the algebra of Poincaré group generators and violation of p invariance*, *JETP Lett.* **13** (1971) 323 [*Pisma Zh. Eksp. Teor. Fiz.* **13** (1971) 452] [[INSPIRE](#)].
- [6] J. Wess and B. Zumino, *Supergauge transformations in four-dimensions*, *Nucl. Phys.* **B 70** (1974) 39 [[INSPIRE](#)].
- [7] S.P. Martin, *A supersymmetry primer*, *Adv. Ser. Direct. High Energy Phys.* **18** (1998) 1 [[hep-ph/9709356](https://arxiv.org/abs/hep-ph/9709356)] [[INSPIRE](#)].
- [8] P. Fayet, *Supergauge invariant extension of the Higgs mechanism and a model for the electron and its neutrino*, *Nucl. Phys.* **B 90** (1975) 104 [[INSPIRE](#)].
- [9] P. Fayet, *Spontaneously broken supersymmetric theories of weak, electromagnetic and strong interactions*, *Phys. Lett. B* **69** (1977) 489 [[INSPIRE](#)].
- [10] LEP, DELPHI, OPAL, ALEPH and L3 collaborations, G. Abbiendi et al., *Search for charged Higgs bosons: combined results using LEP data*, *Eur. Phys. J. C* **73** (2013) 2463 [[arXiv:1301.6065](https://arxiv.org/abs/1301.6065)] [[INSPIRE](#)].
- [11] M. Aoki, S. Kanemura, K. Tsumura and K. Yagyu, *Models of Yukawa interaction in the two Higgs doublet model and their collider phenomenology*, *Phys. Rev. D* **80** (2009) 015017 [[arXiv:0902.4665](https://arxiv.org/abs/0902.4665)] [[INSPIRE](#)].
- [12] CDF collaboration, T. Aaltonen et al., *Search for charged Higgs bosons in decays of top quarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV*, *Phys. Rev. Lett.* **103** (2009) 101803 [[arXiv:0907.1269](https://arxiv.org/abs/0907.1269)] [[INSPIRE](#)].
- [13] D0 collaboration, V.M. Abazov et al., *Search for charged Higgs bosons in top quark decays*, *Phys. Lett. B* **682** (2009) 278 [[arXiv:0908.1811](https://arxiv.org/abs/0908.1811)] [[INSPIRE](#)].

- [14] ATLAS collaboration, *Search for a light charged Higgs boson in the decay channel $H^+ \rightarrow c\bar{s}$ in $t\bar{t}$ events using pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector*, *Eur. Phys. J. C* **73** (2013) 2465 [[arXiv:1302.3694](#)] [[INSPIRE](#)].
- [15] CMS collaboration, *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004 [[INSPIRE](#)].
- [16] CMS collaboration, *Particle-flow event reconstruction in CMS and performance for jets, taus and MET*, *CMS-PAS-PFT-09-001*, CERN, Geneva Switzerland (2009).
- [17] CMS collaboration, *Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector*, *CMS-PAS-PFT-10-001*, CERN, Geneva Switzerland (2010).
- [18] CMS collaboration, *Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV*, 2012 *JINST* **7** P10002 [[arXiv:1206.4071](#)] [[INSPIRE](#)].
- [19] CMS collaboration, *Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV*, 2015 *JINST* **10** P06005 [[arXiv:1502.02701](#)] [[INSPIRE](#)].
- [20] M. Cacciari, G.P. Salam and G. Soyez, *The anti- k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [[arXiv:0802.1189](#)] [[INSPIRE](#)].
- [21] CMS collaboration, *Pileup jet identification*, *CMS-PAS-JME-13-005*, CERN, Geneva Switzerland (2013).
- [22] CMS collaboration, *Missing transverse energy performance of the CMS detector*, 2011 *JINST* **6** P09001 [[arXiv:1106.5048](#)] [[INSPIRE](#)].
- [23] CMS collaboration, *Identification of b -quark jets with the CMS experiment*, 2013 *JINST* **8** P04013 [[arXiv:1211.4462](#)] [[INSPIRE](#)].
- [24] CMS collaboration, *Performance of b tagging at $\sqrt{s} = 8$ TeV in multijet, $t\bar{t}$ and boosted topology events*, *CMS-PAS-BTV-13-001*, CERN, Geneva Switzerland (2013).
- [25] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer and T. Stelzer, *MadGraph 5: going beyond*, *JHEP* **06** (2011) 128 [[arXiv:1106.0522](#)] [[INSPIRE](#)].
- [26] T. Sjöstrand, S. Mrenna and P.Z. Skands, *PYTHIA 6.4 physics and manual*, *JHEP* **05** (2006) 026 [[hep-ph/0603175](#)] [[INSPIRE](#)].
- [27] CMS collaboration, *Measurement of the underlying event activity at the LHC with $\sqrt{s} = 7$ TeV and comparison with $\sqrt{s} = 0.9$ TeV*, *JHEP* **09** (2011) 109 [[arXiv:1107.0330](#)] [[INSPIRE](#)].
- [28] J. Pumplin, D.R. Stump, J. Huston, H.L. Lai, P.M. Nadolsky and W.K. Tung, *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [[hep-ph/0201195](#)] [[INSPIRE](#)].
- [29] M. Czakon, P. Fiedler and A. Mitov, *Total top-quark pair-production cross section at hadron colliders through $O(\alpha_s^4)$* , *Phys. Rev. Lett.* **110** (2013) 252004 [[arXiv:1303.6254](#)] [[INSPIRE](#)].
- [30] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040 [[hep-ph/0409146](#)] [[INSPIRE](#)].
- [31] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the POWHEG method*, *JHEP* **11** (2007) 070 [[arXiv:0709.2092](#)] [[INSPIRE](#)].

- [32] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, *JHEP* **06** (2010) 043 [[arXiv:1002.2581](#)] [[INSPIRE](#)].
- [33] S. Alioli, P. Nason, C. Oleari and E. Re, *NLO single-top production matched with shower in POWHEG: s- and t-channel contributions*, *JHEP* **09** (2009) 111 [Erratum *ibid.* **02** (2010) 011] [[arXiv:0907.4076](#)] [[INSPIRE](#)].
- [34] E. Re, *Single-top Wt-channel production matched with parton showers using the POWHEG method*, *Eur. Phys. J. C* **71** (2011) 1547 [[arXiv:1009.2450](#)] [[INSPIRE](#)].
- [35] Y. Li and F. Petriello, *Combining QCD and electroweak corrections to dilepton production in FEWZ*, *Phys. Rev. D* **86** (2012) 094034 [[arXiv:1208.5967](#)] [[INSPIRE](#)].
- [36] R. Gavin, Y. Li, F. Petriello and S. Quackenbush, *FEWZ 2.0: a code for hadronic Z production at next-to-next-to-leading order*, *Comput. Phys. Commun.* **182** (2011) 2388 [[arXiv:1011.3540](#)] [[INSPIRE](#)].
- [37] N. Kidonakis, *Differential and total cross sections for top pair and single top production*, in *20th International Workshop on Deep-Inelastic Scattering and Related Subjects*, DESY-PROC-2012-02, Bonn Germany (2012), pg. 831.
- [38] J.M. Campbell and R.K. Ellis, *MCFM for the Tevatron and the LHC*, *Nucl. Phys. Proc. Suppl.* **205-206** (2010) 10 [[arXiv:1007.3492](#)] [[INSPIRE](#)].
- [39] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth. A* **506** (2003) 250 [[INSPIRE](#)].
- [40] CMS collaboration, *Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **10** (2011) 132 [[arXiv:1107.4789](#)] [[INSPIRE](#)].
- [41] A. Höcker et al., *TMVA — toolkit for multivariate data analysis*, *PoS(ACAT)040* [[physics/0703039](#)] [[INSPIRE](#)].
- [42] CMS collaboration, *Measurement of differential top-quark pair production cross sections in pp collisions at $\sqrt{s} = 7$ TeV*, *Eur. Phys. J. C* **73** (2013) 2339 [[arXiv:1211.2220](#)] [[INSPIRE](#)].
- [43] CMS collaboration, *Measurement of the differential cross section for top quark pair production in pp collisions at $\sqrt{s} = 8$ TeV*, *Eur. Phys. J. C* **75** (2015) 542 [[arXiv:1505.04480](#)] [[INSPIRE](#)].
- [44] CMS collaboration, *Measurement of the top-quark mass in $t\bar{t}$ events with lepton+jets final states in pp collisions at $\sqrt{s} = 7$ TeV*, *JHEP* **12** (2012) 105 [[arXiv:1209.2319](#)] [[INSPIRE](#)].
- [45] CMS collaboration, *Determination of jet energy calibration and transverse momentum resolution in CMS*, *2011 JINST* **6** P11002 [[arXiv:1107.4277](#)] [[INSPIRE](#)].
- [46] CMS collaboration, *CMS luminosity based on pixel cluster counting — Summer 2013 update*, *CMS-PAS-LUM-13-001*, CERN, Geneva Switzerland (2013).
- [47] A.L. Read, *Presentation of search results: the CL_s technique*, *J. Phys. G* **28** (2002) 2693 [[INSPIRE](#)].
- [48] T. Junk, *Confidence level computation for combining searches with small statistics*, *Nucl. Instrum. Meth. A* **434** (1999) 435 [[hep-ex/9902006](#)] [[INSPIRE](#)].
- [49] ATLAS and CMS collaborations and the LHC HIGGS COMBINATION Group, *Procedure for the LHC Higgs boson search combination in Summer 2011*, *CMS-NOTE-2011-005*, CERN, Geneva Switzerland (2011) [ATL-PHYS-PUB-2011-11].

