Search for heavy bottom-like quarks in $4.9\,\mathrm{fb}^{-1}$ of pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$

The CMS collaboration

ABSTRACT: Results are presented from a search for heavy bottom-like quarks, pair-produced in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$, undertaken with the CMS experiment at the LHC. The b′ quarks are assumed to decay exclusively to tW. The $\mathrm{b'\overline{b}'} \to \mathrm{tW^-\overline{t}W^+}$ process can be identified by its distinctive signatures of three leptons or two leptons of same charge, and at least one b-quark jet. Using a data sample corresponding to an integrated luminosity of $4.9\,\mathrm{fb}^{-1}$, observed events are compared to the standard model background predictions, and the existence of b′ quarks having masses below $611\,\mathrm{GeV}/c^2$ is excluded at 95% confidence level.

JHEP05(2012)123

Contents

1 Introduction

The total number of fermion generations is assumed to be three in the standard model (SM), though the model does not provide an explanation of why this should be the case. Thus the possible existence of a fourth generation remains an important subject for experimental investigation. Adding a fourth generation of massive fermions to the model may strongly affect the Higgs and flavour sectors [1–5]. A fourth generation of heavy quarks would enhance the production of Higgs bosons [6], while the indirect bound from electroweak precision data on the Higgs mass would be relaxed [7, 8]. Additional massive quarks may provide a key to understanding the matter-antimatter asymmetry in the universe [9].

Various searches for fourth-generation fermions have already been reported. Experiments have shown that the number of light neutrino flavours is equal to three [10–13], but the possibility of additional heavier neutrinos has not been excluded. A search for pair-produced bottom-like quarks (b′) by the ATLAS collaboration excludes a b′-quark mass of less than $480\,\mathrm{GeV}/c^2$ [14]. Earlier studies setting mass limits on possible fourth-generation quarks, from experiments at the Tevatron and the Large Hadron Collider (LHC), can be found in ref. [15–21].

Using the Compact Muon Solenoid (CMS) detector, we have searched for a heavy b′ quark that is pair-produced in pp collisions at a centre-of-mass energy of 7 TeV at the LHC. We assume that the mass of the b′ quark $(M_{b'})$ is larger than the sum of the top quark and the W-boson masses. If the b′ quark couples principally to the top quark, the decay chain $b'\overline{b}' \to tW^-\overline{t}W^+ \to bW^+W^-\overline{b}W^-W^+$ will dominate [22]. Given the 11% branching fraction for a W-boson to each lepton, distinctive signatures of $b'\overline{b}'$ production

are expected, specifically those of two isolated leptons with the same charge ("same-charge dileptons") or three isolated leptons ("trileptons"). Although occurring very rarely in the standard model, these two signatures may be present in 7.3% of the $b'\overline{b}'$ events. An earlier search by CMS [17] in the same-charge dilepton and the trilepton channels, utilizing a data set corresponding to an integrated luminosity of $34\,\mathrm{pb}^{-1}$, set a lower limit on the mass of the b' quark of $361\,\mathrm{GeV}/c^2$ at the 95% confidence level (CL). Here we present an update of this search using a much larger data set, corresponding to an integrated luminosit of $4.9\,\mathrm{fb}^{-1}$.

2 CMS detector and trigger

This analysis is based on the data recorded by the CMS experiment in 2011. The central feature of the CMS detector is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. Charged-particle trajectories are determined using silicon pixel and silicon strip tracker measurements. A crystal electromagnetic calorimeter, including lead-silicon preshower detectors in the forward directions, together with a surrounding brass/scintillator hadronic calorimeter, encloses the tracking volume and provides energy measurements of electrons and hadronic jets. Muons are identified and measured in the tracker and in gas-ionization detectors embedded in the steel return yoke outside the solenoid. The detector is nearly hermetic, providing measurements of any imbalance of momentum in the plane transverse to the beam direction. A more detailed description of the CMS detector can be found in ref. [23].

A two-level trigger system [24] selects events for further analysis. The events analyzed in this search are collected with the requirement that the trigger system detects at least two lepton candidates. Efficiencies for these dilepton triggers are determined using events that pass a jet trigger, have two reconstructed electrons or muons, and that also pass the full selection criteria described in the next section. For these selected events, the dilepton trigger efficiencies are estimated to be 91%, 96%, and >99%, for events with two muons, one electron and one muon, and two electrons, respectively.

3 Selection criteria

The use of the CMS particle-flow global event reconstruction procedure [25–28] has been extended beyond its application in ref. [17]. In the present analysis, all physics objects — leptons, jets, and missing transverse energy - are reconstructed with this procedure. The reconstruction and selection criteria for each physics object used in this analysis are described below.

Candidate muons are reconstructed through a global fit to trajectories, using hit signals in the inner tracker and in the muon system. Muons are required to have transverse momenta $p_T > 20\,\mathrm{GeV}/c$ and $|\eta| < 2.4$, where the pseudorapidity $\eta = -\ln[\tan\theta/2]$ and θ is the polar angle relative to the anticlockwise beam direction. The muon candidate must be associated with hits in the silicon pixel and strip detectors, have segments in the muon chambers, and provide a high-quality global fit to the track segments. The efficiency for these muon selection criteria is >99% from Z decays [29]. In addition, the muon track is

required to be consistent with originating from the principal primary interaction vertex, which is defined by the one associated with tracks yielding the largest value for the sum of their p_T^2.

Reconstruction of electron candidates starts from clusters of energy deposits in the ECAL, which are then matched to hits in the silicon tracker. Electron candidates are required to have $p_T > 20$ GeV/c. Candidates are required to be reconstructed in the fiducial volume of the barrel ($|\eta| < 1.44$) or in the end-caps ($1.57 < |\eta| < 2.4$). The electron candidate track is required to be consistent with originating from the principal primary interaction vertex. Electrons are identified using variables which include the ratio between the energies deposited in the HCAL and the ECAL, the shower width in η, and the distance between the calorimeter shower and the particle trajectory in the tracker, measured in both η and azimuthal angle (ϕ). The selection criteria are optimized [30] to reject the background from hadronic jets while maintaining an efficiency of 80% for the electrons from W or Z decays.

Jets are reconstructed by an anti-k_T jet-clustering algorithm with a distance parameter $R = 0.5$ [31]. Particle energies are calibrated [32] separately for each particle type, and resulting jet energies therefore require only small corrections that account for thresholds and residual inefficiencies. All jet candidates must have $p_T > 25$ GeV/c and be within $|\eta| < 2.4$. Neutrinos from W boson decays escape the detector, and thereby give rise to a significant imbalance in the net transverse momentum measured for each event. This missing transverse momentum, expressed as the quantity $\not{E}_T$, is defined as the absolute value of the vector sum of the transverse momenta of all reconstructed particles [33].

In contrast to the earlier analysis of ref. [17], b-tagging is now used to reject events from backgrounds that do not include a top-quark decay. The b-tagging algorithm applied in this analysis generates a list of tracks associated with each jet, and calculates the significance of each track's impact-parameter (IP), as determined by the ratio of the IP to its uncertainty. For the jet to be tagged as a b-jet, the IP significance of at least three of its listed tracks must exceed a threshold value, chosen to give an identification efficiency of 50% for b-jets and a misidentification rate of 1% for other particle jets [34].

Electrons and muons from W $\to \ell\nu$ ($\ell = $ e, μ) decays are expected to be isolated from other particles in the detector. A cone of $\Delta R < 0.3$, where $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, is constructed around each lepton-candidate's direction, and if the scalar sum of the transverse momenta of the particles inside the cone, excluding contributions from the lepton candidate, exceeds 15% of the candidate p_T, then the lepton candidate is rejected. Electron candidates are required to be separated from any selected muon candidates by $\Delta R > 0.1$ to remove misidentified electrons due to muon bremsstrahlung. Electron candidates identified as originating from photon conversions are also rejected.

