



Search for heavy narrow dilepton resonances in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV

CMS Collaboration*

CERN, Switzerland

ARTICLE INFO

Article history:

Received 24 December 2012

Accepted 1 February 2013

Available online 6 February 2013

Editor: M. Doser

Keywords:

CMS

Physics

Resonances

Z'

Muons

Electrons

ABSTRACT

An updated search for heavy narrow resonances decaying to muon or electron pairs using the CMS detector is presented. Data samples from pp collisions at $\sqrt{s} = 7$ TeV and 8 TeV at the LHC, with integrated luminosities of up to 5.3 and 4.1 fb⁻¹, respectively, are combined. No evidence for a heavy narrow resonance is observed. The analysis of the combined data sets excludes, at 95% confidence level, a Sequential Standard Model Z'_{SSM} resonance lighter than 2590 GeV, a superstring-inspired Z'_ψ lighter than 2260 GeV, and Kaluza–Klein gravitons lighter than 2390 (2030) GeV, assuming that the coupling parameter k/\overline{M}_{Pl} is 0.10 (0.05). These are the most stringent limits to date.

© 2013 CERN. Published by Elsevier B.V. Open access under CC BY-NC-ND license.

1. Introduction

A number of scenarios for physics beyond the standard model predict the existence of heavy narrow resonances that decay to lepton pairs. In this Letter, we report on a search for resonances with the Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) [1]. We consider the following three benchmark scenarios: the Sequential Standard Model Z'_{SSM} with standard-model-like couplings [2], the Z'_ψ predicted by grand unified theories [3], and Kaluza–Klein graviton excitations in the Randall–Sundrum (RS) model of extra dimensions [4,5]. The RS model has two free parameters. One parameter is the mass of the first graviton excitation, and the other is the coupling k/\overline{M}_{Pl} , where k is the curvature of the extra dimension and \overline{M}_{Pl} is the reduced Planck scale.

Previous searches for narrow $Z' \rightarrow \ell^+ \ell^-$ ($\ell = \mu, e$) resonances have been reported by the CMS [6] and ATLAS [7] Collaborations, each based on integrated luminosities of 5 fb⁻¹ at $\sqrt{s} = 7$ TeV. The CDF and D0 experiments have published results based on integrated luminosities exceeding 5 fb⁻¹ of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV [8–13]. The best previous direct lower limits on the Z'_{SSM} and Z'_ψ masses are 2330 GeV and 2000 GeV [6], respectively. The best previous direct limits on RS graviton (G_{KK}) production are

2160 GeV for $k/\overline{M}_{Pl} = 0.1$ [7] and 1810 GeV for $k/\overline{M}_{Pl} = 0.05$ [6]. Indirect constraints [14–17] are less stringent.

We use data samples from pp collisions at center-of-mass energy $\sqrt{s} = 8$ TeV, corresponding to an integrated luminosity of 3.6 ± 0.2 fb⁻¹ for the dielectron channel. The dimuon channel does not use information from the calorimeters and incorporates additional data from running periods when the calorimeters were not fully operational. This increases the integrated luminosity of the sample to 4.1 ± 0.2 fb⁻¹. We combine the analysis of these data with previous results from the analysis based on an integrated luminosity of 5 fb⁻¹ at $\sqrt{s} = 7$ TeV [6]. The reconstruction, selection criteria, efficiencies, and systematics for the two data sets are very similar. The results are applicable to any model with a narrow resonance that has equal dimuon and dielectron branching fractions. A resonance is considered narrow if the experimental width is dominated by the detector resolution.

We perform a shape-based analysis of the dilepton mass spectra searching for a peak on a smoothly falling distribution with the overall background normalization determined by an unbinned maximum likelihood fit. The data are consistent with expectations from the standard model. We report limits on the ratio (R_σ) of the production cross sections times branching fractions of a heavy narrow resonance to that of the Z boson, at the 95% confidence level (CL). Many experimental and theoretical uncertainties cancel in this ratio. We further translate these limits into lower limits on the masses of new heavy narrow resonances, using next-to-next-leading-order (NNLO) cross section calculations [18] for the Z boson production.

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

2. The CMS detector

A detailed description of the CMS detector can be found in Ref. [19]. We briefly discuss the systems most relevant to this analysis. The central feature of the CMS detector is an all-silicon inner tracker system, composed of silicon pixel and strip detectors. The tracker is surrounded by a lead-tungstate crystal electromagnetic calorimeter (ECAL) and a brass-scintillator hadron calorimeter (HCAL). The finely segmented ECAL consists of nearly 76 000 lead-tungstate crystals which provide coverage up to pseudorapidity $|\eta| = 3.0$. It is divided in the barrel ($|\eta| < 1.479$) and endcap ($1.479 < |\eta| < 3.0$) detectors. We define pseudorapidity as $\eta = -\ln[\tan(\theta/2)]$. Here, θ is the polar angle with respect to the direction of the counterclockwise proton beam. We use ϕ for the azimuthal angle of a track's momentum at the point of closest approach to the beamline. The tracker and calorimeter systems reside within a 6 m diameter superconducting solenoid, which produces a 3.8 T axial magnetic field. Muons are detected by gas-ionization chambers embedded in the steel flux-return yoke.

The CMS experiment utilizes a two-level trigger system. The first level of the trigger (L1) selects events of interest using custom hardware processors [20]. It uses information from the muon and calorimeter systems to reduce the readout rate from the 20 MHz bunch crossing rate to a maximum rate of 100 kHz. The software based high-level trigger (HLT) further reduces the recorded event rate to a few hundred Hz by adding information from the inner tracker and analyzing event information in greater detail [21].

3. Event selection and object reconstruction

The event selection closely mirrors the one used for the $\sqrt{s} = 7$ TeV analysis. We briefly review the procedure here. Dimuon events are triggered by requiring at least one muon to be reconstructed by the HLT and to have transverse momentum $p_T > 40$ GeV and $|\eta| < 2.1$. Dielectron events are accepted by a double-electron trigger requiring two clusters in the ECAL, each with transverse energy $E_T > 33$ GeV. The trigger allows only small deposits of energy in the HCAL to be associated with the ECAL clusters. HLT clusters are required to be loosely matched to the trajectories of tracks having hits in the pixel detector. The lepton trigger efficiencies are measured using a “tag-and-probe” technique at the Z resonance [6,22,23], up to transverse momenta of roughly 500 GeV for muons and 100 GeV for electrons. For higher transverse momenta, the electron efficiency is measured using a simple trigger which requires only an ECAL cluster with $E_T > 300$ GeV to directly monitor the trigger efficiency for selected high mass events. In order to have a consistent trigger between the low-mass control region and the high-mass signal region, the simple ECAL trigger is used only to validate the efficiency of the primary trigger. The muon trigger efficiency is 97% for events with both muons within the trigger acceptance, across the entire range of dimuon invariant masses of interest. The efficiency of the electron trigger for dielectron candidates passing the analysis selection requirements increases from 80% at electron $E_T = 35$ GeV to a 99% plateau at $E_T > 37$ GeV. The efficiency threshold curve of the trigger is measured using data collected by a lower threshold trigger that is applied to approximately every 5th event passing the L1 part of the trigger. Because the threshold behavior is well-determined, the offline E_T selection cut can be placed at 35 GeV, which improves the normalization to the Z peak. Both muon and electron trigger efficiencies are within 1–2% of those found in Ref. [6]. Standard CMS algorithms [6,23,24] are used to reconstruct and select muon and electron candidates. Muon candidates are formed by matching tracks in the silicon tracker to tracks in the muon systems. Muon tracks are required to have hits in nine or

more layers of the tracker and include at least one hit from each of the pixel and muon systems.