The CMS collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicevic, J. Erö, M. Flechl, M. Friedl, R. Frühwirth¹, V.M. Ghete, C. Hartl, N. Hörmann, J. Hrubec, M. Jeitler¹, V. Knünz, A. König, M. Krammer¹, I. Krätschmer, D. Liko, T. Matsushita, I. Mikulec, D. Rabady², B. Rahbaran, H. Rohringer, J. Schieck¹, R. Schöfbeck, J. Strauss, W. Treberer-Treberspurg, W. Waltenberger, C.-E. Wulz¹

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

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

Universiteit Antwerpen, Antwerpen, Belgium

S. Alderweireldt, T. Cornelis, E.A. De Wolf, X. Janssen, A. Knutsson, J. Lauwers, S. Luyckx, R. Rougny, M. Van De Klundert, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

S. Abu Zeid, F. Blekman, J. D'Hondt, N. Daci, I. De Bruyn, K. Deroover, N. Heracleous, J. Keaveney, S. Lowette, L. Moreels, A. Olbrechts, Q. Python, D. Strom, S. Tavernier, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Van Parijs

Université Libre de Bruxelles, Bruxelles, Belgium

P. Barria, H. Brun, C. Caillol, B. Clerbaux, G. De Lentdecker, G. Fasanella, L. Favart, A. Grebenyuk, G. Karapostoli, T. Lenzi, A. Léonard, T. Maerschalk, A. Marinov, L. Perniè, A. Randle-conde, T. Reis, T. Seva, C. Vander Velde, P. Vanlaer, R. Yonamine, F. Zenoni, F. Zhang³

Ghent University, Ghent, Belgium

K. Beernaert, L. Benucci, A. Cimmino, S. Crucy, D. Dobur, A. Fagot, G. Garcia, M. Gul, J. Mccartin, A.A. Ocampo Rios, D. Poyraz, D. Ryckbosch, S. Salva, M. Sigamani, N. Strobbe, M. Tytgat, W. Van Driessche, E. Yazgan, N. Zaganidis

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

S. Basesmez, C. Beluffi⁴, O. Bondu, S. Brochet, G. Bruno, A. Caudron, L. Ceard, G.G. Da Silveira, C. Delaere, D. Favart, L. Forthomme, A. Giammanco⁵, J. Hollar, A. Jafari, P. Jez, M. Komm, V. Lemaitre, A. Mertens, C. Nuttens, L. Perrini, A. Pin, K. Piotrkowski, A. Popov⁶, L. Quertenmont, M. Selvaggi, M. Vidal Marono

Université de Mons, Mons, Belgium

N. Beliy, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, G.A. Alves, L. Brito, M. Correa Martins Junior, M. Hamer, C. Hensel, C. Mora Herrera, A. Moraes, M.E. Pol, P. Rebello Teles

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

E. Belchior Batista Das Chagas, W. Carvalho, J. Chinellato⁷, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, L.M. Huertas Guativa, H. Malbouisson, D. Matos Figueiredo, L. Mundim, H. Nogima, W.L. Prado Da Silva, A. Santoro, A. Sznajder, E.J. Tonelli Manganote⁷, A. Vilela Pereira

Universidade Estadual Paulista ^a, Universidade Federal do ABC ^b, São Paulo, Brazil

S. Ahuja^a, C.A. Bernardes^b, A. De Souza Santos^b, S. Dogra^a, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, P.G. Mercadante^b, C.S. Moon^{a,8}, S.F. Novaes^a, Sandra S. Padula^a, D. Romero Abad, J.C. Ruiz Vargas

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

A. Aleksandrov, R. Hadjiiska, P. Iaydjiev, M. Rodozov, S. Stoykova, G. Sultanov, M. Vutova

University of Sofia, Sofia, Bulgaria

A. Dimitrov, I. Glushkov, L. Litov, B. Pavlov, P. Petkov

Institute of High Energy Physics, Beijing, China

M. Ahmad, J.G. Bian, G.M. Chen, H.S. Chen, M. Chen, T. Cheng, R. Du, C.H. Jiang, R. Plestina⁹, F. Romeo, S.M. Shaheen, J. Tao, C. Wang, Z. Wang, H. Zhang

State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

C. Asawatrangkuldee, Y. Ban, Q. Li, S. Liu, Y. Mao, S.J. Qian, D. Wang, Z. Xu

Universidad de Los Andes, Bogota, Colombia

C. Avila, A. Cabrera, L.F. Chaparro Sierra, C. Florez, J.P. Gomez, B. Gomez Moreno, J.C. Sanabria

University of Split, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, Croatia

N. Godinovic, D. Lelas, I. Puljak, P.M. Ribeiro Cipriano

University of Split, Faculty of Science, Split, Croatia

Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

V. Brigljevic, K. Kadija, J. Luetic, S. Micanovic, L. Sudic

University of Cyprus, Nicosia, Cyprus

A. Attikis, G. Mavromanolakis, J. Mousa, C. Nicolaou, F. Ptochos, P.A. Razis, H. Rykaczewski

Charles University, Prague, Czech Republic

M. Bodlak, M. Finger¹⁰, M. Finger Jr.¹⁰

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

A.A. Abdelalim^{11,12}, A. Awad, M. El Sawy^{13,14}, A. Mahrous¹¹, A. Radi^{14,15}

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

B. Calpas, M. Kadastik, M. Murumaa, M. Raidal, A. Tiko, C. Veelken

Department of Physics, University of Helsinki, Helsinki, Finland

P. Eerola, J. Pekkanen, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland

J. Härkönen, V. Karimäki, R. Kinnunen, T. Lampén, K. Lassila-Perini, S. Lehti, T. Lindén, P. Luukka, T. Mäenpää, T. Peltola, E. Tuominen, J. Tuominiemi, E. Tuovinen, L. Wendland