Events are required to have at least one well-reconstructed interaction vertex [35]. Events with two leptons of the same electric charge, or with three leptons (two of which must be oppositely charged), are selected. For the same-charge dilepton (trilepton) channel, events with fewer than four (two) jets are rejected. At least one jet must be identified as a b-jet. In addition, events that have any two muons or electrons whose invariant mass $M_{\ell\ell}$ is within 10 GeV/c^2 of the Z-mass ($|M_{\ell\ell} - M_Z| < 10$ GeV/c^2) are rejected, in order

$M_{b'}$ [GeV/c^2]	Cross section [pb]	Same-charge dilepton efficiency [%]	yield	Trilepton efficiency [%]	yield
450	0.662	1.52 ± 0.13	49	0.47 ± 0.05	15
500	0.330	1.64 ± 0.14	26	0.51 ± 0.05	8.2
550	0.171	1.71 ± 0.14	14	0.56 ± 0.05	4.7
600	0.0923	1.69 ± 0.14	7.6	0.60 ± 0.06	2.7
650	0.0511	1.71 ± 0.15	4.3	0.63 ± 0.06	1.6

Table 1. Summary of expected $b'\overline{b}'$ cross sections [40], selection efficiencies, and yields for the two signal channels as a function of the b′ mass.

to suppress the background from $Z \to \ell^+\ell^-$ decays. For each event, the scalar quantity $S_T = \sum |\vec{p_T}(\text{jets})| + \sum |\vec{p_T}(\text{leptons})| + \not{E}_T$ is required to satisfy the condition $S_T > 500\,\text{GeV}$. The selection criteria described above are not fully optimized in terms of discovery reach, but in fact they are more robust because they have a single background component in the background estimation with data.

Signal selection efficiencies are estimated using simulated event samples. Fourth generation quarks production is implemented as a straightforward extension to the standard model configuration of the MADGRAPH/MADEVENT generator version 5.131 [36]. Parton showering and hadronization are provided by PYTHIA 6.424 [37] using the matching prescription described in ref. [38]. Finally, these generated signal events are passed through the CMS detector simulation based on GEANT4 [39].

Table 1 shows the expected efficiencies for a b′ signal, for $450 \leq M_{b'} \leq 650\,\text{GeV}/c^2$. The efficiencies vary between 1.5% and 1.7% for the same-charge dilepton channel, and between 0.47% and 0.63% for the trilepton events, in the chosen range of $M_{b'}$. These efficiencies include the branching fractions for W-decay and the b-tagging performance [34]. Jet multiplicities for the same-charge dilepton and the trilepton channels are shown in figure 1, and the S_T distributions are presented in figure 2. The expected distributions for a b′ signal having $M_{b'} = 500\,\text{GeV}/c^2$ are normalized to the production cross sections from ref. [40] that include approximate next-to-next-to-leading-order perturbative QCD corrections, and standard QCD couplings are assumed.

4 Background estimation

Because of the b-tagging requirement, 98% of the expected background events in the same-charge dilepton channel have at least one top quark from $t\overline{t}$, $t\overline{t} + W/Z$, or single-top processes. These backgrounds are categorized into three sources: (i) true $\ell^+\ell^-$ events with a electron of misidentified charge, (ii) single-lepton events with an extra misidentified or non-isolated lepton candidate, and (iii) events with two prompt leptons of the same charge. The contribution due to the charge misidentification of electrons is determined using a control sample that, while keeping the remaining signal selection criteria, has oppositely-
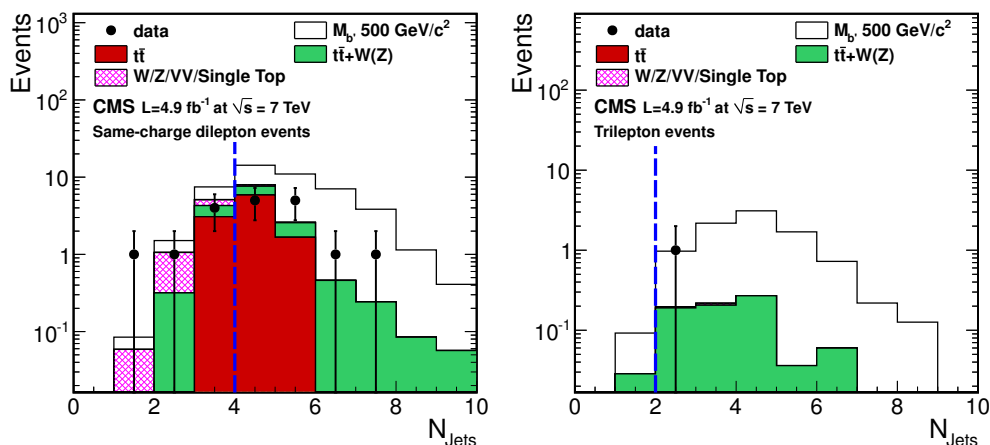
Figure 1. Jet multiplicity distributions for the same-charge dilepton channel (left), and the trilepton channel (right). The open histogram shows the contribution expected from a b′ having $M_{b'} = 500 \, \text{GeV}/c^2$. The contributions from standard model processes are normalized to the total estimated background. All selection criteria are applied except the one corresponding to the plotted variable. The vertical dotted lines indicate the minimum number of jets required in events selected for each of the channels.
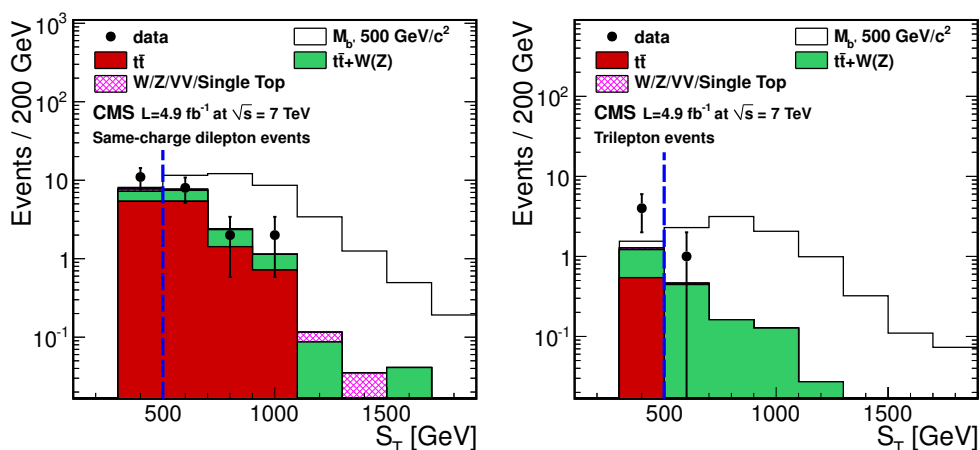

Figure 2. Distributions in S_{T}, the scalar sum of the transverse momenta of objects, in the same-charge dilepton channel (left), and the trilepton channel (right). The open histogram is the contribution expected from a b′ having $M_{b'} = 500 \, \text{GeV}/c^2$. The histograms for standard model processes are normalized to the total expected background. All selection criteria are applied except the one corresponding to the plotted variable. The vertical dotted line indicates the lower bound on S_{T} used in the analysis.

charged electron pairs or electrons and muons. The charge misidentification rate (0.03% and 0.31% for barrel and endcap candidates, respectively) is determined by counting the events containing two same-charge electron candidates, whose invariant mass is consistent with that of a Z-boson, relative to the yield of $Z \rightarrow e^+e^-$ events. Background from source (ii) is estimated as follows. Leptons passing the selection criteria described in section 3 for

signal are denoted as "tight", while muon candidates passing relaxed isolation thresholds and track-fit quality requirements, or electron candidates passing relaxed identification and isolation requirements, are referred to as "loose". Tight lepton candidates are excluded from the selection of loose lepton candidates. The background from events containing a false or non-isolated lepton candidate is estimated using another data control sample containing one tight lepton candidate and one loose lepton candidate, with the remaining selection criteria kept identical to those used for the signal sample. By definition, this control sample excludes events in the signal sample. The contributions of the backgrounds in the selected events are calculated using the yields observed in the control sample multiplied by the ratio of the number of lepton candidates passing tight selection criteria to those passing the loose criteria. This ratio, also determined in data, is calculated as the number of events containing one loose and one tight lepton candidate divided by the number of those containing two loose lepton candidates. Applying the above methods to data, a background yield of 7.8 ± 2.8 events is estimated to originate from sources (i) and (ii).