Muon candidates are required to be isolated in a cone about the muon direction of $\Delta R < 0.3$ in the tracker and to have $p_T > 45$ GeV and $|\eta| < 2.4$. The quantity ΔR is defined as $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$, where $\Delta\phi$ is in radians. The combined fit of the muon trajectory through the tracker and muon systems provides a reliable measurement of muon momenta extending to order 1 TeV [23,25]. Electron candidates are formed by matching ECAL clusters to reconstructed tracks, and are required to have $|\eta| < 1.442$ and $1.560 < |\eta| < 2.5$ for the ECAL barrel and ECAL endcap regions, respectively. As in Ref. [6], electrons are additionally required to have little associated activity in the HCAL, have a shower shape consistent with that of an electromagnetic object, and be isolated in a cone about the electron direction of $\Delta R < 0.3$ in the calorimeter and tracker. To account for the contamination which varies with the number of additional proton–proton interactions per event, the calorimeter isolation of the electron is corrected for the average energy density in the event [26].

The ECAL is capable of measuring energies in a single crystal of up to approximately 1.7 TeV in the barrel region and 2.8 TeV in the endcap region. Saturation effects become an issue for resonance masses around 4 TeV, which are beyond the reach of the current analysis, within the framework of the models considered here. Occasionally, anomalously large signals are observed in the barrel ECAL due to the direct deposition of energy into the avalanche photo-diodes (APDs) by particles transiting the detector [27]. Since the APDs are normally used to detect the scintillation light produced by the crystals, the equivalent energies of these signals can reach into the TeV range. The deposits are generally in a single channel and have different pulse timings from scintillation signals. They are rejected by cutting on the timing of the pulse and the amount of energy recorded in neighboring crystals.

More than 99% of the anomalous clusters are rejected with a negligible loss of real electrons [27]. When combined with the requirement of a compatible track in the silicon tracker, this requirement reduces background from anomalous clusters to a negligible level. However, the energy deposit pattern of all selected high energy electrons is scrutinized even further. There is no evidence that any of the remaining events is due to these anomalous signals.

Previously established techniques [6,22,23] are used to measure event reconstruction and selection efficiencies. The efficiencies for reconstructing and selecting leptons are roughly 90%, for both muons and electrons with $p_T > 100$ GeV. The efficiencies include the isolation requirements and are measured with total uncertainties of a few percent. Part of the systematic uncertainty cancels in the ratio of high-mass dilepton cross section to the Z boson cross section. Studies with Monte Carlo simulated samples predict both lepton reconstruction and selection efficiencies to be constant within 1% for transverse momenta $p_T \geq 100$ GeV.

Each dilepton candidate is required to have two isolated leptons of the same flavor that pass the identification criteria described above. When multiple dilepton candidates are present, the most energetic pair in the bunch crossing is selected. For dimuon events, one muon must have $|\eta| < 2.1$ to satisfy the trigger requirements. For dielectron events, at least one electron must have $|\eta| < 1.442$. This removes events in which both electrons are in the endcap, a topology where little signal is expected but which has a significant background arising from misidentified jets. Muons are required to have opposite charge, since a charge mis-assignment implies a large mismeasurement of momentum. The energy estimate for electrons is dominated by electromagnetic calorimeter information and is not sensitive to the momentum mis-measurement indicated by a charge mis-assignment. The charge requirement would also result in a few percent efficiency loss in a region with

little background and would degrade the sensitivity of the analysis. Therefore, we do not impose a charge requirement for dielectron candidates at high mass. Muon candidates are additionally required to originate from the same vertex. The χ^2 per degree of freedom for the fit to a common vertex is required to be less than 10. The tracker-measured transverse impact parameter with respect to the beam spot must be less than 2 mm for each muon. The mass resolution of a dielectron candidate is predicted by Monte Carlo simulation to be approximately 1.8% for masses above 800 GeV. The dimuon mass resolution is 5% (9%) at 1 TeV (2 TeV) and increases linearly with dimuon mass.

The opening angle of the muon pair is required to be less than $\pi - 0.02$ radians. This requirement greatly reduces the cosmic ray background associated with muons traversing the detector.

4. Backgrounds

The dilepton background in pp collisions at $\sqrt{s} = 8$ TeV is very similar to that found in $\sqrt{s} = 7$ TeV collisions [6] even though there were significantly more interactions per bunch crossing at the higher energy. The effect of this “event pileup” is included in our simulations of background processes and our data-driven estimates of the background from misidentified jets. The dominant standard model background is due to Drell–Yan production. The shape of this contribution is determined from Monte Carlo simulation using the PYTHIA v6.4 [28] event generator. The background contribution is normalized to the event count at the Z peak by counting same-flavor dilepton candidates within the mass window $60 < m_{\ell\ell} < 120$ GeV. The next largest background contribution is due to other standard model processes that produce isolated dileptons. We consider the lepton flavor symmetric processes of $t\bar{t}$, tW , $Z \rightarrow \tau^+\tau^-$, and diboson (WW, WZ, and ZZ) production when estimating this background component. The absolute normalization and shape for these backgrounds is taken directly from Monte Carlo simulation generated using MADGRAPH 5 [29], POWHEG [30–33], and PYTHIA. We validate this background prediction by comparing the $e\mu$ dilepton mass spectra for data and simulation.

Track-based lepton isolation strongly suppresses backgrounds from jets misreconstructed as leptons. This background is almost negligible for the dimuon channel but is a significant portion of the non-Drell–Yan background in the dielectron channel. Since misidentification of jets as leptons is more likely to occur for electrons than for muons, electrons have additional isolation and jet discrimination requirements. In the dielectron channel, the main contributing processes apart from Drell–Yan are dijet, W + jet, and photon + jet production (where the photon is misidentified as an electron). The probability that a jet is misidentified as an electron is measured in bins of E_T and η , using a jet-dominated sample. This probability is then used to weight events in which one electron satisfies all selection criteria and the other is a candidate for being a misidentified jet, to obtain the jet background prediction. The dimuon resonance search is susceptible to backgrounds from cosmic ray muons. The expected cosmic ray background for dimuons with $m_{\mu\mu} > 200$ GeV is determined from two complementary samples. For events in the first sample, the requirement on the dimuon opening angle is removed. In the second sample, the impact parameter requirement on the muon tracks is not applied. From the populations of these two samples, the remaining cosmic ray background contamination is estimated to be less than 0.2 events.