Lappeenranta University of Technology, Lappeenranta, Finland

J. Talvitie, T. Tuuva

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

M. Besancon, F. Couderc, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, C. Favaro, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, M. Machet, J. Malcles, J. Rander, A. Rosowsky, M. Titov, A. Zghiche

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

I. Antropov, S. Baffioni, F. Beaudette, P. Busson, L. Cadamuro, E. Chapon, C. Charlot, T. Dahms, O. Davignon, N. Filipovic, A. Florent, R. Granier de Cassagnac, S. Lisniak, L. Mastrolorenzo, P. Miné, I.N. Naranjo, M. Nguyen, C. Ochando, G. Ortona, P. Paganini, P. Pigard, S. Regnard, R. Salerno, J.B. Sauvan, Y. Sirois, T. Strebler, Y. Yilmaz, A. Zabi

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

J.-L. Agram¹⁶, J. Andrea, A. Aubin, D. Bloch, J.-M. Brom, M. Buttignol, E.C. Chabert, N. Chanon, C. Collard, E. Conte¹⁶, X. Coubez, J.-C. Fontaine¹⁶, D. Gelé, U. Goerlach, C. Goetzmann, A.-C. Le Bihan, J.A. Merlin², K. Skovpen, P. Van Hove

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

S. Gadrat

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

S. Beauceron, C. Bernet, G. Boudoul, E. Bouvier, C.A. Carrillo Montoya, R. Chierici, D. Contardo, B. Courbon, P. Depasse, H. El Mamouni, J. Fan, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, F. Lagarde, I.B. Laktineh, M. Lethuillier, L. Mirabito, A.L. Pequegnot, S. Perries, J.D. Ruiz Alvarez, D. Sabes, L. Sgandurra, V. Sordini, M. Vander Donckt, P. Verdier, S. Viret

Georgian Technical University, Tbilisi, Georgia

T. Toriashvili¹⁷

Tbilisi State University, Tbilisi, Georgia

Z. Tsamalaidze¹⁰

RWTH Aachen University, I. Physikalisches Institut, Aachen, Germany

C. Autermann, S. Beranek, M. Edelhoff, L. Feld, A. Heister, M.K. Kiesel, K. Klein, M. Lipinski, A. Ostapchuk, M. Preuten, F. Raupach, S. Schael, J.F. Schulte, T. Verlage, H. Weber, B. Wittmer, V. Zhukov⁶

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

M. Ata, M. Brodski, E. Dietz-Laursonn, D. Duchardt, M. Endres, M. Erdmann, S. Erdweg, T. Esch, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, S. Knutzen, P. Kreuzer, M. Merschmeyer, A. Meyer, P. Millet, M. Olschewski, K. Padeken, P. Papacz, T. Pook, M. Radziej, H. Reithler, M. Rieger, F. Scheuch, L. Sonnenschein, D. Teysier, S. Thüer

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

V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, A. Künsken, J. Lingemann², A. Nehr Korn, A. Nowack, I.M. Nugent, C. Pistone, O. Pooth, A. Stahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, I. Asin, N. Bartosik, O. Behnke, U. Behrens, A.J. Bell, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, S. Choudhury, F. Costanza, C. Diez Pardos, G. Dolinska, S. Dooling, T. Dorland, G. Eckerlin, D. Eckstein, T. Eichhorn, G. Flucke, E. Gallo¹⁸, J. Garay Garcia, A. Geiser, A. Gzhko, P. Gunnellini, J. Hauk, M. Hempel¹⁹, H. Jung, A. Kalogeropoulos, O. Karacheban¹⁹, M. Kasemann, P. Katsas, J. Kieseler, C. Kleinwort, I. Korol, W. Lange, J. Leonard, K. Lipka, A. Lobanov, W. Lohmann¹⁹, R. Mankel, I. Marfin¹⁹, I.-A. Melzer-Pellmann, A.B. Meyer, G. Mittag, J. Mnich, A. Mussgiller, S. Naumann-Emme, A. Nayak, E. Ntomari, H. Perrey, D. Pitzl, R. Placakyte, A. Raspereza, B. Roland, M.Ö. Sahin, P. Saxena, T. Schoerner-Sadenius, M. Schröder, C. Seitz, S. Spannagel, K.D. Trippkewitz, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

V. Blobel, M. Centis Vignali, A.R. Draeger, J. Erfle, E. Garutti, K. Goebel, D. Gonzalez, M. Görner, J. Haller, M. Hoffmann, R.S. Höing, A. Junkes, R. Klanner, R. Kogler, T. Lapsien, T. Lenz, I. Marchesini, D. Marconi, M. Meyer, D. Nowatschin, J. Ott, F. Pantaleo², T. Peiffer, A. Perieanu, N. Pietsch, J. Poehlsen, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, J. Schwandt, M. Seidel, V. Sola, H. Stadie, G. Steinbrück, H. Tholen, D. Troendle, E. Usai, L. Vanelderden, A. Vanhoefer, B. Vormwald

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

M. Akbiyik, C. Barth, C. Baus, J. Berger, C. Böser, E. Butz, T. Chwalek, F. Colombo, W. De Boer, A. Descroix, A. Dierlamm, S. Fink, F. Frensch, M. Giffels, A. Gilbert,

F. Hartmann², S.M. Heindl, U. Husemann, I. Katkov⁶, A. Kornmayer², P. Lobelle Pardo, B. Maier, H. Mildner, M.U. Mozer, T. Müller, Th. Müller, M. Plagge, G. Quast, K. Rabbertz, S. Röcker, F. Roscher, H.J. Simonis, F.M. Stober, R. Ulrich, J. Wagner-Kuhr, S. Wayand, M. Weber, T. Weiler, C. Wöhrmann, R. Wolf

Institute of Nuclear and Particle Physics (INPP), NCSR Demokritos, Aghia Paraskevi, Greece

G. Anagnostou, G. Daskalakis, T. Gerasis, V.A. Giakoumopoulou, A. Kyriakis, D. Loukas, A. Psallidas, I. Topsis-Giotis

University of Athens, Athens, Greece

A. Agapitos, S. Kesisoglou, A. Panagiotou, N. Saoulidou, E. Tziaferi

University of Ioánnina, Ioánnina, Greece

I. Evangelou, G. Flouris, C. Foudas, P. Kokkas, N. Loukas, N. Manthos, I. Papadopoulos, E. Paradas, J. Strologas

Wigner Research Centre for Physics, Budapest, Hungary

G. Bencze, C. Hajdu, A. Hazi, P. Hidas, D. Horvath²⁰, F. Sikler, V. Veszpremi, G. Vesztergombi²¹, A.J. Zsigmond

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

N. Beni, S. Czellar, J. Karancsi²², J. Molnar, Z. Szillasi

University of Debrecen, Debrecen, Hungary

M. Bartók²³, A. Makovec, P. Raics, Z.L. Trocsanyi, B. Ujvari

National Institute of Science Education and Research, Bhubaneswar, India

P. Mal, K. Mandal, D.K. Sahoo, N. Sahoo, S.K. Swain

Panjab University, Chandigarh, India

S. Bansal, S.B. Beri, V. Bhatnagar, R. Chawla, R. Gupta, U. Bhawandeep, A.K. Kalsi, A. Kaur, M. Kaur, R. Kumar, A. Mehta, M. Mittal, J.B. Singh, G. Walia

University of Delhi, Delhi, India

Ashok Kumar, A. Bhardwaj, B.C. Choudhary, R.B. Garg, A. Kumar, S. Malhotra, M. Naimuddin, N. Nishu, K. Ranjan, R. Sharma, V. Sharma

Saha Institute of Nuclear Physics, Kolkata, India

S. Bhattacharya, K. Chatterjee, S. Dey, S. Dutta, Sa. Jain, N. Majumdar, A. Modak, K. Mondal, S. Mukherjee, S. Mukhopadhyay, A. Roy, D. Roy, S. Roy Chowdhury, S. Sarkar, M. Sharan