The estimated yield to the same-charge dilepton channel from processes that produce prompt same-charge dileptons, including $t\bar{t} + Z$, $t\bar{t} + W$, and diboson channels (WZ, ZZ, and same-charge $W^{\pm}W^{\pm}$+jets), is determined using simulations of these processes. The contribution in the signal region is estimated to be 3.6 ± 0.6 events.

For the trilepton channel, the background is an order of magnitude smaller than for the same-charge dilepton channel, and is dominated by processes that produce three prompt leptons, such as $t\bar{t} + W/Z$. The yield in the signal region, which is only 0.78 ± 0.21 events, is estimated using simulated samples. Contributions from $pp \to t\bar{t}$ and W/Z processes are normalized to the cross sections measured by CMS [41, 42]. The single-top contributions are normalized to the next-to-next-to-leading-logarithm cross sections [43, 44]. Production rates for dibosons are estimated from the next-to-leading-order cross sections given by MCFM [45]. The $t\bar{t} + W/Z$ and same-charge $W^{\pm}W^{\pm}$+jets processes are normalized to the next-to-leading-order cross sections given in ref. [46].

The multijet background contribution is estimated using a control sample of events containing two (three) loose lepton candidates for the same-charge dilepton (trilepton) channel, maintaining other selection criteria. The yield of multijet events in the signal region is calculated by multiplying the yield observed in the control sample by the ratio squared (cubed) of the number of lepton candidates passing tight selection to the number passing loose selection. The contribution of multijet events to the signal region is estimated to be smaller than 0.12 (0.001) events for the same-charge dilepton (trilepton) channel, and thus is negligible compared to contributions from the other background processes.

5   Systematic uncertainties

To validate the procedure for estimating background, and to assign a proper systematic uncertainty, the study in the same-charge dilepton channel is repeated using a mixture of simulated samples representing the potential background sources. The full estimation procedure is then applied to the simulated samples, and results are compared to the input values. The observed difference (2.7 ± 0.9 events) is included as a systematic un-

certainty. The statistical uncertainties in the control samples are also included in the systematic uncertainties.

The following uncertainties are included in both dilepton and trilepton channels. The b-tagging efficiency as measured in data has a precision of 10% per b-jet [34], resulting in a 6.7% uncertainty in the efficiency of signal samples. The effect of this uncertainty on the background contributions determined using simulated samples is estimated to be 0.35 (0.08) events for the dilepton (trilepton) channel. Lepton selection efficiencies are measured using inclusive $Z \to \ell^+\ell^-$ data, and the difference between efficiencies measured in data and simulation is taken as a systematic uncertainty. An additional systematic uncertainty of 50% of the difference in efficiency between simulated Z and b′ samples is included, to cover the effects of different event topologies. This estimation yields uncertainties of 1.7% and 2.7% for electrons and muons, respectively. The uncertainty in signal efficiency, calculated using appropriate weighting of the electron and muon contributions, is 3.3% (5.0%) for the dilepton (trilepton) channel.

The uncertainties in the background normalization are estimated to be 0.74 and 0.12 events for dilepton and trilepton channels, respectively, and the uncertainties for each of the individual processes are included as follows: $\pm11\%$ for $t\bar{t}$ [41], $\pm3\%$ ($\pm4\%$) for W (Z) [42], $\pm30\%$ for single top processes, $\pm26\%$ for WW, $\pm30\%$ for WZ, $\pm21\%$ for ZZ, $\pm30\%$ for ttW, $\pm30\%$ for ttZ, $\pm49\%$ for $W^{\pm}W^{\pm}$+jets, and $\pm100\%$ for multijet. The uncertainties in the normalization of diboson, ttW, ttZ, and $W^{\pm}W^{\pm}$+jets processes are taken from a comparison of next-to-leading-order and leading-order predictions. The uncertainty related to the presence of additional interactions (pile-up) in the same beam crossing interval as an event is examined by varying the number of such interactions included in the simulations. The systematic effects of the uncertainties in jet-energy-scale, jet resolution, $\not{E}_{\mathrm{T}}$ resolution, pile-up events, and trigger efficiency are found to be small [32, 33]. Uncertainty sets given by CTEQ6 [47] are used to determine the uncertainties from the choice of parton distribution functions. The relative uncertainty in the integrated luminosity measurement is estimated to be 2.2% [48], and is included in the calculation of limits. The details of uncertainties in the signal selection efficiency and in the background estimation are presented in table 2.

6 Results

There are 12 (1) events found in the signal region for the dilepton (trilepton) channel, to be compared with an estimated background of 11.4 ± 2.9 (0.78 ± 0.21) (table 3).

Most of the background sources contain at least one top quark in the final state, with a b-quark produced in the top quark decay. Therefore, modifying the required number of b-tagged jets, in a separate study, provides a good check of the analysis. The observed yields when requiring ≥ 0, ≥ 1, or ≥ 2 b-tagged jets are consistent with the estimated background, and in agreement with the expected dominance of background from top quarks.

For each b′ mass hypothesis, cross sections, selection efficiencies, and associated uncertainties are estimated (tables 1 and 2). From these values, the estimated background yield, and the number of observed events, upper limits on b′$\overline{\mathrm{b}}$′ pair production cross sections at 95% CL are derived, using a modified frequentist approach (CL_s) [49]. These limits are

	Same-charge dilepton		Trilepton	
	$\Delta\epsilon/\epsilon$ [%]	ΔB	$\Delta\epsilon/\epsilon$ [%]	ΔB
Accuracy of control-sample method	—	2.63	—	—
Control sample statistics	—	0.76	—	—
b-tagging	6.7	0.35	6.7	0.08
Lepton selection	3.3	0.03	4.9–5.1	0.04
Background normalization	—	0.74	—	0.12
Pile-up events	0.5	0.13	0.6	0.03
Jet energy scale	1.1–2.0	0.31	0.3–1.0	0.02
Jet energy resolution	0.3–1.4	0.22	0.3–0.9	0.02
Missing energy resolution	0.1–0.7	0.38	0.1 — 2.2	0.07
Trigger	1.4	0.11	0.7	0.01
PDF	0.4–1.9	0.26	0.4–1.3	0.03
Simulated sample statistics	2.7–3.4	0.26	4.5–6.5	0.12
Integrated luminosity	2.2	0.24	2.2	0.05
Total	8.6–9.0	2.9	10–11	0.21

Table 2. Summary of relative systematic uncertainties in signal selection efficiencies ($\Delta\epsilon/\epsilon$) and the absolute systematic uncertainties in the number of expected background events (ΔB). The ranges given below represent the dependence on $M_{b'}$, varying from $450\,\mathrm{GeV}/c^2$ to $650\,\mathrm{GeV}/c^2$.