5. Results

The dilepton mass distributions for events passing all the selection criteria are shown in Fig. 1. The “jets” distribution illustrates

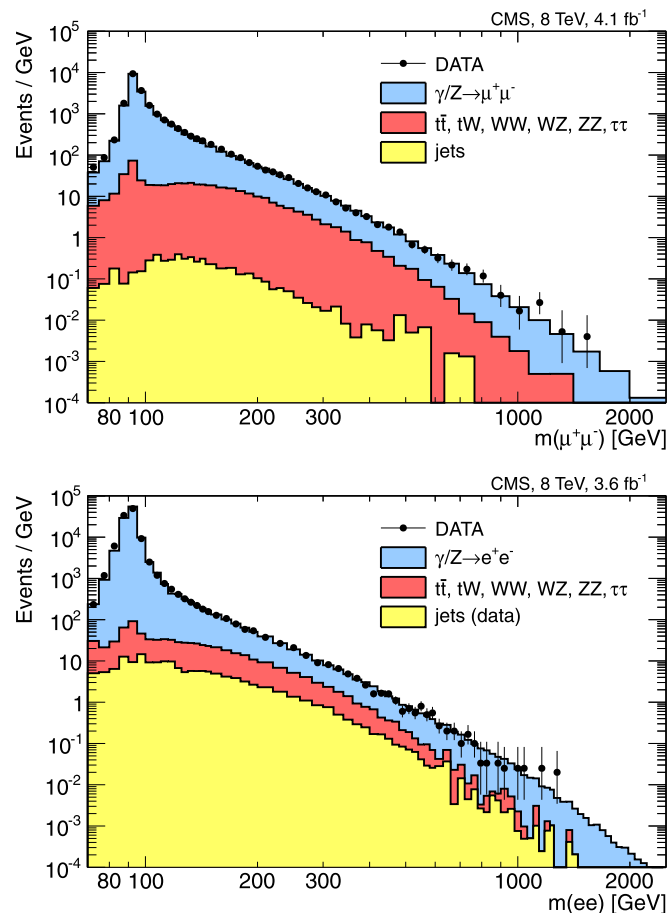


Fig. 1. The invariant mass spectrum of $\mu^+\mu^-$ (top) and ee (bottom) events for the $\sqrt{s} = 8$ TeV data set. The points with error bars represent the data. The solid histograms represent the standard model predicted background contributions.

the contribution of events in which at least one jet is misreconstructed as a lepton. This distribution is derived from data while all other components are derived from simulation. The relative fractions of the different background components are fixed to the ratios of their theoretical cross sections. The total simulated background is normalized to data at the Z peak ($60 < m_{\ell\ell} < 120$ GeV). The expected yields in the control region ($120 < m_{\ell\ell} < 200$ GeV) and in the search region ($m_{\ell\ell} > 200$ GeV) are compared with observed yields in Table 1. The observed mass spectra and event counts agree with standard model predictions both in shape and normalization.

We set a 95% CL limit on the ratio R_σ of the product of the cross section and branching fraction for each Z' boson to that of the standard model Z boson. The cross section of the Z' boson is calculated in a window of $\pm 40\%$ about the on-shell mass of the resonance, while for the Z boson it is calculated in the peak window defined above. We follow the Bayesian procedure of Ref. [6], which is based on an unbinned extended maximum likelihood analysis. We calculate the limits using the 8 TeV data alone, as well as from a combination of the 8 TeV and 7 TeV data sets. Mass-dependent ratios of parton distribution functions (PDF) at $\sqrt{s} = 7$ TeV and 8 TeV are used as an additional input to derive limits on R_σ at 8 TeV, $R_{\sigma,8\text{TeV}}$, that combine both data sets. The CTEQ6.1 LO PDF set [34] was used to calculate these ratios, and the result was cross-checked with the MSTW2008 PDF set [35]. The CTEQ and MSTW calculations agreed well and the uncertainty in this ratio does not significantly contribute to the final result. The most significant uncertainty in the limit computation is associated

Table 1
The dilepton event count in the control region $120 < m_{\ell\ell} < 200$ GeV and in the search region $m_{\ell\ell} > 200$ GeV for the $\sqrt{s} = 8$ TeV data set. The total background is the sum of the events for the standard model processes listed. Uncertainties represent a quadrature sum of statistical and systematic uncertainties.

Source	Number of events			
	Dimuon sample		Dielectron sample	
	(120–200) GeV	>200 GeV	(120–200) GeV	>200 GeV
Data	13 831	3503	12 030	2904
Total background	$13\,010 \pm 590$	$3\,630 \pm 160$	$12\,240 \pm 590$	$2\,970 \pm 260$
Z/γ^*	$11\,700 \pm 570$	$2\,920 \pm 140$	$10\,660 \pm 530$	$2\,200 \pm 220$
$t\bar{t}$ + others	$1\,280 \pm 150$	698 ± 78	$1\,220 \pm 180$	560 ± 80
Jets	26 ± 3	10 ± 1	360 ± 180	210 ± 110

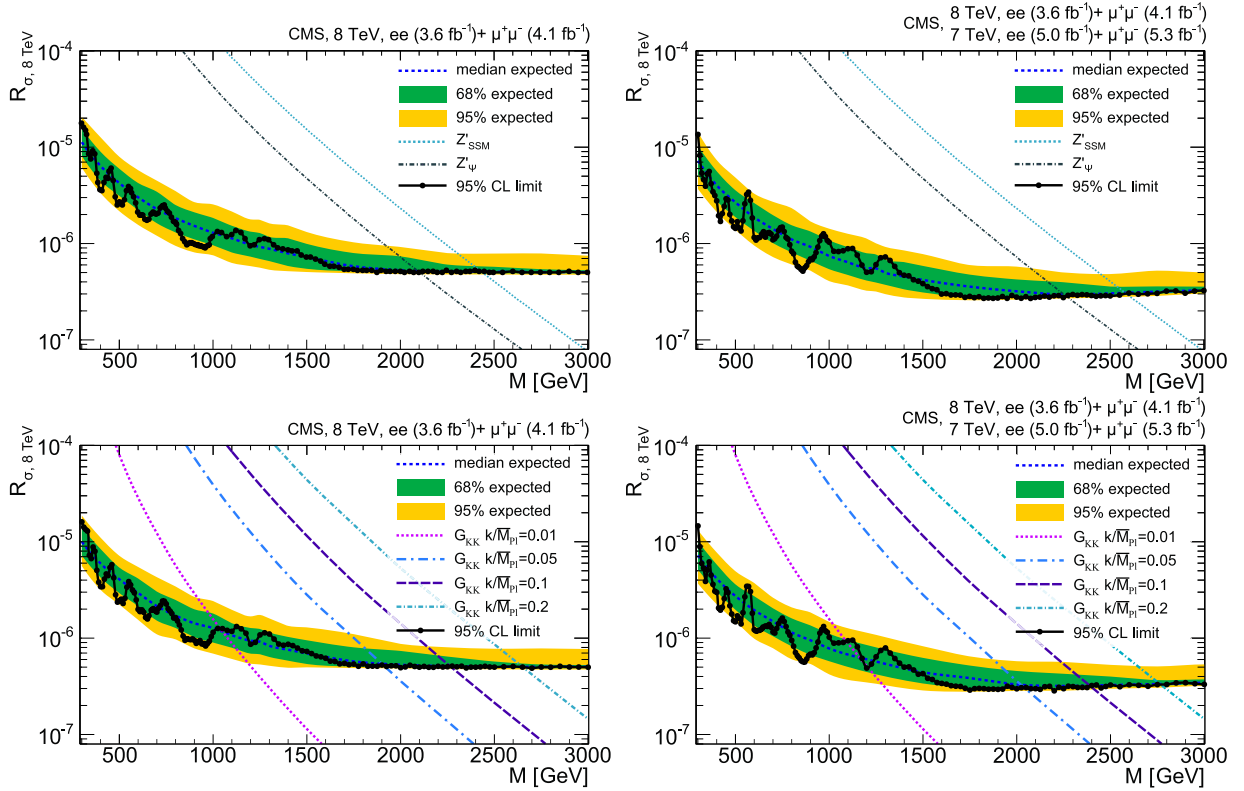


Fig. 2. Upper limits on the ratio R_σ of the production cross section times branching fraction into lepton pairs to the same quantity for Z bosons, as a function of resonance mass M for spin-1 (top) and spin-2 (bottom) boson production. The left plots are for the 8 TeV data set while the right plots are for the combination of the 7 and 8 TeV data sets. For the spin-2 case, the 7 and 8 TeV data set combination is only valid for models that have the same fraction of $q\bar{q}$ to coupling as an RS graviton. For the spin-1 case no coupling is considered. Shaded bands identified in the legend correspond to the 68% and 95% quantiles for the expected limits, respectively.