Bhabha Atomic Research Centre, Mumbai, India

A. Abdulsalam, R. Chudasama, D. Dutta, V. Jha, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla, A. Topkar

Tata Institute of Fundamental Research, Mumbai, India

T. Aziz, S. Banerjee, S. Bhowmik²⁴, R.M. Chatterjee, R.K. Dewanjee, S. Dugad, S. Ganguly, S. Ghosh, M. Guchait, A. Gurtu²⁵, G. Kole, S. Kumar, B. Mahakud, M. Maity²⁴,

G. Majumder, K. Mazumdar, S. Mitra, G.B. Mohanty, B. Parida, T. Sarkar²⁴, K. Sudhakar, N. Sur, B. Sutar, N. Wickramage²⁶

Indian Institute of Science Education and Research (IISER), Pune, India

S. Chauhan, S. Dube, S. Sharma

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

H. Bakhshiansohi, H. Behnamian, S.M. Etesami²⁷, A. Fahim²⁸, R. Goldouzian, M. Khakzad, M. Mohammadi Najafabadi, M. Naseri, S. Paktinat Mehdiabadi, F. Rezaei Hosseinabadi, B. Safarzadeh²⁹, M. Zeinali

University College Dublin, Dublin, Ireland

M. Felcini, M. Grunewald

INFN Sezione di Bari ^a, Università di Bari ^b, Politecnico di Bari ^c, Bari, Italy

M. Abbrescia^{a,b}, C. Calabria^{a,b}, C. Caputo^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, L. Cristella^{a,b}, N. De Filippis^{a,c}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, G. Miniello^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, A. Pompili^{a,b}, G. Pugliese^{a,c}, R. Radogna^{a,b}, A. Ranieri^a, G. Selvaggi^{a,b}, L. Silvestris^{a,2}, R. Venditti^{a,b}, P. Verwilligen^a

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

G. Abbiendi^a, C. Battilana², A.C. Benvenuti^a, D. Bonacorsi^{a,b}, S. Braibant-Giacomelli^{a,b}, L. Brigliadori^{a,b}, R. Campanini^{a,b}, P. Capiluppi^{a,b}, A. Castro^{a,b}, F.R. Cavallo^a, S.S. Chhibra^{a,b}, G. Codispoti^{a,b}, M. Cuffiani^{a,b}, G.M. Dallavalle^a, F. Fabbri^a, A. Fanfani^{a,b}, D. Fasanella^{a,b}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, A. Montanari^a, F.L. Navarria^{a,b}, A. Perrotta^a, A.M. Rossi^{a,b}, T. Rovelli^{a,b}, G.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

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

G. Cappello^a, M. Chiorboli^{a,b}, S. Costa^{a,b}, F. Giordano^{a,b}, R. Potenza^{a,b}, A. Tricomi^{a,b}, C. Tuve^{a,b}

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

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, S. Gonzi^{a,b}, V. Gori^{a,b}, P. Lenzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,b}, L. Viliani^{a,b}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

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

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

V. Calvelli^{a,b}, F. Ferro^a, M. Lo Vetere^{a,b}, M.R. Monge^{a,b}, E. Robutti^a, S. Tosi^{a,b}

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

L. Brianza, M.E. Dinardo^{a,b}, S. Fiorendi^{a,b}, S. Gennai^a, R. Gerosa^{a,b}, A. Ghezzi^{a,b}, P. Govoni^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, B. Marzocchi^{a,b,2}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, T. Tabarelli de Fatis^{a,b}

INFN Sezione di Napoli ^a, Università di Napoli 'Federico II' ^b, Napoli, Italy, Università della Basilicata ^c, Potenza, Italy, Università G. Marconi ^d, Roma, Italy

S. Buontempo^a, N. Cavallo^{a,c}, S. Di Guida^{a,d,2}, M. Esposito^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, G. Lanza^a, L. Lista^a, S. Meola^{a,d,2}, M. Merola^a, P. Paolucci^{a,2}, C. Sciacca^{a,b}, F. Thyssen

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

P. Azzi^{a,2}, N. Bacchetta^a, M. Bellato^a, L. Benato^{a,b}, D. Bisello^{a,b}, A. Boletti^{a,b}, A. Branca^{a,b}, R. Carlin^{a,b}, P. Checchia^a, M. Dall'Osso^{a,b,2}, T. Dorigo^a, U. Dosselli^a, F. Fanzago^a, F. Gasparini^{a,b}, U. Gasparini^{a,b}, A. Gozzelino^a, S. Lacaprara^a, M. Margoni^{a,b}, A.T. Meneguzzo^{a,b}, J. Pazzini^{a,b}, N. Pozzobon^{a,b}, P. Ronchese^{a,b}, F. Simonetto^{a,b}, E. Torassa^a, M. Tosi^{a,b}, M. Zanetti, P. Zotto^{a,b}, A. Zucchetta^{a,b,2}, G. Zumerle^{a,b}

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

A. Braghieri^a, A. Magnani^a, P. Montagna^{a,b}, S.P. Ratti^{a,b}, V. Re^a, C. Riccardi^{a,b}, P. Salvini^a, I. Vai^a, P. Vitulo^{a,b}

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

L. Alunni Solestizi^{a,b}, M. Biasini^{a,b}, G.M. Bilei^a, D. Ciangottini^{a,b,2}, L. Fanò^{a,b}, P. Lariccia^{a,b}, G. Mantovani^{a,b}, M. Menichelli^a, A. Saha^a, A. Santocchia^{a,b}, A. Spiezia^{a,b}

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

K. Androsov^{a,30}, P. Azzurri^a, G. Bagliesi^a, J. Bernardini^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, M.A. Ciocci^{a,30}, R. Dell'Orso^a, S. Donato^{a,c,2}, G. Fedi, L. Foà^{a,c†}, A. Giassi^a, M.T. Grippo^{a,30}, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,b}, A. Messineo^{a,b}, F. Palla^a, A. Rizzi^{a,b}, A. Savoy-Navarro^{a,31}, A.T. Serban^a, P. Spagnolo^a, P. Squillacioti^{a,30}, R. Tenchini^a, G. Tonelli^{a,b}, A. Venturi^a, P.G. Verdini^a

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

L. Barone^{a,b}, F. Cavallari^a, G. D'imperio^{a,b,2}, D. Del Re^{a,b}, M. Diemoz^a, S. Gelli^{a,b}, C. Jorda^a, E. Longo^{a,b}, F. Margaroli^{a,b}, P. Meridiani^a, G. Organtini^{a,b}, R. Paramatti^a, F. Preiato^{a,b}, S. Rahatlou^{a,b}, C. Rovelli^a, F. Santanastasio^{a,b}, P. Traczyk^{a,b,2}

INFN Sezione di Torino ^a, Università di Torino ^b, Torino, Italy, Università del Piemonte Orientale ^c, Novara, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c,2}, S. Argiro^{a,b}, M. Arneodo^{a,c}, R. Bellan^{a,b}, C. Biino^a, N. Cartiglia^a, M. Costa^{a,b}, R. Covarelli^{a,b}, A. Degano^{a,b}, N. Demaria^a, L. Finco^{a,b,2}, B. Kiani^{a,b}, C. Mariotti^a, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, E. Monteil^{a,b}, M. Musich^a, M.M. Obertino^{a,b}, L. Pacher^{a,b}, N. Pastrone^a, M. Pelliccioni^a, G.L. Pinna Angioni^{a,b}, F. Ravera^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, A. Solano^{a,b}, A. Staiano^a, U. Tamponi^a

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

S. Belforte^a, V. Candelise^{a,b,2}, M. Casarsa^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a,
C. La Licata^{a,b}, M. Marone^{a,b}, A. Schizzi^{a,b}, A. Zanetti^a