Sources	Same-charge dilepton	Trilepton
Same-charge dilepton with a charge-misidentified electron, or a misidentified or non-isolated lepton (from data)	7.8 ± 2.8	
Prompt same-charge dilepton, or trilepton (simulated)	3.6 ± 0.6	0.78 ± 0.21
Background sum	11.4 ± 2.9	0.78 ± 0.21
Observed yield in data	12	1

Table 3. Summary of the estimated background contributions to the same-charge dilepton channel and the trilepton channel, and the observed event yield in data. The given uncertainties are systematic.

plotted as the solid line in figure 3, while the dotted line represents the limits expected with the available integrated luminosity, assuming the presence of standard model processes alone. By comparing to the theoretical production cross section for pp $\rightarrow$ b′$\overline{\mathrm{b}}$′, a lower limit of $611\,\mathrm{GeV}/c^2$ is extracted for the mass of the b′ quark, at 95% CL, while a limit of $619\,\mathrm{GeV}/c^2$ is expected for a background-only hypothesis.
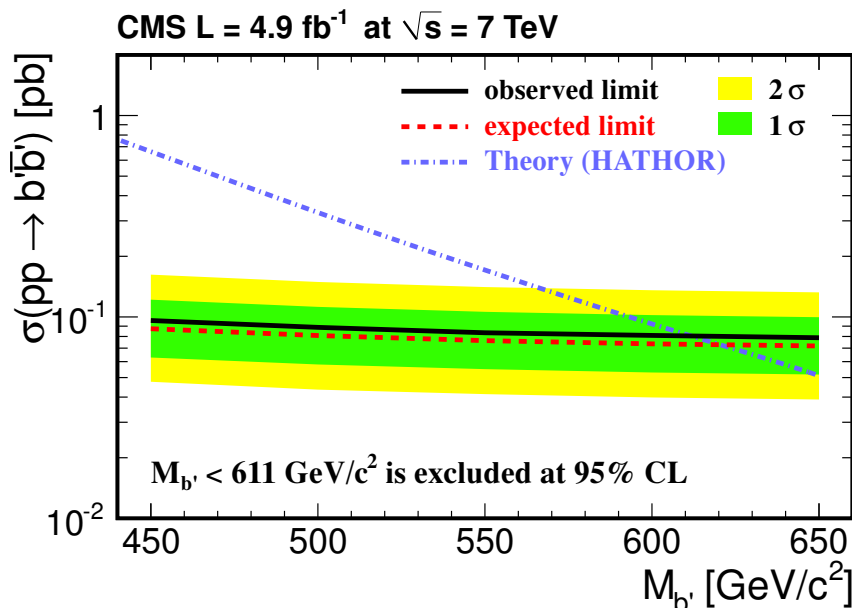
Figure 3. Exclusion limits at 95% CL on the pp $\to$ b$'\overline{\text{b}}'$ production cross section (σ). The solid line represents the observed limits, while the dotted line represents the limits expected for the available integrated luminosity, assuming the presence of standard model processes alone. A comparison with the production cross-sections excludes b$'$ masses $M_{\text{b}'} < 611\,\text{GeV}/c^2$ at 95% CL for a 100% b$' \to$ tW decay branching fraction.

7 Summary

Results have been presented from a search for heavy bottom-like quarks pair-produced in proton-proton collisions at $\sqrt{s} = 7\,\text{TeV}$. The process of pp $\to$ b$'\overline{\text{b}}' \to$ t$\overline{\text{t}}$W$^+$W$^-$ has been studied in data corresponding to an integrated luminosity of $4.9\,\text{fb}^{-1}$, collected with the CMS detector. Estimated background contributions have been found to be small, since final states containing the signatures of trileptons or same-charge dileptons are produced rarely in standard model processes. Assuming a branching fraction of 100% for the decay b$' \to$ tW, b$'$ quarks with masses below $611\,\text{GeV}/c^2$ are excluded at 95% CL. This is the most stringent limit to date.

Acknowledgments

References

[1] B. Holdom et al., *Four statements about the fourth generation*, *PMC Phys.* **A 3** (2009) 4 [arXiv:0904.4698] [INSPIRE].

[2] A. Soni, A.K. Alok, A. Giri, R. Mohanta and S. Nandi, *SM with four generations: selected implications for rare B and K decays*, *Phys. Rev.* **D 82** (2010) 033009 [arXiv:1002.0595] [INSPIRE].

[3] A.J. Buras et al., *Patterns of flavour violation in the presence of a fourth generation of quarks and leptons*, *JHEP* **09** (2010) 106 [arXiv:1002.2126] [INSPIRE].

[4] J. Erler and P. Langacker, *Precision constraints on extra fermion generations*, *Phys. Rev. Lett.* **105** (2010) 031801 [arXiv:1003.3211] [INSPIRE].

[5] C.J. Flacco, D. Whiteson, T.M. Tait and S. Bar-Shalom, *Direct mass limits for chiral fourth-generation quarks in all mixing scenarios*, *Phys. Rev. Lett.* **105** (2010) 111801 [arXiv:1005.1077] [INSPIRE].

[6] A. Denner et al., *Higgs production and decay with a fourth standard-model-like fermion generation*, arXiv:1111.6395 [INSPIRE].

[7] P.H. Frampton, P. Hung and M. Sher, *Quarks and leptons beyond the third generation*, *Phys. Rept.* **330** (2000) 263 [hep-ph/9903387] [INSPIRE].

[8] G.D. Kribs, T. Plehn, M. Spannowsky and T.M. Tait, *Four generations and Higgs physics*, *Phys. Rev.* **D 76** (2007) 075016 [arXiv:0706.3718] [INSPIRE].

[9] W.-S. Hou, *Source of CP-violation for the baryon asymmetry of the universe*, *Chin. J. Phys.* **47** (2009) 134 [arXiv:0803.1234] [INSPIRE].

[10] ALEPH collaboration, *Determination of the number of light neutrino species*, *Phys. Lett.* **B 231** (1989) 519 [INSPIRE].

[11] DELPHI collaboration, *Measurement of the mass and width of the Z^0 particle from multi-hadronic final states produced in e^+e^- annihilations*, *Phys. Lett.* **B 231** (1989) 539 [INSPIRE].

[12] L3 collaboration, *A determination of the properties of the neutral intermediate vector boson Z^0*, *Phys. Lett.* **B 231** (1989) 509 [INSPIRE].

[13] OPAL collaboration, *Measurement of the Z^0 mass and width with the OPAL detector at LEP*, *Phys. Lett.* **B 231** (1989) 530 [INSPIRE].

[14] ATLAS collaboration, G. Aad et al., *Search for down-type fourth generation quarks with the ATLAS detector in events with one lepton and high transverse momentum hadronically decaying W bosons in* $\sqrt{s} = 7$ *TeV pp collisions*, `arXiv:1202.6540` [INSPIRE].

[15] CDF collaboration, T. Aaltonen et al., *Search for new bottomlike quark pair decays* $Q\bar{Q} \rightarrow (tW^{\mp})(\bar{t}W^{\pm})$ *in same-charge dilepton events*, *Phys. Rev. Lett.* **104** (2010) 091801 [`arXiv:0912.1057`] [INSPIRE].

[16] THE CDF collaboration, T. Aaltonen et al., *Search for heavy bottom-like quarks decaying to an electron or muon and jets in* $p\bar{p}$ *collisions at* $\sqrt{s} = 1.96$ *TeV*, *Phys. Rev. Lett.* **106** (2011) 141803 [`arXiv:1101.5728`] [INSPIRE].

[17] CMS collaboration, S. Chatrchyan et al., *Search for a heavy bottom-like quark in pp collisions at* $\sqrt{s} = 7$ *TeV*, *Phys. Lett.* **B 701** (2011) 204 [`arXiv:1102.4746`] [INSPIRE].

[18] D0 collaboration, V.M. Abazov et al., *Search for a fourth generation t' quark in* $p\bar{p}$ *collisions at* $\sqrt{s} = 1.96$ *TeV*, `arXiv:1104.4522` [INSPIRE].

[19] ATLAS collaboration, G. Aad et al., *Search for pair-produced heavy quarks decaying to Wq in the two-lepton channel at* $\sqrt{s} = 7$ *TeV with the ATLAS detector*, `arXiv:1202.3389` [INSPIRE].

[20] ATLAS collaboration, G. Aad et al., *Search for pair production of a heavy quark decaying to a W boson and a b quark in the lepton+jets channel with the ATLAS detector*, submitted to *Phys. Rev. Lett.*, `arXiv:1202.3076` [INSPIRE].

[21] CMS collaboration, S. Chatrchyan et al., *Search for heavy, top-like quark pair production in the dilepton final state in pp collisions at* $\sqrt{s} = 7$ *TeV*, submitted to *Phys. Lett. B*, `arXiv:1203.5410` [INSPIRE].