with our understanding of the selection efficiency and detector acceptance ratio for Z' bosons relative to the Z , denoted R_ϵ . The uncertainty in the total lepton selection efficiency at high mass dominates the R_ϵ uncertainty. The lepton selection efficiencies are measured in data up to $p_T \sim 500$ GeV, but above 100 GeV the uncertainties in these measurements become large. This leads to a total uncertainty in R_ϵ of 3% for the dimuon channel and 8% for the dielectron channel after including PDF uncertainties in the acceptance. The effects of misalignment, higher order corrections to the background shape, and the uncertainty in backgrounds due to jets misidentified as leptons have only negligible impact on the limits. The upper limits on the ratio R_σ for spin-1 and spin-2 particles obtained from the dilepton combined mass spectra are shown in Fig. 2. Table 2 shows the limits on R_σ converted into mass limits on specific models. The resonance is assumed to be narrow, meaning that the detector resolution dominates the width of the peak. The Z'_ψ with a relative width of 0.6% is therefore considered narrow. A wider resonance, such as the Z'_{SSM} , which has a width of

3%, will have more background under the peak. Consequently, we would set weaker limits on its production cross sections. The two cases provide similar results when there is very little background after all selection criteria have been imposed. This occurs around 1.4 TeV. For a resonance below 1.4 TeV not to have been discovered, it must have a small coupling and therefore be narrow. For the spin-2 case an additional requirement is that the ratio of $g\bar{g}$ to $q\bar{q}$ production of the resonance must be the same as the ratio for an RS graviton. The combination of the 7 and 8 TeV data sets relies on this assumption, as $g\bar{g}$ and $q\bar{q}$ cross sections scale differently with \sqrt{s} . For the spin-1 case, no $g\bar{g}$ coupling is considered. The Z' and RS Graviton cross sections are calculated using the PYTHIA event generator with the CTEQ6.1 PDF set. The LO cross sections are corrected for next-to-leading (NLO) or NNLO QCD contributions using the same k -factors as Ref. [6]. A mass dependent NNLO k -factor calculated with ZWPRODP [36–38] is used for the Z' models. A flat NLO k -factor of 1.6 is applied to the RS graviton cross sections [39].

Table 2

Mass lower limits at the 95% CL on specific models obtained using dilepton data at $\sqrt{s} = 7$ and 8 TeV separately and combined. The 7 TeV results are taken from Ref. [6].

Model	Mass limits (GeV)		
	7 TeV	8 TeV	7 + 8 TeV
Z'_{SSM}	2330	2440	2590
Z'_ψ	2000	2110	2260
$G_{KK} (k/\overline{M}_{Pl} = 0.1)$	2140	2260	2390
$G_{KK} (k/\overline{M}_{Pl} = 0.05)$	1810	1900	2030

6. Summary

The CMS Collaboration has searched for heavy narrow resonances in dimuon and dielectron invariant mass spectra. The search combined data samples from pp collisions at $\sqrt{s} = 7$ TeV [6] and 8 TeV. The $\sqrt{s} = 8$ TeV data sets have integrated luminosities of 4.1 fb^{-1} (3.6 fb^{-1}) for the dimuon (dielectron) channel. The $\sqrt{s} = 7$ TeV data sets have integrated luminosities of 5.3 fb^{-1} (5.0 fb^{-1}) for the dimuon (dielectron) channel, and have been previously published [6]. The measured dilepton mass spectra are consistent with predictions from the standard model. Upper limits on the cross section times branching fraction for the production of new heavy narrow resonances relative to Z boson production are presented. The findings exclude, at 95% CL, a Z'_{SSM} with standard-model-like couplings below 2590 GeV and the superstring-inspired Z'_ψ below 2260 GeV. An RS graviton with k/\overline{M}_{Pl} of 0.1 (0.05) is excluded below 2390 (2030) GeV. These are the most restrictive limits to date for the classes of models considered.

Acknowledgements

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 centers 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: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MEYS (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); MoER, SF0690030s09 and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Republic of Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); MSI (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MON, RosAtom, RAS and RFBR (Russia); MSTD (Serbia); SEIDI and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); ThePCenter, IPST and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

Open access

This article is published Open Access at sciencedirect.com. It is distributed under the terms of the Creative Commons Attribution

License 3.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original authors and source are credited.