Kangwon National University, Chunchon, Korea

A. Kropivnitskaya, S.K. Nam

Kyungpook National University, Daegu, Korea

D.H. Kim, G.N. Kim, M.S. Kim, D.J. Kong, S. Lee, Y.D. Oh, A. Sakharov, D.C. Son

Chonbuk National University, Jeonju, Korea

J.A. Brochero Cifuentes, H. Kim, T.J. Kim, M.S. Ryu

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

S. Song

Korea University, Seoul, Korea

S. Choi, Y. Go, D. Gyun, B. Hong, M. Jo, H. Kim, Y. Kim, B. Lee, K. Lee, K.S. Lee,
S. Lee, S.K. Park, Y. Roh

Seoul National University, Seoul, Korea

H.D. Yoo

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

Y. Choi, J. Goh, D. Kim, E. Kwon, J. Lee, I. Yu

Vilnius University, Vilnius, Lithuania

A. Juodagalvis, J. Vaitkus

**National Centre for Particle Physics, Universiti Malaya, Kuala Lumpur,
Malaysia**

I. Ahmed, Z.A. Ibrahim, J.R. Komaragiri, M.A.B. Md Ali³², F. Mohamad Idris³³,
W.A.T. Wan Abdullah, M.N. Yusli

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

E. Casimiro Linares, H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-De La Cruz³⁴,
A. Hernandez-Almada, R. Lopez-Fernandez, A. Sanchez-Hernandez

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

I. Pedraza, H.A. Salazar Ibarguen

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

A. Morelos Pineda

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

P.H. Butler

National Centre for Physics, Quaid-I-Azam University, Islamabad, Pakistan

A. Ahmad, M. Ahmad, Q. Hassan, H.R. Hoorani, W.A. Khan, T. Khurshid, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland

H. Bialkowska, M. Bluj, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, P. Zalewski

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

G. Brona, K. Bunkowski, A. Byszuk³⁵, K. Doroba, A. Kalinowski, M. Konecki, J. Krolikowski, M. Misiura, M. Olszewski, M. Walczak

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

P. Bargassa, C. Beirão Da Cruz E Silva, A. Di Francesco, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, N. Leonardo, L. Lloret Iglesias, F. Nguyen, J. Rodrigues Antunes, J. Seixas, O. Toldaiev, D. Vadrucio, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia

S. Afanasiev, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, V. Konoplyanikov, A. Lanev, A. Malakhov, V. Matveev³⁶, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, S. Shulha, N. Skatchkov, V. Smirnov, A. Zarubin

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

V. Golovtsov, Y. Ivanov, V. Kim³⁷, E. Kuznetsova, P. Levchenko, V. Murzin, V. Oreshkin, I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev

Institute for Nuclear Research, Moscow, Russia

Yu. Andreev, A. Dermenev, S. Gninenko, N. Golubev, A. Karneyev, M. Kirsanov, N. Krasnikov, A. Pashenkov, D. Tlisov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia

V. Epshteyn, V. Gavrilov, N. Lychkovskaya, V. Popov, I. Pozdnyakov, G. Safronov, A. Spiridonov, E. Vlasov, A. Zhokin

National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia

A. Bylinkin

P.N. Lebedev Physical Institute, Moscow, Russia

V. Andreev, M. Azarkin³⁸, I. Dremin³⁸, M. Kirakosyan, A. Leonidov³⁸, G. Mesyats, S.V. Rusakov, A. Vinogradov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

A. Baskakov, A. Belyaev, E. Boos, V. Bunichev, M. Dubinin³⁹, L. Dudko, A. Ershov, V. Klyukhin, O. Kodolova, I. Lokhtin, I. Myagkov, S. Obraztsov, S. Petrushanko, V. Savrin, A. Snigirev

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

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Kachanov, A. Kalinin, D. Konstantinov, V. Krychkin, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic⁴⁰, M. Ekmedzic, J. Milosevic, V. Rekovic

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

J. Alcaraz Maestre, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, D. Domínguez Vázquez, A. Escalante Del Valle, C. Fernandez Bedoya, J.P. Fernández Ramos, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, E. Navarro De Martino, A. Pérez-Calero Yzquierdo, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares

Universidad Autónoma de Madrid, Madrid, Spain

C. Albajar, J.F. de Trocóniz, M. Missiroli, D. Moran

Universidad de Oviedo, Oviedo, Spain

J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, E. Palencia Cortezon, J.M. Vizán Garcia

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

I.J. Cabrillo, A. Calderon, J.R. Castiñeiras De Saa, P. De Castro Manzano, J. Duarte Campderros, M. Fernandez, J. Garcia-Ferrero, G. Gomez, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, J. Piedra Gomez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, A. Benaglia, J. Bendavid, L. Benhabib, J.F. Benitez, G.M. Berruti, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, R. Castello, G. Cerminara, S. Colafranceschi⁴¹, M. D'Alfonso, D. d'Enterria, A. Dabrowski, V. Daponte, A. David, M. De Gruttola, F. De Guio, A. De Roeck, S. De Visscher, E. Di Marco, M. Dobson, M. Dordevic, B. Dorney, T. du Pree, M. Dünser, N. Dupont, A. Elliott-Peisert, G. Franzoni, W. Funk, D. Gigi, K. Gill, D. Giordano, M. Girone, F. Glege, R. Guida, S. Gundacker, M. Guthoff, J. Hammer,

P. Harris, J. Hegeman, V. Innocente, P. Janot, H. Kirschenmann, M.J. Kortelainen, K. Kousouris, K. Krajczar, P. Lecoq, C. Lourenço, M.T. Lucchini, N. Magini, L. Malgeri, M. Mannelli, A. Martelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, F. Moortgat, S. Morovic, M. Mulders, M.V. Nemallapudi, H. Neugebauer, S. Orfanelli⁴², L. Orsini, L. Pape, E. Perez, M. Peruzzi, A. Petrilli, G. Petrucciani, A. Pfeiffer, D. Piparo, A. Racz, G. Rolandi⁴³, M. Rovere, M. Ruan, H. Sakulin, C. Schäfer, C. Schwick, A. Sharma, P. Silva, M. Simon, P. Sphicas⁴⁴, D. Spiga, J. Steggemann, B. Stieger, M. Stoye, Y. Takahashi, D. Treille, A. Triossi, A. Tsirou, G.I. Veres²¹, N. Wardle, H.K. Wöhri, A. Zagozdzińska³⁵, W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, R. Horisberger, Q. Ingram, H.C. Kaestli, D. Kotlinski, U. Langenegger, D. Renker, T. Rohe

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

F. Bachmair, L. Bäni, L. Bianchini, M.A. Buchmann, B. Casal, G. Dissertori, M. Dittmar, M. Donegà, P. Eller, C. Grab, C. Heidegger, D. Hits, J. Hoss, G. Kasieczka, W. Luster, B. Mangano, M. Marionneau, P. Martinez Ruiz del Arbol, M. Masciovecchio, D. Meister, F. Micheli, P. Musella, F. Nessi-Tedaldi, F. Pandolfi, J. Pata, F. Pauss, L. Perrozzi, M. Quittnat, M. Rossini, A. Starodumov⁴⁵, M. Takahashi, V.R. Tavolaro, K. Theofilatos, R. Wallny

Universität Zürich, Zurich, Switzerland

T.K. Aarrestad, C. Amsler⁴⁶, L. Caminada, M.F. Canelli, V. Chiochia, A. De Cosa, C. Galloni, A. Hinzmann, T. Hreus, B. Kilminster, C. Lange, J. Ngadiuba, D. Pinna, P. Robmann, F.J. Ronga, D. Salerno, Y. Yang

National Central University, Chung-Li, Taiwan

M. Cardaci, K.H. Chen, T.H. Doan, Sh. Jain, R. Khurana, M. Konyushikhin, C.M. Kuo, W. Lin, Y.J. Lu, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