[22] A. Arhrib and W.-S. Hou, *Flavor changing neutral currents involving heavy quarks with four generations*, *JHEP* **07** (2006) 009 [`hep-ph/0602035`] [INSPIRE].

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

[24] CMS TRIGGER AND DATA ACQUISITION GROUP collaboration, W. Adam et al., *The CMS high level trigger*, *Eur. Phys. J.* **C 46** (2006) 605 [`hep-ex/0512077`] [INSPIRE].

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

[26] CMS collaboration, *Commissioning of the Particle-flow Event Reconstruction with the first LHC collisions recorded in the CMS detector*, PAS-PFT-10-001 (2010).

[27] CMS collaboration, *Commissioning of the particle-flow reconstruction in minimum-bias and jet events from pp Collisions at* 7 *TeV*, PAS-PFT-10-002 (2010).

[28] CMS collaboration, *Commissioning of the particle-flow event reconstruction with leptons from* J/Ψ *and W decays at* 7 *TeV*, PAS-PFT-10-003 (2010).

[29] CMS collaboration, *Performance of muon identification in pp collisions at* $S^{0.5} = 7$ *TeV*, PAS-MUO-10-002 (2010).

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

[31] M. Cacciari, G.P. Salam and G. Soyez, *The Anti-k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [`arXiv:0802.1189`] [INSPIRE].

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

[33] CMS collaboration, S. Chatrchyan et al., *Missing transverse energy performance of the CMS detector*, 2011 *JINST* **6** P09001 [arXiv:1106.5048] [InSPIRE].

[34] CMS collaboration, *Performance of the b-jet identification in CMS*, PAS-BTV-11-001 (2011).

[35] CMS collaboration, V. Khachatryan et al., *CMS Tracking Performance Results from early LHC Operation*, *Eur. Phys. J.* **C 70** (2010) 1165 [arXiv:1007.1988] [InSPIRE].

[36] F. Maltoni and T. Stelzer, *MadEvent: automatic event generation with MadGraph*, *JHEP* **02** (2003) 027 [hep-ph/0208156] [InSPIRE].

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

[38] S. Hoeche et al., *Matching parton showers and matrix elements*, hep-ph/0602031 [InSPIRE].

[39] GEANT4 collaboration, *GEANT4 — A simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250.

[40] M. Aliev et al., *HATHOR: HAdronic Top and Heavy quarks crOss section calculatoR*, *Comput. Phys. Commun.* **182** (2011) 1034 [arXiv:1007.1327] [InSPIRE].

[41] CMS collaboration, S. Chatrchyan et al., *Measurement of the $t\bar{t}$ production cross section in pp collisions at 7 TeV in lepton + jets events using b-quark jet identification*, *Phys. Rev.* **D 84** (2011) 092004 [arXiv:1108.3773] [InSPIRE].

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

[43] N. Kidonakis, *Next-to-next-to-leading-order collinear and soft gluon corrections for t-channel single top quark production*, *Phys. Rev.* **D 83** (2011) 091503 [arXiv:1103.2792] [InSPIRE].

[44] N. Kidonakis, *Two-loop soft anomalous dimensions for single top quark associated production with a W^- or H^-*, *Phys. Rev.* **D 82** (2010) 054018 [arXiv:1005.4451] [InSPIRE].

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

[46] V. Hirschi et al., *Automation of one-loop QCD corrections*, *JHEP* **05** (2011) 044 [arXiv:1103.0621] [InSPIRE].

[47] J. Pumplin et al., *New generation of parton distributions with uncertainties from global QCD analysis*, *JHEP* **07** (2002) 012 [hep-ph/0201195] [InSPIRE].

[48] CMS collaboration, *Absolute calibration of luminosity measurement at CMS: summer 2011 update*, PAS-EWK-11-001 (2011).

[49] A.L. Read, *Presentation of search results: the CL_s technique*, *J. Phys.* **G 28** (2002) 2693 [InSPIRE].

The CMS collaboration

Yerevan Physics Institute, Yerevan, Armenia

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

Institut für Hochenergiephysik der OeAW, Wien, Austria

W. Adam, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, J. Hammer[1], N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, M. Krammer, D. Liko, I. Mikulec, M. Pernicka[†], B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, F. Teischinger, P. Wagner, W. Waltenberger, G. Walzel, E. Widl, C.-E. Wulz

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

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

Universiteit Antwerpen, Antwerpen, Belgium

S. Bansal, K. Cerny, T. Cornelis, E.A. De Wolf, X. Janssen, S. Luyckx, T. Maes, L. Mucibello, S. Ochesanu, B. Roland, R. Rougny, M. Selvaggi, H. Van Haevermaet, P. Van Mechelen, N. Van Remortel, A. Van Spilbeeck

Vrije Universiteit Brussel, Brussel, Belgium

F. Blekman, S. Blyweert, J. D'Hondt, R. Gonzalez Suarez, A. Kalogeropoulos, M. Maes, A. Olbrechts, W. Van Doninck, P. Van Mulders, G.P. Van Onsem, I. Villella

Université Libre de Bruxelles, Bruxelles, Belgium

O. Charaf, B. Clerbaux, G. De Lentdecker, V. Dero, A.P.R. Gay, T. Hreus, A. Léonard, P.E. Marage, T. Reis, L. Thomas, C. Vander Velde, P. Vanlaer

Ghent University, Ghent, Belgium

V. Adler, K. Beernaert, A. Cimmino, S. Costantini, G. Garcia, M. Grunewald, B. Klein, J. Lellouch, A. Marinov, J. Mccartin, A.A. Ocampo Rios, D. Ryckbosch, N. Strobbe, F. Thyssen, M. Tytgat, L. Vanelderen, P. Verwilligen, S. Walsh, E. Yazgan, N. Zaganidis

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

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

Université de Mons, Mons, Belgium

N. Beliy, T. Caebergs, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

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

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

W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, C. De Oliveira Martins, S. Fonseca De Souza, D. Matos Figueiredo, L. Mundim, H. Nogima, V. Oguri, W.L. Prado Da Silva, A. Santoro, S.M. Silva Do Amaral, L. Soares Jorge, A. Sznajder

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

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

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

J.G. Bian, G.M. Chen, H.S. Chen, C.H. Jiang, D. Liang, S. Liang, X. Meng, J. Tao, J. Wang, J. Wang, X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

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

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

Universidad de Los Andes, Bogota, Colombia

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

Technical University of Split, Split, Croatia

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

University of Split, Split, Croatia

Z. Antunovic, M. Dzelalija, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

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

Charles University, Prague, Czech Republic

M. Finger, M. Finger Jr.

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

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

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

Department of Physics, University of Helsinki, Helsinki, Finland

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

Helsinki Institute of Physics, Helsinki, Finland

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

Lappeenranta University of Technology, Lappeenranta, Finland

K. Banzuzi, A. Korpela, T. Tuuva

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

M. Besancon, S. Choudhury, M. Dejardin, D. Denegri, B. Fabbro, J.L. Faure, F. Ferri, S. Ganjour, A. Givernaud, P. Gras, G. Hamel de Monchenault, P. Jarry, E. Locci, J. Malcles, L. Millischer, A. Nayak, J. Rander, A. Rosowsky, I. Shreyber, M. Titov

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

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

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

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

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

F. Fassi, D. Mercier

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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, H. Brun, J. Chasserat, R. Chierici[1], D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, V. Sordini, S. Tosi, Y. Tschudi, P. Verdier, S. Viret

E. Andronikashvili Institute of Physics, Academy of Science, Tbilisi, Georgia

L. Rurua

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

G. Anagnostou, S. Beranek, M. Edelhoff, L. Feld, N. Heracleous, O. Hindrichs, R. Jussen, K. Klein, J. Merz, A. Ostapchuk, A. Perieanu, F. Raupach, J. Sammet, S. Schael, D. Sprenger, H. Weber, B. Wittmer, V. Zhukov[13]

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

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, T. Klimkovich, D. Klingebiel, P. Kreuzer, D. Lanske[†], J. Lingemann, C. Magass, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, M. Weber