References

- [1] L. Evans, P. Bryant (Eds.), JINST 3 (2008) S08001, <http://dx.doi.org/10.1088/1748-0221/3/08/S08001>.
- [2] G. Altarelli, B. Mele, M. Ruiz-Altaba, Z. Phys. C 45 (1989) 109, <http://dx.doi.org/10.1007/BF01556677>.
- [3] A. Leike, Phys. Rep. 317 (1999) 143, [http://dx.doi.org/10.1016/S0370-1573\(98\)00133-1](http://dx.doi.org/10.1016/S0370-1573(98)00133-1), arXiv:hep-ph/9805494.
- [4] L. Randall, R. Sundrum, Phys. Rev. Lett. 83 (1999) 4690, <http://dx.doi.org/10.1103/PhysRevLett.83.4690>, arXiv:hep-th/9906064.
- [5] L. Randall, R. Sundrum, Phys. Rev. Lett. 83 (1999) 3370, <http://dx.doi.org/10.1103/PhysRevLett.83.3370>, arXiv:hep-ph/9905221.
- [6] CMS Collaboration, Phys. Lett. B 714 (2012) 158, <http://dx.doi.org/10.1016/j.physletb.2012.06.051>, arXiv:1206.1849.
- [7] ATLAS Collaboration, JHEP 11 (2012) 138, [http://dx.doi.org/10.1007/JHEP11\(2012\)138](http://dx.doi.org/10.1007/JHEP11(2012)138), arXiv:1209.2535.
- [8] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 102 (2009) 031801, <http://dx.doi.org/10.1103/PhysRevLett.102.031801>, arXiv:0810.2059.
- [9] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 102 (2009) 091805, <http://dx.doi.org/10.1103/PhysRevLett.102.091805>, arXiv:0811.0053.
- [10] V.M. Abazov, et al., D0 Collaboration, Phys. Rev. Lett. 104 (2010) 241802, <http://dx.doi.org/10.1103/PhysRevLett.104.241802>, arXiv:1004.1826.
- [11] V.M. Abazov, et al., D0 Collaboration, Phys. Lett. B 695 (2011) 88, <http://dx.doi.org/10.1016/j.physletb.2010.10.059>, arXiv:1008.2023.
- [12] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 107 (2011) 051801, <http://dx.doi.org/10.1103/PhysRevLett.107.051801>, arXiv:1103.4650.
- [13] T. Aaltonen, et al., CDF Collaboration, Phys. Rev. Lett. 106 (2011) 121801, <http://dx.doi.org/10.1103/PhysRevLett.106.121801>, arXiv:1101.4578.
- [14] G. Abbiendi, et al., OPAL Collaboration, Eur. Phys. J. C 33 (2004) 173, <http://dx.doi.org/10.1140/epjc/s2004-01595-9>, arXiv:hep-ex/0309053.
- [15] J. Abdallah, et al., DELPHI Collaboration, Eur. Phys. J. C 45 (2006) 589, <http://dx.doi.org/10.1140/epjc/s2005-02461-0>, arXiv:hep-ex/0512012.
- [16] P. Achard, et al., L3 Collaboration, Eur. Phys. J. C 47 (2006) 1, <http://dx.doi.org/10.1140/epjc/s2006-02539-1>, arXiv:hep-ex/0603022.
- [17] S. Schael, et al., ALEPH Collaboration, Eur. Phys. J. C 49 (2007) 411, <http://dx.doi.org/10.1140/epjc/s10052-006-0156-8>, arXiv:hep-ex/0609051.
- [18] R. Gavin, Y. Li, F. Petriello, S. Quackenbush, Comput. Phys. Commun. 182 (2011) 2388, <http://dx.doi.org/10.1016/j.cpc.2011.06.008>, arXiv:1011.3540.
- [19] CMS Collaboration, JINST 3 (2008) S08004, <http://dx.doi.org/10.1088/1748-0221/3/08/S08004>.
- [20] CMS Collaboration, The TriDAS Project Technical Design Report, vol. I: The Trigger Systems, CMS TDR CERN/LHCC 2000-038, CERN, 2000, <http://cdsweb.cern.ch/record/706847>.
- [21] CMS Collaboration, The TriDAS Project Technical Design Report, vol. II: Data Acquisition and High-Level Trigger, CMS TDR CERN/LHCC 2002-026, CERN, 2002, <http://cdsweb.cern.ch/record/578006>.
- [22] CMS Collaboration, JHEP 01 (2011) 080, [http://dx.doi.org/10.1007/JHEP01\(2011\)080](http://dx.doi.org/10.1007/JHEP01(2011)080), arXiv:1012.2466.
- [23] CMS Collaboration, JINST 7 (2012) P10002, <http://dx.doi.org/10.1088/1748-0221/7/10/P10002>, arXiv:1206.4071.
- [24] CMS Collaboration, CMS Physics Analysis Summary CMS-PAS-EGM-10-004, 2010, <http://cdsweb.cern.ch/record/1299116>.
- [25] CMS Collaboration, Phys. Lett. B 692 (2010) 83, <http://dx.doi.org/10.1016/j.physletb.2010.07.033>, arXiv:1005.5332.
- [26] M. Cacciari, G.P. Salam, Phys. Lett. B 659 (2008) 119, <http://dx.doi.org/10.1016/j.physletb.2007.09.077>, arXiv:0707.1378.
- [27] D.A. Petyt, Nucl. Instr. Meth. A 695 (2012) 293, <http://dx.doi.org/10.1016/j.nima.2011.10.025>.
- [28] T. Sjöstrand, S. Mrenna, P.Z. Skands, JHEP 05 (2006) 026, <http://dx.doi.org/10.1088/1126-6708/2006/05/026>, arXiv:hep-ph/0603175.
- [29] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer, JHEP 06 (2011) 128, [http://dx.doi.org/10.1007/JHEP06\(2011\)128](http://dx.doi.org/10.1007/JHEP06(2011)128), arXiv:1106.0522.
- [30] P. Nason, JHEP 11 (2004) 040, <http://dx.doi.org/10.1088/1126-6708/2004/11/040>, arXiv:hep-ph/0409146.
- [31] S. Frixione, P. Nason, C. Oleari, JHEP 11 (2007) 070, <http://dx.doi.org/10.1088/1126-6708/2007/11/070>, arXiv:0709.2092.
- [32] S. Alioli, P. Nason, C. Oleari, E. Re, JHEP 06 (2010) 043, [http://dx.doi.org/10.1007/JHEP06\(2010\)043](http://dx.doi.org/10.1007/JHEP06(2010)043), arXiv:1002.2581.
- [33] E. Re, Eur. Phys. J. C 71 (2011) 1547, <http://dx.doi.org/10.1140/epjc/s10052-011-1547-z>, arXiv:1009.2450.
- [34] J. Pumplin, D.R. Stump, J. Huston, H.-L. Lai, P. Nadolsky, W.-K. Tung, JHEP 07 (2002) 012, <http://dx.doi.org/10.1088/1126-6708/2002/07/012>, arXiv:hep-ph/0201195.

- [35] A.D. Martin, W.J. Stirling, R.S. Thorne, G. Watt, *Eur. Phys. J. C* 63 (2009) 189, <http://dx.doi.org/10.1140/epjc/s10052-009-1072-5>, arXiv:0901.0002.
- [36] E. Accomando, A. Belyaev, L. Fedeli, S.F. King, C. Shepherd-Themistocleous, *Phys. Rev. D* 83 (2011) 075012, <http://dx.doi.org/10.1103/PhysRevD.83.075012>, arXiv:1010.6058.
- [37] R. Hamberg, W.L. van Neerven, T. Matsuura, *Nucl. Phys. B* 359 (1991) 343, [http://dx.doi.org/10.1016/0550-3213\(91\)90064-5](http://dx.doi.org/10.1016/0550-3213(91)90064-5);
- R. Hamberg, W.L. van Neerven, T. Matsuura, *Nucl. Phys. B* 644 (2002) 403 (Erratum).
- [38] W.L. van Neerven, E.B. Zijlstra, *Nucl. Phys. B* 382 (1992) 11, [http://dx.doi.org/10.1016/0550-3213\(92\)90078-P](http://dx.doi.org/10.1016/0550-3213(92)90078-P);
- W.L. van Neerven, E.B. Zijlstra, *Nucl. Phys. B* 680 (2004) 513 (Erratum).
- [39] P. Mathews, V. Ravindran, K. Sridhar, *JHEP* 10 (2005) 031, <http://dx.doi.org/10.1088/1126-6708/2005/10/031>, arXiv:hep-ph/0506158.

CMS Collaboration

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

Yerevan Physics Institute, Yerevan, Armenia

W. Adam, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan¹, M. Friedl, R. Frühwirth¹, V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler¹, W. Kiesenhofer, V. Knünz, M. Krammer¹, I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka[†], D. Rabady², B. Rahbaran, C. Rohringer, H. Rohringer, R. Schöfbeck, J. Strauss, A. Taurok, W. Waltenberger, C.-E. Wulz¹

Institut für Hochenergiephysik der OeAW, Wien, Austria

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

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

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

Universiteit Antwerpen, Antwerpen, Belgium

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

Vrije Universiteit Brussel, Brussel, Belgium

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

Université Libre de Bruxelles, Bruxelles, Belgium

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

Ghent University, Ghent, Belgium

S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco³, J. Hollar, V. Lemaitre, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrkowski, J.M. Vizan Garcia

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

N. Belyi, T. Caebegs, E. Daubie, G.H. Hammad

Université de Mons, Mons, Belgium

G.A. Alves, M. Correa Martins Junior, T. Martins, M.E. Pol, M.H.G. Souza

Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil

W.L. Aldá Júnior, W. Carvalho, A. Custódio, E.M. Da Costa, D. De Jesus Damiao, C. De Oliveira Martins, S. Fonseca De Souza, H. Malbouisson, M. Malek, D. Matos Figueiredo, L. Mundim, H. Nogima,

W.L. Prado Da Silva, A. Santoro, L. Soares Jorge, A. Sznajder, A. Vilela Pereira

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

T.S. Anjos^b, C.A. Bernardes^b, F.A. Dias^{a,4}, T.R. Fernandez Perez Tomei^a, E.M. Gregores^b, C. Lagana^a, F. Marinho^a, P.G. Mercadante^b, S.F. Novaes^a, Sandra S. Padula^a