Arun Kumar, R. Bartek, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, P.H. Chen, C. Dietz, F. Fiori, U. Grundler, W.-S. Hou, Y. Hsiung, Y.F. Liu, R.-S. Lu, M. Miñano Moya, E. Petrakou, J.f. Tsai, Y.M. Tzeng

Chulalongkorn University, Faculty of Science, Department of Physics, Bangkok, Thailand

B. Asavapibhop, K. Kovitanggoon, G. Singh, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey

A. Adiguzel, M.N. Bakirci⁴⁷, S. Cerci⁴⁸, Z.S. Demiroglu, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, Y. Guler, E. Gurpinar, I. Hos, E.E. Kangal⁴⁹, G. Onengut⁵⁰, K. Ozdemir⁵¹, A. Polatoz, D. Sunar Cerci⁴⁸, M. Vergili, C. Zorbilmez

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, B. Bilin, S. Bilmis, B. Isildak⁵², G. Karapinar⁵³, M. Yalvac, M. Zeyrek

Bogazici University, Istanbul, TurkeyE.A. Albayrak⁵⁴, E. Gülmez, M. Kaya⁵⁵, O. Kaya⁵⁶, T. Yetkin⁵⁷**Istanbul Technical University, Istanbul, Turkey**K. Cankocak, S. Sen⁵⁸, F.I. Vardarli**Institute for Scintillation Materials of National Academy of Science of Ukraine, Kharkov, Ukraine**

B. Grynyov

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

L. Levchuk, P. Sorokin

University of Bristol, Bristol, United KingdomR. Aggleton, F. Ball, L. Beck, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, J. Jacob, L. Kreczko, C. Lucas, Z. Meng, D.M. Newbold⁵⁹, S. Paramesvaran, A. Poll, T. Sakuma, S. Seif El Nasr-storey, S. Senkin, D. Smith, V.J. Smith**Rutherford Appleton Laboratory, Didcot, United Kingdom**K.W. Bell, A. Belyaev⁶⁰, C. Brew, R.M. Brown, D. Cieri, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, E. Olaiya, D. Petyt, C.H. Shepherd-Themistocleous, A. Thea, I.R. Tomalin, T. Williams, W.J. Womersley, S.D. Worm**Imperial College, London, United Kingdom**M. Baber, R. Bainbridge, O. Buchmuller, A. Bundock, D. Burton, S. Casasso, M. Citron, D. Colling, L. Corpe, N. Cripps, P. Dauncey, G. Davies, A. De Wit, M. Della Negra, P. Dunne, A. Elwood, W. Ferguson, J. Fulcher, D. Futyan, G. Hall, G. Iles, M. Kenzie, R. Lane, R. Lucas⁵⁹, L. Lyons, A.-M. Magnan, S. Malik, J. Nash, A. Nikitenko⁴⁵, J. Pela, M. Pesaresi, K. Petridis, D.M. Raymond, A. Richards, A. Rose, C. Seez, A. Tapper, K. Uchida, M. Vazquez Acosta⁶¹, T. Virdee, S.C. Zenz**Brunel University, Uxbridge, United Kingdom**

J.E. Cole, P.R. Hobson, A. Khan, P. Kyberd, D. Leggat, D. Leslie, I.D. Reid, P. Symonds, L. Teodorescu, M. Turner

Baylor University, Waco, U.S.A.

A. Borzou, K. Call, J. Dittmann, K. Hatakeyama, A. Kasmi, H. Liu, N. Pastika

The University of Alabama, Tuscaloosa, U.S.A.

O. Charaf, S.I. Cooper, C. Henderson, P. Rumerio

Boston University, Boston, U.S.A.

A. Avetisyan, T. Bose, C. Fantasia, D. Gastler, P. Lawson, D. Rankin, C. Richardson, J. Rohlf, J. St. John, L. Sulak, D. Zou

Brown University, Providence, U.S.A.

J. Alimena, E. Berry, S. Bhattacharya, D. Cutts, N. Dhir, A. Ferapontov, A. Garabedian, J. Hakala, U. Heintz, E. Laird, G. Landsberg, Z. Mao, M. Narain, S. Piperov, S. Sagir, T. Sinthuprasith, R. Syarif

University of California, Davis, Davis, U.S.A.

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, R. Erbacher, M. Gardner, W. Ko, R. Lander, M. Mulhearn, D. Pellett, J. Pilot, F. Ricci-Tam, S. Shalhout, J. Smith, M. Squires, D. Stolp, M. Tripathi, S. Wilbur, R. Yohay

University of California, Los Angeles, U.S.A.

R. Cousins, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, D. Saltzberg, E. Takasugi, V. Valuev, M. Weber

University of California, Riverside, Riverside, U.S.A.

K. Burt, R. Clare, J. Ellison, J.W. Gary, G. Hanson, J. Heilman, M. Iova PANEVA, P. Jandir, E. Kennedy, F. Lacroix, O.R. Long, A. Luthra, M. Malberti, M. Olmedo Negrete, A. Shrinivas, H. Wei, S. Wimpenny, B. R. Yates

University of California, San Diego, La Jolla, U.S.A.

J.G. Branson, G.B. Cerati, S. Cittolin, R.T. D’Agnolo, A. Holzner, R. Kelley, D. Klein, J. Letts, I. Macneill, D. Olivito, S. Padhi, M. Pieri, M. Sani, V. Sharma, S. Simon, M. Tadel, A. Vartak, S. Wasserbaech⁶², C. Welke, F. Würthwein, A. Yagil, G. Zevi Della Porta

University of California, Santa Barbara, Santa Barbara, U.S.A.

D. Barge, J. Bradmiller-Feld, C. Campagnari, A. Dishaw, V. Dutta, K. Flowers, M. Franco Sevilla, P. Geffert, C. George, F. Golf, L. Gouskos, J. Gran, J. Incandela, C. Justus, N. Mccoll, S.D. Mullin, J. Richman, D. Stuart, I. Suarez, W. To, C. West, J. Yoo

California Institute of Technology, Pasadena, U.S.A.

D. Anderson, A. Apresyan, A. Bornheim, J. Bunn, Y. Chen, J. Duarte, A. Mott, H.B. Newman, C. Pena, M. Pierini, M. Spiropulu, J.R. Vlimant, S. Xie, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, U.S.A.

M.B. Andrews, V. Azzolini, A. Calamba, B. Carlson, T. Ferguson, M. Paulini, J. Russ, M. Sun, H. Vogel, I. Vorobiev

University of Colorado Boulder, Boulder, U.S.A.

J.P. Cumalat, W.T. Ford, A. Gaz, F. Jensen, A. Johnson, M. Krohn, T. Mulholland, U. Nauenberg, K. Stenson, S.R. Wagner

Cornell University, Ithaca, U.S.A.

J. Alexander, A. Chatterjee, J. Chaves, J. Chu, S. Dittmer, N. Eggert, N. Mirman, G. Nicolas Kaufman, J.R. Patterson, A. Rinkevicius, A. Ryd, L. Skinnari, L. Soffi, W. Sun, S.M. Tan, W.D. Teo, J. Thom, J. Thompson, J. Tucker, Y. Weng, P. Wittich

Fermi National Accelerator Laboratory, Batavia, U.S.A.