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

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

Deutsches Elektronen-Synchrotron, Hamburg, Germany

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz[14], A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, G. Eckerlin, D. Eckstein, D. Fischer, G. Flucke, A. Geiser, I. Glushkov, S. Habib, J. Hauk, H. Jung[1], M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, W. Lohmann[14], B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, M. Rosin, J. Salfeld-Nebgen, R. Schmidt[14], T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

University of Hamburg, Hamburg, Germany

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

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

C. Barth, J. Berger, T. Chwalek, W. De Boer, A. Dierlamm, M. Feindt, M. Guthoff[1], C. Hackstein, F. Hartmann, M. Heinrich, H. Held, K.H. Hoffmann, S. Honc, U. Husemann, I. Katkov[13], J.R. Komaragiri, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, T. Peiffer, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, C. Saout, A. Scheurer, F.-P. Schilling, M. Schmanau, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, T. Weiler, M. Zeise, E.B. Ziebarth

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

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

University of Athens, Athens, Greece

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

University of Ioánnina, Ioánnina, Greece

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

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

G. Bencze, C. Hajdu[1], P. Hidas, D. Horvath[15], K. Krajczar[16], B. Radics, F. Sikler[1], V. Veszpremi, G. Vesztergombi[16]

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

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

Saha Institute of Nuclear Physics, Kolkata, India

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

Bhabha Atomic Research Centre, Mumbai, India

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

Tata Institute of Fundamental Research - EHEP, Mumbai, India

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

Tata Institute of Fundamental Research - HECR, Mumbai, India

S. Banerjee, S. Dugad

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

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

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

M. Abbrescia[a,b], L. Barbone[a,b], C. Calabria[a,b,1], S.S. Chhibra[a,b], A. Colaleo[a], D. Creanza[a,c], N. De Filippis[a,c,1], M. De Palma[a,b], L. Fiore[a], G. Iaselli[a,c], L. Lusito[a,b], G. Maggi[a,c], M. Maggi[a], B. Marangelli[a,b], S. My[a,c], S. Nuzzo[a,b], N. Pacifico[a,b], A. Pompili[a,b], G. Pugliese[a,c], G. Selvaggi[a,b], L. Silvestris[a], G. Singh[a,b], G. Zito[a]

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

G. Abbiendi[a], A.C. Benvenuti[a], D. Bonacorsi[a,b], S. Braibant-Giacomelli[a,b], L. Brigliadori[a,b], P. Capiluppi[a,b], A. Castro[a,b], F.R. Cavallo[a], M. Cuffiani[a,b], G.M. Dallavalle[a], F. Fabbri[a], A. Fanfani[a,b], D. Fasanella[a,b,1], P. Giacomelli[a], C. Grandi[a], L. Guiducci, S. Marcellini[a], G. Masetti[a], M. Meneghelli[a,b,1], A. Montanari[a], F.L. Navarria[a,b], F. Odorici[a], A. Perrotta[a], F. Primavera[a,b], A.M. Rossi[a,b], T. Rovelli[a,b], G. Siroli[a,b], R. Travaglini[a,b]

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

S. Albergo[a,b], G. Cappello[a,b], M. Chiorboli[a,b], S. Costa[a,b], R. Potenza[a,b], A. Tricomi[a,b], C. Tuve[a,b]

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

G. Barbagli^a, V. Ciulli^{a,b}, C. Civinini^a, R. D'Alessandro^{a,b}, E. Focardi^{a,b}, S. Frosali^{a,b}, E. Gallo^a, S. Gonzi^{a,b}, M. Meschini^a, S. Paoletti^a, G. Sguazzoni^a, A. Tropiano^{a,1}

INFN Laboratori Nazionali di Frascati, Frascati, Italy

L. Benussi, S. Bianco, S. Colafranceschi^{24}, F. Fabbri, D. Piccolo

INFN Sezione di Genova, Genova, Italy

P. Fabbricatore, R. Musenich

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

A. Benaglia^{a,b,1}, F. De Guio^{a,b}, L. Di Matteo^{a,b,1}, S. Fiorendi^{a,b}, S. Gennai^{a,1}, A. Ghezzi^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b,1}, D. Menasce^a, L. Moroni^a, M. Paganoni^{a,b}, D. Pedrini^a, S. Ragazzi^{a,b}, N. Redaelli^a, S. Sala^a, T. Tabarelli de Fatis^{a,b}

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

S. Buontempo^a, C.A. Carrillo Montoya^{a,1}, N. Cavallo^{a,25}, A. De Cosa^{a,b}, O. Dogangun^{a,b}, F. Fabozzi^{a,25}, A.O.M. Iorio^{a,1}, L. Lista^a, S. Meola^{a,26}, M. Merola^{a,b}, P. Paolucci^a

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

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

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

M. Gabusi^{a,b}, S.P. Ratti^{a,b}, C. Riccardi^{a,b}, P. Torre^{a,b}, P. Vitulo^{a,b}

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

G.M. Bilei^a, L. Fanò^{a,b}, P. Lariccia^{a,b}, A. Lucaroni^{a,b,1}, G. Mantovani^{a,b}, M. Menichelli^a, A. Nappi^{a,b}, F. Romeo^{a,b}, A. Saha, A. Santocchia^{a,b}, S. Taroni^{a,b,1}

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

P. Azzurri^{a,c}, G. Bagliesi^a, T. Boccali^a, G. Broccolo^{a,c}, R. Castaldi^a, R.T. D'Agnolo^{a,c}, R. Dell'Orso^a, F. Fiori^{a,b,1}, L. Foà^{a,c}, A. Giassi^a, A. Kraan^a, F. Ligabue^{a,c}, T. Lomtadze^a, L. Martini^{a,27}, A. Messineo^{a,b}, F. Palla^a, F. Palmonari^a, A. Rizzi^{a,b}, A.T. Serban^{a,28}, P. Spagnolo^a, P. Squillacioti^1, R. Tenchini^a, G. Tonelli^{a,b,1}, A. Venturi^{a,1}, P.G. Verdini^a

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

L. Barone^{a,b}, F. Cavallari^a, D. Del Re^{a,b,1}, M. Diemoz^a, C. Fanelli^{a,b}, M. Grassi^{a,1}, E. Longo^{a,b}, P. Meridiani^{a,1}, F. Micheli^{a,b}, S. Nourbakhsh^a, G. Organtini^{a,b}, F. Pandolfi^{a,b}, R. Paramatti^a, S. Rahatlou^{a,b}, M. Sigamani^a, L. Soffi^{a,b}

INFN Sezione di Torino ^{a}, Università di Torino ^{b}, Università del Piemonte Orientale (Novara) ^{c}, Torino, Italy

N. Amapane^{a,b}, R. Arcidiacono^{a,c}, S. Argiro^{a,b}, M. Arneodo^{a,c}, C. Biino^a, C. Botta^{a,b}, N. Cartiglia^a, R. Castello^{a,b}, M. Costa^{a,b}, N. Demaria^a, A. Graziano^{a,b}, C. Mariotti^{a,1}, S. Maselli^a, E. Migliore^{a,b}, V. Monaco^{a,b}, M. Musich^{a,1}, M.M. Obertino^{a,c}, N. Pastrone^a, M. Pelliccioni^a, A. Potenza^{a,b}, A. Romero^{a,b}, M. Ruspa^{a,c}, R. Sacchi^{a,b}, V. Sola^{a,b}, A. Solano^{a,b}, A. Staiano^a, A. Vilela Pereira^a

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

S. Belforte^a, F. Cossutti^a, G. Della Ricca^{a,b}, B. Gobbo^a, M. Marone^{a,b,1}, D. Montanino^{a,b,1}, A. Penzo^a, A. Schizzi^{a,b}