^a *Universidade Estadual Paulista, São Paulo, Brazil*

^b *Universidade Federal do ABC, São Paulo, Brazil*

V. Genchev², P. Iaydjiev², S. Piperov, M. Rodozov, S. Stoykova, G. Sultanov, V. Tcholakov, R. Trayanov, M. Vutova

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria

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

University of Sofia, Sofia, Bulgaria

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

Institute of High Energy Physics, Beijing, China

C. Asawatangtrakuldee, Y. Ban, Y. Guo, W. Li, S. Liu, Y. Mao, S.J. Qian, H. Teng, D. Wang, L. Zhang, W. Zou

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

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

Universidad de Los Andes, Bogota, Colombia

N. Godinovic, D. Lelas, R. Plestina⁵, D. Polic, I. Puljak²

Technical University of Split, Split, Croatia

Z. Antunovic, M. Kovac

University of Split, Split, Croatia

V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

Institute Rudjer Boskovic, Zagreb, Croatia

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

University of Cyprus, Nicosia, Cyprus

M. Finger, M. Finger Jr.

Charles University, Prague, Czech Republic

Y. Assran⁶, S. Elgammal⁷, A. Ellithi Kamel⁸, A.M. Kuotb Awad⁹, M.A. Mahmoud⁹, A. Radi^{10,11}

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

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

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia

P. Eerola, G. Fedi, M. Voutilainen

Department of Physics, University of Helsinki, 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

Helsinki Institute of Physics, Helsinki, Finland

A. Korpela, T. Tuuva

Lappeenranta University of Technology, Lappeenranta, Finland

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, M. Titov

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

S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Bluj¹², P. Busson, C. Charlot, N. Daci, T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenaer, P. Miné, C. Mironov, I.N. Naranjo, M. Nguyen, C. Ochando, P. Paganini, D. Sabes, R. Salerno, Y. Sirois, C. Veelken, A. Zabi

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

J.-L. Agram¹³, J. Andrea, D. Bloch, D. Bodin, J.-M. Brom, M. Cardaci, E.C. Chabert, C. Collard, E. Conte¹³, F. Drouhin¹³, J.-C. Fontaine¹³, D. Gelé, U. Goerlach, P. Juillot, A.-C. Le Bihan, P. Van Hove

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

S. Beauceron, N. Beaupere, O. Bondu, G. Boudoul, S. Brochet, J. Chasserat, R. Chierici², D. Contardo, P. Depasse, H. El Mamouni, J. Fay, S. Gascon, M. Gouzevitch, B. Ille, T. Kurca, M. Lethuillier, L. Mirabito, S. Perries, L. Sgandurra, V. Sordini, Y. Tschudi, P. Verdier, S. Viret

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

Z. Tsamalaidze¹⁴

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

C. Autermann, S. Beranek, B. Calpas, 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. Zhukov¹⁵

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

M. Ata, J. Caudron, E. Dietz-Laursonn, D. Duchardt, M. Erdmann, R. Fischer, A. Güth, T. Hebbeker, C. Heidemann, K. Hoepfner, D. Klingebiel, P. Kreuzer, M. Merschmeyer, A. Meyer, M. Olschewski, P. Papacz, H. Pieta, H. Reithler, S.A. Schmitz, L. Sonnenschein, J. Steggemann, D. Teyssier, S. Thüer, M. Weber

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

M. Bontenackels, V. Cherepanov, Y. Erdogan, G. Flügge, H. Geenen, M. Geisler, W. Haj Ahmad, F. Hoehle, B. Kargoll, T. Kress, Y. Kuessel, J. Lingemann², A. Nowack, L. Perchalla, O. Pooth, P. Sauerland, A. Stahl

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

M. Aldaya Martin, J. Behr, W. Behrenhoff, U. Behrens, M. Bergholz¹⁶, A. Bethani, K. Borras, A. Burgmeier, A. Cakir, L. Calligaris, A. Campbell, E. Castro, F. Costanza, D. Dammann, C. Diez Pardos, T. Dorland, G. Eckerlin, D. Eckstein, G. Flucke, A. Geiser, I. Glushkov, P. Gunnellini, S. Habib, J. Hauk, G. Hellwig, H. Jung, M. Kasemann, P. Katsas, C. Kleinwort, H. Kluge, A. Knutsson, M. Krämer, D. Krücker, E. Kuznetsova, W. Lange, J. Leonard, W. Lohmann¹⁶, B. Lutz, R. Mankel, I. Marfin, M. Marienfeld, I.-A. Melzer-Pellmann, A.B. Meyer, J. Mnich, A. Mussgiller, S. Naumann-Emme, O. Novgorodova,

F. Nowak, J. Olzem, H. Perrey, A. Petrukhin, D. Pitzl, A. Raspereza, P.M. Ribeiro Cipriano, C. Riedl, E. Ron, M. Rosin, J. Salfeld-Nebgen, R. Schmidt¹⁶, T. Schoerner-Sadenius, N. Sen, A. Spiridonov, M. Stein, R. Walsh, C. Wissing

Deutsches Elektronen-Synchrotron, Hamburg, Germany

V. Blobel, H. Enderle, J. Erfle, U. Gebbert, M. Görner, M. Gosselink, J. Haller, T. Hermanns, R.S. Höing, K. Kaschube, G. Kaussen, H. Kirschenmann, R. Klanner, J. Lange, T. Peiffer, N. Pietsch, D. Rathjens, C. Sander, H. Schettler, P. Schleper, E. Schlieckau, A. Schmidt, M. Schröder, T. Schum, M. Seidel, J. Sibille¹⁷, V. Sola, H. Stadie, G. Steinbrück, J. Thomsen, L. Vanelderden

University of Hamburg, Hamburg, Germany

C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff², C. Hackstein, F. Hartmann², T. Hauth², M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov¹⁵, J.R. Komaragiri, P. Lobelle Pardo, D. Martschei, S. Mueller, Th. Müller, M. Niegel, A. Nürnberg, O. Oberst, A. Oehler, J. Ott, G. Quast, K. Rabbertz, F. Ratnikov, N. Ratnikova, S. Röcker, F.-P. Schilling, G. Schott, H.J. Simonis, F.M. Stober, D. Troendle, R. Ulrich, J. Wagner-Kuhr, S. Wayand, T. Weiler, M. Zeise

Institut für Experimentelle Kernphysik, Karlsruhe, Germany

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

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

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

University of Athens, Athens, Greece

I. Evangelou, C. Foudas, P. Kokkas, N. Manthos, I. Papadopoulos

University of Ioánnina, Ioánnina, Greece

G. Bencze, C. Hajdu, P. Hidas, D. Horvath¹⁸, F. Sikler, V. Veszpremi, G. Vesztergombi¹⁹, A.J. Zsigmond

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

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

Institute of Nuclear Research ATOMKI, Debrecen, Hungary

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

University of Debrecen, Debrecen, Hungary

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

Panjab University, Chandigarh, India

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

University of Delhi, Delhi, India

S. Banerjee, S. Bhattacharya, K. Chatterjee, S. Dutta, B. Gomber, Sa. Jain, Sh. Jain, R. Khurana, A. Modak, S. Mukherjee, D. Roy, S. Sarkar, M. Sharan

Saha Institute of Nuclear Physics, Kolkata, India

A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty², L.M. Pant, P. Shukla

Bhabha Atomic Research Centre, Mumbai, India

T. Aziz, R.M. Chatterjee, S. Ganguly, M. Guchait²⁰, A. Gurtu²¹, M. Maity²², G. Majumder, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research – EHEP, Mumbai, India