S. Abdullin, M. Albrow, J. Anderson, G. Apollinari, S. Banerjee, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, G. Bolla, K. Burkett, J.N. Butler, H.W.K. Cheung, F. Chlebana, S. Cihangir, V.D. Elvira, I. Fisk, J. Freeman, E. Gottschalk, L. Gray, D. Green, S. Grünendahl, O. Gutsche, J. Hanlon, D. Hare, R.M. Harris, S. Hasegawa, J. Hirschauer, Z. Hu, S. Jindariani, M. Johnson, U. Joshi, A.W. Jung, B. Klima, B. Kreis, S. Kwan[†], S. Lammel, J. Linacre, D. Lincoln, R. Lipton, T. Liu, R. Lopes De Sá, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, P. Merkel, K. Mishra, S. Mrenna, S. Nahn, C. Newman-Holmes, V. O'Dell, K. Pedro, O. Prokofyev, G. Rakness, E. Sexton-Kennedy, A. Soha, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, C. Vernieri, M. Verzocchi, R. Vidal, H.A. Weber, A. Whitbeck, F. Yang

University of Florida, Gainesville, U.S.A.

D. Acosta, P. Avery, P. Bortignon, D. Bourilkov, A. Carnes, M. Carver, D. Curry, S. Das, G.P. Di Giovanni, R.D. Field, I.K. Furic, J. Hugon, J. Konigsberg, A. Korytov, J.F. Low, P. Ma, K. Matchev, H. Mei, P. Milenovic⁶³, G. Mitselmakher, D. Rank, R. Rossin, L. Shchutska, M. Snowball, D. Sperka, N. Terentyev, L. Thomas, J. Wang, S. Wang, J. Yelton

Florida International University, Miami, U.S.A.

S. Hewamanage, S. Linn, P. Markowitz, G. Martinez, J.L. Rodriguez

Florida State University, Tallahassee, U.S.A.

A. Ackert, J.R. Adams, T. Adams, A. Askew, J. Bochenek, B. Diamond, J. Haas, S. Hagopian, V. Hagopian, K.F. Johnson, A. Khatiwada, H. Prosper, M. Weinberg

Florida Institute of Technology, Melbourne, U.S.A.

M.M. Baarmand, V. Bhopatkar, M. Hohlmann, H. Kalakhety, D. Noonan, T. Roy, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, U.S.A.

M.R. Adams, L. Apanasevich, D. Berry, R.R. Betts, I. Bucinskaite, R. Cavanaugh, O. Evdokimov, L. Gauthier, C.E. Gerber, D.J. Hofman, P. Kurt, C. O'Brien, I.D. Sandoval Gonzalez, C. Silkworth, P. Turner, N. Varelas, Z. Wu, M. Zakaria

The University of Iowa, Iowa City, U.S.A.

B. Bilki⁶⁴, W. Clarida, K. Dilsiz, S. Durgut, R.P. Gandrajula, M. Haytmyradov, V. Khristenko, J.-P. Merlo, H. Mermerkaya⁶⁵, A. Mestvirishvili, A. Moeller, J. Nachtman, H. Ogul, Y. Onel, F. Ozok⁵⁴, A. Penzo, C. Snyder, P. Tan, E. Tiras, J. Wetzel, K. Yi

Johns Hopkins University, Baltimore, U.S.A.

I. Anderson, B.A. Barnett, B. Blumenfeld, N. Eminizer, D. Fehling, L. Feng, A.V. Gritsan, P. Maksimovic, C. Martin, M. Osherson, J. Roskes, A. Sady, U. Sarica, M. Swartz, M. Xiao, Y. Xin, C. You

The University of Kansas, Lawrence, U.S.A.

P. Baringer, A. Bean, G. Benelli, C. Bruner, R.P. Kenny III, D. Majumder, M. Malek, M. Murray, S. Sanders, R. Stringer, Q. Wang

Kansas State University, Manhattan, U.S.A.

A. Ivanov, K. Kaadze, S. Khalil, M. Makouski, Y. Maravin, A. Mohammadi, L.K. Saini, N. Skhirtladze, S. Toda

Lawrence Livermore National Laboratory, Livermore, U.S.A.

D. Lange, F. Rebassoo, D. Wright

University of Maryland, College Park, U.S.A.

C. Anelli, A. Baden, O. Baron, A. Belloni, B. Calvert, S.C. Eno, C. Ferraioli, J.A. Gomez, N.J. Hadley, S. Jabeen, R.G. Kellogg, T. Kolberg, J. Kunkle, Y. Lu, A.C. Mignerey, Y.H. Shin, A. Skuja, M.B. Tonjes, S.C. Tonwar

Massachusetts Institute of Technology, Cambridge, U.S.A.

A. Apyan, R. Barbieri, A. Baty, K. Bierwagen, S. Brandt, W. Busza, I.A. Cali, Z. Demiragli, L. Di Matteo, G. Gomez Ceballos, M. Goncharov, D. Gulhan, Y. Iiyama, G.M. Innocenti, M. Klute, D. Kovalskyi, Y.S. Lai, Y.-J. Lee, A. Levin, P.D. Luckey, A.C. Marini, C. Mcginn, C. Mironov, X. Niu, C. Paus, D. Ralph, C. Roland, G. Roland, J. Salfeld-Nebgen, G.S.F. Stephans, K. Sumorok, M. Varma, D. Velicanu, J. Veverka, J. Wang, T.W. Wang, B. Wyslouch, M. Yang, V. Zhukova

University of Minnesota, Minneapolis, U.S.A.

B. Dahmes, A. Evans, A. Finkel, A. Gude, P. Hansen, S. Kalafut, S.C. Kao, K. Klapoetke, Y. Kubota, Z. Lesko, J. Mans, S. Nourbakhsh, N. Ruckstuhl, R. Rusack, N. Tambe, J. Turkewitz

University of Mississippi, Oxford, U.S.A.

J.G. Acosta, S. Oliveros

University of Nebraska-Lincoln, Lincoln, U.S.A.

E. Avdeeva, K. Bloom, S. Bose, D.R. Claes, A. Dominguez, C. Fangmeier, R. Gonzalez Suarez, R. Kamalieddin, J. Keller, D. Knowlton, I. Kravchenko, J. Lazo-Flores, F. Meier, J. Monroy, F. Ratnikov, J.E. Siado, G.R. Snow

State University of New York at Buffalo, Buffalo, U.S.A.

M. Alyari, J. Dolen, J. George, A. Godshalk, C. Harrington, I. Iashvili, J. Kaisen, A. Kharchilava, A. Kumar, S. Rappoccio

Northeastern University, Boston, U.S.A.

G. Alverson, E. Barberis, D. Baumgartel, M. Chasco, A. Hortiangtham, A. Massironi, D.M. Morse, D. Nash, T. Orimoto, R. Teixeira De Lima, D. Trocino, R.-J. Wang, D. Wood, J. Zhang

Northwestern University, Evanston, U.S.A.

K.A. Hahn, A. Kubik, N. Mucia, N. Odell, B. Pollack, A. Pozdnyakov, M. Schmitt, S. Stoynev, K. Sung, M. Trovato, M. Velasco

University of Notre Dame, Notre Dame, U.S.A.

A. Brinkerhoff, N. Dev, M. Hildreth, C. Jessop, D.J. Karmgard, N. Kellams, K. Lannon, S. Lynch, N. Marinelli, F. Meng, C. Mueller, Y. Musienko³⁶, T. Pearson, M. Planer, A. Reinsvold, R. Ruchti, G. Smith, S. Taroni, N. Valls, M. Wayne, M. Wolf, A. Woodard

The Ohio State University, Columbus, U.S.A.

L. Antonelli, J. Brinson, B. Bylsma, L.S. Durkin, S. Flowers, A. Hart, C. Hill, R. Hughes, W. Ji, K. Kotov, T.Y. Ling, B. Liu, W. Luo, D. Puigh, M. Rodenburg, B.L. Winer, H.W. Wulsin

Princeton University, Princeton, U.S.A.

O. Driga, P. Elmer, J. Hardenbrook, P. Hebda, S.A. Koay, P. Lujan, D. Marlow, T. Medvedeva, M. Mooney, J. Olsen, C. Palmer, P. Piroué, X. Quan, H. Saka, D. Stickland, C. Tully, J.S. Werner, A. Zuranski

University of Puerto Rico, Mayaguez, U.S.A.