Kangwon National University, Chunchon, Korea

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

Kyungpook National University, Daegu, Korea

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

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

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

Konkuk University, Seoul, Korea

H.Y. Jo

Korea University, Seoul, Korea

S. Choi, D. Gyun, B. Hong, M. Jo, H. Kim, T.J. Kim, K.S. Lee, D.H. Moon, S.K. Park, E. Seo

University of Seoul, Seoul, Korea

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

Sungkyunkwan University, Suwon, Korea

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

Vilnius University, Vilnius, Lithuania

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

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

H. Castilla-Valdez, E. De La Cruz-Burelo, I. Heredia-de La Cruz, R. Lopez-Fernandez, R. Magaña Villalba, J. Martínez-Ortega, A. Sánchez-Hernández, L.M. Villasenor-Cendejas

Universidad Iberoamericana, Mexico City, Mexico

S. Carrillo Moreno, F. Vazquez Valencia

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

H.A. Salazar Ibarguen

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

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

University of Auckland, Auckland, New Zealand

D. Krofcheck

University of Canterbury, Christchurch, New Zealand

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

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

M. Ahmad, M.I. Asghar, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi,
M.A. Shah, M. Shoaib

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

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

Soltan Institute for Nuclear Studies, Warsaw, Poland

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

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

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

Joint Institute for Nuclear Research, Dubna, Russia

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

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

S. Evstyukhin, V. Golovtsov, Y. Ivanov, V. Kim, P. Levchenko, V. Murzin, V. Oreshkin,
I. Smirnov, V. Sulimov, L. Uvarov, S. Vavilov, A. Vorobyev, An. Vorobyev

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

Moscow State University, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

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

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

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

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

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

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

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, C. Diez Pardos, D. Domínguez Vázquez, C. Fernandez Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. Garcia-Abia, O. Gonzalez Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

Universidad Autónoma de Madrid, Madrid, Spain

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

Universidad de Oviedo, Oviedo, Spain

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

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

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini[31], M. Fernandez, G. Gomez, J. Gonzalez Sanchez, C. Jorda, P. Lobelle Pardo, A. Lopez Virto, J. Marco, R. Marco, C. Martinez Rivero, F. Matorras, F.J. Munoz Sanchez, T. Rodrigo, A.Y. Rodríguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, M. Sobron Sanudo, I. Vila, R. Vilar Cortabitarte

CERN, European Organization for Nuclear Research, Geneva, Switzerland

D. Abbaneo, E. Auffray, G. Auzinger, P. Baillon, A.H. Ball, D. Barney, C. Bernet[5], G. Bianchi, P. Bloch, A. Bocci, A. Bonato, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. De Roeck, S. Di Guida, M. Dobson, N. Dupont-Sagorin, A. Elliott-Peisert, B. Frisch, W. Funk, G. Georgiou, M. Giffels, D. Gigi, K. Gill, D. Giordano, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, P. Lenzi, C. Lourenço, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers,

S. Mersi, E. Meschi, R. Moser, M.U. Mozer, M. Mulders, E. Nesvold, M. Nguyen, T. Orimoto, L. Orsini, E. Palencia Cortezon, E. Perez, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi[32], T. Rommerskirchen, C. Rovelli[33], M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas[34], D. Spiga, M. Spiropulu[4], M. Stoye, A. Tsirou, G.I. Veres[16], J.R. Vlimant, H.K. Wöhri, S.D. Worm[35], W.D. Zeuner

Paul Scherrer Institut, Villigen, Switzerland

W. Bertl, K. Deiters, W. Erdmann, K. Gabathuler, R. Horisberger, Q. Ingram, H.C. Kaestli, S. König, D. Kotlinski, U. Langenegger, F. Meier, D. Renker, T. Rohe, J. Sibille[36]

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, Z. Chen, A. Deisher, G. Dissertori, M. Dittmar, M. Dünser, J. Eugster, K. Freudenreich, C. Grab, P. Lecomte, W. Lustermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli[37], P. Nef, F. Nessi-Tedaldi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov[38], B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Universität Zürich, Zurich, Switzerland

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

National Central University, Chung-Li, Taiwan

Y.H. Chang, K.H. Chen, A. Go, C.M. Kuo, S.W. Li, W. Lin, Z.K. Liu, Y.J. Lu, D. Mekterovic, A.P. Singh, R. Volpe, S.S. Yu

National Taiwan University (NTU), Taipei, Taiwan

P. Bartalini, P. Chang, Y.H. Chang, Y.W. Chang, Y. Chao, K.F. Chen, C. Dietz, U. Grundler, W.-S. Hou, Y. Hsiung, K.Y. Kao, Y.J. Lei, R.-S. Lu, D. Majumder, E. Petrakou, X. Shi, J.G. Shiu, Y.M. Tzeng, M. Wang

Cukurova University, Adana, Turkey

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

Middle East Technical University, Physics Department, Ankara, Turkey

I.V. Akin, T. Aliev, B. Bilin, S. Bilmis, M. Deniz, H. Gamsizkan, A.M. Guler, K. Ocalan, A. Ozpineci, M. Serin, R. Sever, U.E. Surat, M. Yalvac, E. Yildirim, M. Zeyrek

Bogazici University, Istanbul, Turkey

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

Istanbul Technical University, Istanbul, Turkey

K. Cankocak

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

L. Levchuk

University of Bristol, Bristol, United Kingdom

F. Bostock, J.J. Brooke, E. Clement, D. Cussans, H. Flacher, R. Frazier, J. Goldstein, M. Grimes, G.P. Heath, H.F. Heath, L. Kreczko, S. Metson, D.M. Newbold[35], K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom

L. Basso[46], K.W. Bell, A. Belyaev[46], C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Imperial College, London, United Kingdom

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko[38], A. Papageorgiou, J. Pela[1], M. Pesaresi, K. Petridis, M. Pioppi[47], D.M. Raymond, S. Rogerson, N. Rompotis, A. Rose, M.J. Ryan, C. Seez, P. Sharp[†], A. Sparrow, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Brunel University, Uxbridge, United Kingdom

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

Baylor University, Waco, USA

K. Hatakeyama, H. Liu, T. Scarborough

The University of Alabama, Tuscaloosa, USA

C. Henderson, P. Rumerio

Boston University, Boston, USA

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

Brown University, Providence, USA

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

University of California, Davis, Davis, USA

R. Breedon, G. Breto, M. Calderon De La Barca Sanchez, S. Chauhan, M. Chertok, J. Conway, R. Conway, P.T. Cox, J. Dolen, R. Erbacher, M. Gardner, R. Houtz, W. Ko,

A. Kopecky, R. Lander, O. Mall, T. Miceli, R. Nelson, D. Pellett, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra

University of California, Los Angeles, Los Angeles, USA

V. Andreev, D. Cline, R. Cousins, J. Duris, S. Erhan, P. Everaerts, C. Farrell, J. Hauser, M. Ignatenko, C. Plager, G. Rakness, P. Schlein[†], J. Tucker, V. Valuev, M. Weber

University of California, Riverside, Riverside, USA

J. Babb, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanson, G.Y. Jeng[48], H. Liu, O.R. Long, A. Luthra, H. Nguyen, S. Paramesvaran, J. Sturdy, S. Sumowidagdo, R. Wilken, S. Wimpenny

University of California, San Diego, La Jolla, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, F. Golf, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, J. Muelmenstaedt, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, R. Ranieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech[49], F. Würthwein, A. Yagil, J. Yoo

University of California, Santa Barbara, Santa Barbara, USA

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, J. Incandela, C. Justus, P. Kalavase, S.A. Koay, D. Kovalskyi[1], V. Krutelyov, S. Lowette, N. Mccoll, V. Pavlunin, F. Rebassoo, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

California Institute of Technology, Pasadena, USA

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

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado at Boulder, Boulder, USA

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

Cornell University, Ithaca, USA

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

Fairfield University, Fairfield, USA

D. Winn

Fermi National Accelerator Laboratory, Batavia, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, I. Bloch, K. Burkett, J.N. Butler, V. Chetluru, H.W.K. Cheung, F. Chlebana,