S. Banerjee, S. Dugad

Tata Institute of Fundamental Research – HECR, Mumbai, India

H. Arfaei²³, H. Bakhshiansohi, S.M. Etesami²⁴, A. Fahim²³, M. Hashemi²⁵, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdiabadi, B. Safarzadeh²⁶, M. Zeinali

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

M. Abbrescia^{a,b}, L. Barbone^{a,b}, C. Calabria^{a,b,2}, S.S. Chhibra^{a,b}, A. Colaleo^a, D. Creanza^{a,c}, N. De Filippis^{a,c,2}, M. De Palma^{a,b}, L. Fiore^a, G. Iaselli^{a,c}, G. Maggi^{a,c}, M. Maggi^a, B. Marangelli^{a,b}, S. My^{a,c}, S. Nuzzo^{a,b}, N. Pacifico^a, A. Pompili^{a,b}, G. Pugliese^{a,c}, G. Selvaggi^{a,b}, L. Silvestris^a, G. Singh^{a,b}, R. Venditti^{a,b}, P. Verwilligen^a, G. Zito^a

^a INFN Sezione di Bari, Bari, Italy

^b Università di Bari, Bari, Italy

^c Politecnico di Bari, Bari, Italy

G. Abbiendi^a, A.C. Benvenuti^a, D. Bonacorsi^{a,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}, P. Giacomelli^a, C. Grandi^a, L. Guiducci^{a,b}, S. Marcellini^a, G. Masetti^a, M. Meneghelli^{a,b,2}, 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.P. Siroli^{a,b}, N. Tosi^{a,b}, R. Travaglini^{a,b}

^a INFN Sezione di Bologna, Bologna, Italy

^b Università di Bologna, Bologna, Italy

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

^a INFN Sezione di Catania, Catania, Italy

^b Università di Catania, Catania, Italy

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

^a INFN Sezione di Firenze, Firenze, Italy

^b Università di Firenze, Firenze, Italy

L. Benussi, S. Bianco, S. Colafranceschi²⁷, F. Fabbri, D. Piccolo

INFN Laboratori Nazionali di Frascati, Frascati, Italy

P. Fabbricatore^a, R. Musenich^a, S. Tosi^{a,b}

^a INFN Sezione di Genova, Genova, Italy

^b Università di Genova, Genova, Italy

A. Benaglia^a, F. De Guio^{a,b}, L. Di Matteo^{a,b,2}, S. Fiorendi^{a,b}, S. Gennai^{a,2}, A. Ghezzi^{a,b}, S. Malvezzi^a, R.A. Manzoni^{a,b}, A. Martelli^{a,b}, A. Massironi^{a,b}, 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}

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

^b Università di Milano-Bicocca, Milano, Italy

S. Buontempo^a, N. Cavallo^{a,c}, A. De Cosa^{a,b,2}, O. Dogangun^{a,b}, F. Fabozzi^{a,c}, A.O.M. Iorio^{a,b}, L. Lista^a, S. Meola^{a,d,28}, M. Merola^a, P. Paolucci^{a,2}

^a INFN Sezione di Napoli, Napoli, Italy

^b Università di Napoli 'Federico II', Napoli, Italy

^c *Università della Basilicata (Potenza), Napoli, Italy*^d *Università G. Marconi (Roma), Napoli, Italy*

P. Azzi ^a, N. Bacchetta ^{a,2}, A. Branca ^{a,b,2}, R. Carlin ^{a,b}, P. Checchia ^a, T. Dorigo ^a, F. Gasparini ^{a,b},
 U. 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}, F. Montecassiano ^a, J. Pazzini ^{a,b}, N. Pozzobon ^{a,b}, P. Ronchese ^{a,b}, F. Simonetto ^{a,b},
 E. Torassa ^a, M. Tosi ^{a,b}, S. Vanini ^{a,b}, P. Zotto ^{a,b}, A. Zucchetta ^{a,b}, G. Zumerle ^{a,b}

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

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

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

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

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

P. Azzurri ^{a,c}, G. Bagliesi ^a, J. Bernardini ^a, T. Boccali ^a, G. Broccolo ^{a,c}, R. Castaldi ^a, R.T. D'Agnolo ^{a,c,2},
 R. Dell'Orso ^a, F. Fiori ^{a,b,2}, L. Foà ^{a,c}, A. Giassi ^a, A. Kraan ^a, F. Ligabue ^{a,c}, T. Lomtadze ^a, L. Martini ^{a,29},
 A. Messineo ^{a,b}, F. Palla ^a, A. Rizzi ^{a,b}, A.T. Serban ^{a,30}, P. Spagnolo ^a, P. Squillacioti ^{a,2}, R. Tenchini ^a,
 G. Tonelli ^{a,b}, A. Venturi ^a, P.G. Verdini ^a

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

L. Barone ^{a,b}, F. Cavallari ^a, D. Del Re ^{a,b}, M. Diemoz ^a, C. Fanelli ^{a,b}, M. Grassi ^{a,b,2}, E. Longo ^{a,b},
 P. Meridiani ^{a,2}, F. Micheli ^{a,b}, S. Nourbakhsh ^{a,b}, G. Organtini ^{a,b}, R. Paramatti ^a, S. Rahatlou ^{a,b}, L. Soffi ^{a,b}

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

N. Amapane ^{a,b}, R. Arcidiacono ^{a,c}, S. Argiro ^{a,b}, M. Arneodo ^{a,c}, C. Biino ^a, N. Cartiglia ^a, S. Casasso ^{a,b},
 M. Costa ^{a,b}, N. Demaria ^a, C. Mariotti ^{a,2}, S. Maselli ^a, E. Migliore ^{a,b}, V. Monaco ^{a,b}, M. Musich ^{a,2},
 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},
 A. Solano ^{a,b}, A. Staiano ^a

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

S. Belforte ^a, V. Candelise ^{a,b}, M. Casarsa ^a, F. Cossutti ^a, G. Della Ricca ^{a,b}, B. Gobbo ^a, M. Marone ^{a,b,2},
 D. Montanino ^{a,b,2}, A. Penzo ^a, A. Schizzi ^{a,b}

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

T.Y. Kim, S.K. Nam

Kangwon National University, Chunchon, Republic of Korea

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

Kyungpook National University, Daegu, Republic of Korea

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

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

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

Korea University, Seoul, Republic of Korea

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

University of Seoul, Seoul, Republic of Korea

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

Sungkyunkwan University, Suwon, Republic of Korea

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

Vilnius University, Vilnius, Lithuania

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

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

S. Carrillo Moreno, F. Vazquez Valencia

Universidad Iberoamericana, Mexico City, Mexico

H.A. Salazar Ibarquen

Benemerita Universidad Autonoma de Puebla, Puebla, Mexico

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

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

D. Krofcheck

University of Auckland, Auckland, New Zealand

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

University of Canterbury, Christchurch, New Zealand

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

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

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

National Centre for Nuclear Research, Swierk, Poland

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

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

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

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

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

Joint Institute for Nuclear Research, Dubna, Russia

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

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

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

Institute for Nuclear Research, Moscow, Russia

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

Institute for Theoretical and Experimental Physics, Moscow, Russia

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

Moscow State University, Moscow, Russia

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

P.N. Lebedev Physical Institute, Moscow, Russia

I. Azhgirey, I. Bayshev, S. Bitioukov, V. Grishin², V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourtchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

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

P. Adzic³¹, M. Djordjevic, M. Ekmedzic, D. Krpic³¹, J. Milosevic

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

M. Aguilar-Benitez, J. Alcaraz Maestre, P. Arce, C. Battilana, E. Calvo, M. Cerrada, M. Chamizo Llatas, N. Colino, B. De La Cruz, A. Delgado Peris, 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, A. Quintario Olmeda, I. Redondo, L. Romero, J. Santaolalla, M.S. Soares, C. Willmott