S. Malik

Purdue University, West Lafayette, U.S.A.

V.E. Barnes, D. Benedetti, D. Bortoletto, L. Gutay, M.K. Jha, M. Jones, K. Jung, D.H. Miller, N. Neumeister, B.C. Radburn-Smith, X. Shi, I. Shipsey, D. Silvers, J. Sun, A. Svyatkovskiy, F. Wang, W. Xie, L. Xu

Purdue University Calumet, Hammond, U.S.A.

N. Parashar, J. Stupak

Rice University, Houston, U.S.A.

A. Adair, B. Akgun, Z. Chen, K.M. Ecklund, F.J.M. Geurts, M. Guilbaud, W. Li, B. Michlin, M. Northup, B.P. Padley, R. Redjimi, J. Roberts, J. Rorie, Z. Tu, J. Zabel

University of Rochester, Rochester, U.S.A.

B. Betchart, A. Bodek, P. de Barbaro, R. Demina, Y. Eshaq, T. Ferbel, M. Galanti, A. Garcia-Bellido, J. Han, A. Harel, O. Hindrichs, A. Khukhunaishvili, G. Petrillo, M. Verzetti

The Rockefeller University, New York, U.S.A.

L. Demortier

Rutgers, The State University of New Jersey, Piscataway, U.S.A.

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Dugan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, E. Hughes, S. Kaplan, R. Kunnawalkam Elayavalli, A. Lath, K. Nash, S. Panwalkar, M. Park, S. Salur, S. Schnetzer, D. Sheffield, S. Somalwar, R. Stone, S. Thomas, P. Thomassen, M. Walker

University of Tennessee, Knoxville, U.S.A.

M. Foerster, G. Riley, K. Rose, S. Spanier, A. York

Texas A&M University, College Station, U.S.A.

O. Bouhali⁶⁶, A. Castaneda Hernandez⁶⁶, M. Dalchenko, M. De Mattia, A. Delgado, S. Dildick, R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁷, V. Krutelyov, R. Mueller, I. Osipenkov, Y. Pakhotin, R. Patel, A. Perloff, A. Rose, A. Safonov, A. Tatarinov, K.A. Ulmer²

Texas Tech University, Lubbock, U.S.A.

N. Akchurin, C. Cowden, J. Damgov, C. Dragoiu, P.R. Duderov, J. Faulkner, S. Kunori, K. Lamichhane, S.W. Lee, T. Libeiro, S. Undleeb, I. Volobouev

Vanderbilt University, Nashville, U.S.A.

E. Appelt, A.G. Delannoy, S. Greene, A. Gurrola, R. Janjam, W. Johns, C. Maguire, Y. Mao, A. Melo, H. Ni, P. Sheldon, B. Snook, S. Tuo, J. Velkovska, Q. Xu

University of Virginia, Charlottesville, U.S.A.

M.W. Arenton, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, H. Li, C. Lin, C. Neu, X. Sun, Y. Wang, E. Wolfe, J. Wood, F. Xia

Wayne State University, Detroit, U.S.A.

C. Clarke, R. Harr, P.E. Karchin, C. Kottachchi Kankanamge Don, P. Lamichhane, J. Sturdy

University of Wisconsin, Madison, U.S.A.

D.A. Belknap, D. Carlsmith, M. Cepeda, A. Christian, S. Dasu, L. Dodd, S. Duric, E. Friis, B. Gomber, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, A. Lanaro, A. Levine, K. Long, R. Loveless, A. Mohapatra, I. Ojalvo, T. Perry, G.A. Pierro, G. Polese, T. Ruggles, T. Sarangi, A. Savin, A. Sharma, N. Smith, W.H. Smith, D. Taylor, N. Woods

†: Deceased

1: Also at Vienna University of Technology, Vienna, Austria

2: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland

3: Also at State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

4: Also at Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

5: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

6: Also at Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia

7: Also at Universidade Estadual de Campinas, Campinas, Brazil

8: Also at Centre National de la Recherche Scientifique (CNRS) - IN2P3, Paris, France

9: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France

10: Also at Joint Institute for Nuclear Research, Dubna, Russia

11: Also at Helwan University, Cairo, Egypt

12: Now at Zewail City of Science and Technology, Zewail, Egypt

13: Also at Beni-Suef University, Bani Sweif, Egypt

14: Now at British University in Egypt, Cairo, Egypt

15: Now at Ain Shams University, Cairo, Egypt

- 16: Also at Université de Haute Alsace, Mulhouse, France
- 17: Also at Tbilisi State University, Tbilisi, Georgia
- 18: Also at University of Hamburg, Hamburg, Germany
- 19: Also at Brandenburg University of Technology, Cottbus, Germany
- 20: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
- 21: Also at Eötvös Loránd University, Budapest, Hungary
- 22: Also at University of Debrecen, Debrecen, Hungary
- 23: Also at Wigner Research Centre for Physics, Budapest, Hungary
- 24: Also at University of Visva-Bharati, Santiniketan, India
- 25: Now at King Abdulaziz University, Jeddah, Saudi Arabia
- 26: Also at University of Ruhuna, Matara, Sri Lanka
- 27: Also at Isfahan University of Technology, Isfahan, Iran
- 28: Also at University of Tehran, Department of Engineering Science, Tehran, Iran
- 29: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran
- 30: Also at Università degli Studi di Siena, Siena, Italy
- 31: Also at Purdue University, West Lafayette, U.S.A.
- 32: Also at International Islamic University of Malaysia, Kuala Lumpur, Malaysia
- 33: Also at Malaysian Nuclear Agency, MOSTI, Kajang, Malaysia
- 34: Also at Consejo Nacional de Ciencia y Tecnología, Mexico city, Mexico
- 35: Also at Warsaw University of Technology, Institute of Electronic Systems, Warsaw, Poland
- 36: Also at Institute for Nuclear Research, Moscow, Russia
- 37: Also at St. Petersburg State Polytechnical University, St. Petersburg, Russia
- 38: Also at National Research Nuclear University 'Moscow Engineering Physics Institute' (MEPhI), Moscow, Russia
- 39: Also at California Institute of Technology, Pasadena, U.S.A.
- 40: Also at Faculty of Physics, University of Belgrade, Belgrade, Serbia
- 41: Also at Facoltà Ingegneria, Università di Roma, Roma, Italy
- 42: Also at National Technical University of Athens, Athens, Greece
- 43: Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy
- 44: Also at University of Athens, Athens, Greece
- 45: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
- 46: Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland
- 47: Also at Gaziosmanpasa University, Tokat, Turkey
- 48: Also at Adiyaman University, Adiyaman, Turkey
- 49: Also at Mersin University, Mersin, Turkey
- 50: Also at Cag University, Mersin, Turkey
- 51: Also at Piri Reis University, Istanbul, Turkey
- 52: Also at Ozyegin University, Istanbul, Turkey
- 53: Also at Izmir Institute of Technology, Izmir, Turkey
- 54: Also at Mimar Sinan University, Istanbul, Istanbul, Turkey
- 55: Also at Marmara University, Istanbul, Turkey
- 56: Also at Kafkas University, Kars, Turkey
- 57: Also at Yildiz Technical University, Istanbul, Turkey
- 58: Also at Hacettepe University, Ankara, Turkey
- 59: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
- 60: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom

- 61: Also at Instituto de Astrofísica de Canarias, La Laguna, Spain
- 62: Also at Utah Valley University, Orem, U.S.A.
- 63: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
- 64: Also at Argonne National Laboratory, Argonne, U.S.A.
- 65: Also at Erzincan University, Erzincan, Turkey
- 66: Also at Texas A&M University at Qatar, Doha, Qatar
- 67: Also at Kyungpook National University, Daegu, Korea