V.D. Elvira, I. Fisk, J. Freeman, Y. Gao, D. Green, O. Gutsche, A. Hahn, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Kilminster, B. Klima, S. Kunori, S. Kwan, D. Lincoln, R. Lipton, L. Lueking, J. Lykken, K. Maeshima, J.M. Marraffino, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko[50], C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, P. Tan, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, F. Yumiceva, J.C. Yun

University of Florida, Gainesville, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, S. Das, M. De Gruttola, G.P. Di Giovanni, D. Dobur, A. Drozdetskiy, R.D. Field, M. Fisher, Y. Fu, I.K. Furic, J. Gartner, J. Hugon, B. Kim, J. Konigsberg, A. Korytov, A. Kropivnitskaya, T. Kypreos, J.F. Low, K. Matchev, P. Milenovic[51], G. Mitselmakher, L. Muniz, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

T. Adams, A. Askew, J. Bochenek, J. Chen, B. Diamond, S.V. Gleyzer, J. Haas, S. Hagopian, V. Hagopian, M. Jenkins, K.F. Johnson, H. Prosper, V. Veeraraghavan, M. Weinberg

Florida Institute of Technology, Melbourne, USA

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

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

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

The University of Iowa, Iowa City, USA

U. Akgun, E.A. Albayrak, B. Bilki[52], K. Chung, W. Clarida, F. Duru, S. Griffiths, C.K. Lae, J.-P. Merlo, H. Mermerkaya[53], A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, J. Olson, Y. Onel, F. Ozok, S. Sen, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

Johns Hopkins University, Baltimore, USA

B.A. Barnett, B. Blumenfeld, S. Bolognesi, D. Fehling, G. Giurgiu, A.V. Gritsan, Z.J. Guo, G. Hu, P. Maksimovic, S. Rappoccio, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

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

Lawrence Livermore National Laboratory, Livermore, USA

J. Gronberg, D. Lange, D. Wright

University of Maryland, College Park, USA

A. Baden, M. Boutemeur, B. Calvert, S.C. Eno, J.A. Gomez, N.J. Hadley, R.G. Kellogg, M. Kirn, T. Kolberg, Y. Lu, M. Marionneau, A.C. Mignerey, A. Peterman, K. Rossato, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar, E. Twedt

Massachusetts Institute of Technology, Cambridge, USA

G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, K.A. Hahn, Y. Kim, M. Klute, Y.-J. Lee, W. Li, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Veli021canu, E.A. Wenger, R. Wolf, B. Wyslouch, S. Xie, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti

University of Minnesota, Minneapolis, USA

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

University of Mississippi, University, USA

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

University of Nebraska-Lincoln, Lincoln, USA

E. Avdeeva, K. Bloom, S. Bose, J. Butt, D.R. Claes, A. Dominguez, M. Eads, P. Jindal, J. Keller, I. Kravchenko, J. Lazo-Flores, H. Malbouisson, S. Malik, G.R. Snow

State University of New York at Buffalo, Buffalo, USA

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

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

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

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, USA

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

Princeton University, Princeton, USA

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

University of Puerto Rico, Mayaguez, USA

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

Purdue University, West Lafayette, USA

E. Alagoz, V.E. Barnes, D. Benedetti, G. Bolla, D. Bortoletto, M. De Mattia, A. Everett, Z. Hu, M. Jones, O. Koybasi, M. Kress, A.T. Laasanen, N. Leonardo, V. Maroussov, P. Merkel, D.H. Miller, N. Neumeister, I. Shipsey, D. Silvers, A. Svyatkovskiy, M. Vidal Marono, H.D. Yoo, J. Zablocki, Y. Zheng

Purdue University Calumet, Hammond, USA

S. Guragain, N. Parashar

Rice University, Houston, USA

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

University of Rochester, Rochester, USA

B. Betchart, A. Bodek, Y.S. Chung, R. Covarelli, P. de Barbaro, R. Demina, Y. Eshaq, A. Garcia-Bellido, P. Goldenzweig, Y. Gotra, J. Han, A. Harel, S. Korjenevski, D.C. Miner, D. Vishnevskiy, M. Zielinski

The Rockefeller University, New York, USA

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

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

S. Arora, A. Barker, J.P. Chou, C. Contreras-Campana, E. Contreras-Campana, D. Duggan, D. Ferencek, Y. Gershtein, R. Gray, E. Halkiadakis, D. Hidas, D. Hits, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, A. Richards, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas

University of Tennessee, Knoxville, USA

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

Texas A&M University, College Station, USA

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon[54], V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA

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

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hirosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood, R. Yohay

Wayne State University, Detroit, USA

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

University of Wisconsin, Madison, USA

M. Anderson, M. Bachtis, D. Belknap, L. Borrello, D. Carlsmith, M. Cepeda, S. Dasu, L. Gray, K.S. Grogg, M. Grothe, R. Hall-Wilton, M. Herndon, A. Hervé, P. Klabbers, J. Klukas, A. Lanaro, C. Lazaridis, J. Leonard, R. Loveless, A. Mohapatra, I. Ojalvo, G.A. Pierro, I. Ross, A. Savin, W.H. Smith, J. Swanson

†: Deceased
1: Also at CERN, European Organization for Nuclear Research, Geneva, Switzerland
2: Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
3: Also at Universidade Federal do ABC, Santo Andre, Brazil
4: Also at California Institute of Technology, Pasadena, USA
5: Also at Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
6: Also at Suez Canal University, Suez, Egypt
7: Also at Cairo University, Cairo, Egypt
8: Also at British University, Cairo, Egypt
9: Also at Fayoum University, El-Fayoum, Egypt
10: Now at Ain Shams University, Cairo, Egypt
11: Also at Soltan Institute for Nuclear Studies, Warsaw, Poland
12: Also at Université de Haute-Alsace, Mulhouse, France
13: Also at Moscow State University, Moscow, Russia
14: Also at Brandenburg University of Technology, Cottbus, Germany
15: Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary
16: Also at Eötvös Loránd University, Budapest, Hungary
17: Also at Tata Institute of Fundamental Research - HECR, Mumbai, India
18: Now at King Abdulaziz University, Jeddah, Saudi Arabia
19: Also at University of Visva-Bharati, Santiniketan, India
20: Also at Sharif University of Technology, Tehran, Iran
21: Also at Isfahan University of Technology, Isfahan, Iran
22: Also at Shiraz University, Shiraz, Iran

23: Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Teheran, Iran
24: Also at Facoltà Ingegneria Università di Roma, Roma, Italy
25: Also at Università della Basilicata, Potenza, Italy
26: Also at Università degli Studi Guglielmo Marconi, Roma, Italy
27: Also at Università degli studi di Siena, Siena, Italy
28: Also at University of Bucharest, Bucuresti-Magurele, Romania
29: Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia
30: Also at University of Florida, Gainesville, USA
31: Also at University of California, Los Angeles, Los Angeles, USA
32: Also at Scuola Normale e Sezione dell' INFN, Pisa, Italy
33: Also at INFN Sezione di Roma; Università di Roma "La Sapienza", Roma, Italy
34: Also at University of Athens, Athens, Greece
35: Also at Rutherford Appleton Laboratory, Didcot, United Kingdom
36: Also at The University of Kansas, Lawrence, USA
37: Also at Paul Scherrer Institut, Villigen, Switzerland
38: Also at Institute for Theoretical and Experimental Physics, Moscow, Russia
39: Also at Gaziosmanpasa University, Tokat, Turkey
40: Also at Adiyaman University, Adiyaman, Turkey
41: Also at The University of Iowa, Iowa City, USA
42: Also at Mersin University, Mersin, Turkey
43: Also at Kafkas University, Kars, Turkey
44: Also at Suleyman Demirel University, Isparta, Turkey
45: Also at Ege University, Izmir, Turkey
46: Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom
47: Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy
48: Also at University of Sydney, Sydney, Australia
49: Also at Utah Valley University, Orem, USA
50: Also at Institute for Nuclear Research, Moscow, Russia
51: Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
52: Also at Argonne National Laboratory, Argonne, USA
53: Also at Erzincan University, Erzincan, Turkey
54: Also at Kyungpook National University, Daegu, Korea