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

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

Universidad Autónoma de Madrid, Madrid, Spain

H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

Universidad de Oviedo, Oviedo, Spain

J.A. Brochero Cifuentes, I.J. Cabrillo, A. Calderon, S.H. Chuang, J. Duarte Campderros, M. Felcini³², M. Fernandez, G. Gomez, J. Gonzalez Sanchez, A. Graziano, C. Jorda, 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, I. Vila, R. Vilar Cortabitarte

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

D. Abbaneo, E. Auffray, G. Auzinger, M. Bachtis, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet⁵, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D'Enterria, A. Dabrowski, 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. Girone, M. Giunta, F. Glege, R. Gomez-Reino Garrido, P. Govoni, S. Gowdy, R. Guida, S. Gundacker, J. Hammer,

M. Hansen, P. Harris, C. Hartl, J. Harvey, B. Hegner, A. Hinzmann, V. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, Y.-J. Lee, P. Lenzi, C. Lourenço, N. Magini, T. Mäki, M. Malberti, L. Malgeri, M. Mannelli, L. Masetti, F. Meijers, S. Mersi, E. Meschi, R. Moser, M. Mulders, P. Musella, E. Nesvold, L. Orsini, E. Palencia Cortezon, E. Perez, L. Perrozzi, A. Petrilli, A. Pfeiffer, M. Pierini, M. Pimiä, D. Piparo, G. Polese, L. Quertenmont, A. Racz, W. Reece, J. Rodrigues Antunes, G. Rolandi³³, C. Rovelli³⁴, M. Rovere, H. Sakulin, F. Santanastasio, C. Schäfer, C. Schwick, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Sphicas³⁵, D. Spiga, A. Tsirou, G.I. Veres¹⁹, J.R. Vlimant, H.K. Wöhri, S.D. Worm³⁶, W.D. Zeuner

CERN, European Organization for Nuclear Research, Geneva, Switzerland

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

Paul Scherrer Institut, Villigen, Switzerland

F. Bachmair, L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Dissertori, M. Dittmar, M. Donegà, M. Dünser, P. Eller, J. Eugster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Luster, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägeli³⁷, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, F. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov³⁸, B. Stieger, M. Takahashi, L. Tauscher[†], A. Thea, K. Theofilatos, D. Treille, C. Urscheler, R. Wallny, H.A. Weber, L. Wehrli

Institute for Particle Physics, ETH Zurich, Zurich, Switzerland

C. Amsler³⁹, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougova, P. Robmann, H. Snoek, S. Tuppiti, M. Verzetti

Universität Zürich, Zurich, Switzerland

Y.H. Chang, K.H. Chen, C. Ferro, C.M. Kuo, S.W. Li, W. Lin, Y.J. Lu, A.P. Singh, R. Volpe, S.S. Yu

National Central University, Chung-Li, Taiwan

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

National Taiwan University (NTU), Taipei, Taiwan

B. Asavapibhop, N. Srimanobhas, N. Suwonjandee

Chulalongkorn University, Bangkok, Thailand

A. Adiguzel, M.N. Bakirci⁴⁰, S. Cerci⁴¹, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar⁴², A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk⁴³, A. Polatoz, K. Sogut⁴⁴, D. Sunar Cerci⁴¹, B. Tali⁴¹, H. Topakli⁴⁰, L.N. Vergili, M. Vergili

Cukurova University, Adana, Turkey

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

Middle East Technical University, Physics Department, Ankara, Turkey

E. Gülmez, B. Isildak⁴⁵, M. Kaya⁴⁶, O. Kaya⁴⁶, S. Ozkorucuklu⁴⁷, N. Sonmez⁴⁸

Bogazici University, Istanbul, Turkey

H. Bahtiyar, E. Barlas, K. Cankocak, Y.O. Günaydin⁴⁹, F.I. Vardarli, M. Yücel

Istanbul Technical University, Istanbul, Turkey

L. Levchuk

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

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. Newbold³⁶, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

University of Bristol, Bristol, United Kingdom

L. Basso⁵⁰, K.W. Bell, A. Belyaev⁵⁰, C. Brew, R.M. Brown, D.J.A. Cockerill, J.A. Coughlan, K. Harder, S. Harper, J. Jackson, B.W. Kennedy, E. Olaiya, D. Petyt, B.C. Radburn-Smith, C.H. Shepherd-Themistocleous, I.R. Tomalin, W.J. Womersley

Rutherford Appleton Laboratory, Didcot, United Kingdom

R. Bainbridge, G. Ball, R. Beuselinck, O. Buchmuller, D. Colling, N. Cripps, M. Cutajar, P. Dauncey, G. Davies, M. Della Negra, W. Ferguson, J. Fulcher, D. Futyan, A. Gilbert, A. Guneratne Bryer, G. Hall, Z. Hatherell, J. Hays, G. Iles, M. Jarvis, G. Karapostoli, L. Lyons, A.-M. Magnan, J. Marrouche, B. Mathias, R. Nandi, J. Nash, A. Nikitenko³⁸, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi⁵¹, D.M. Raymond, S. Rogerson, A. Rose, C. Seez, P. Sharp[†], A. Sparrow, M. Stoye, A. Tapper, M. Vazquez Acosta, T. Virdee, S. Wakefield, N. Wardle, T. Whyntie

Imperial College, London, United Kingdom

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

Brunel University, Uxbridge, United Kingdom

K. Hatakeyama, H. Liu, T. Scarborough

Baylor University, Waco, USA

O. Charaf, C. Henderson, P. Rumerio

The University of Alabama, Tuscaloosa, USA

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

Boston University, Boston, USA

J. Alimena, S. Bhattacharya, G. Christopher, D. Cutts, Z. Demiragli, A. Ferapontov, A. Garabedian, U. Heintz, S. Jabeen, G. Kukartsev, E. Laird, G. Landsberg, M. Luk, M. Narain, M. Segala, T. Sinthuprasith, T. Speer

Brown University, Providence, 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, D. Pellett, F. Ricci-Tam, B. Rutherford, M. Searle, J. Smith, M. Squires, M. Tripathi, R. Vasquez Sierra, R. Yohay

University of California, Davis, Davis, USA

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

University of California, Los Angeles, USA

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

University of California, Riverside, Riverside, USA

W. Andrews, J.G. Branson, G.B. Cerati, S. Cittolin, D. Evans, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrucciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech⁵², F. Würthwein, A. Yagil, J. Yoo

University of California, San Diego, La Jolla, USA

D. Barge, R. Bellan, C. Campagnari, M. D'Alfonso, T. Danielson, K. Flowers, P. Geffert, C. George, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magaña Villalba, N. Mccoll, V. Pavlunin, J. Ribnik, J. Richman, R. Rossin, D. Stuart, W. To, C. West

University of California, Santa Barbara, Santa Barbara, USA

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

California Institute of Technology, Pasadena, USA

V. Azzolini, A. Calamba, R. Carroll, T. Ferguson, Y. Iiyama, D.W. Jang, Y.F. Liu, M. Paulini, H. Vogel, I. Vorobiev

Carnegie Mellon University, Pittsburgh, USA

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

University of Colorado at Boulder, Boulder, USA

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. Tucker, J. Vaughan, Y. Weng, L. Winstrom, P. Wittich

Cornell University, Ithaca, USA

D. Winn

Fairfield University, Fairfield, USA

S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerdick, A. Beretvas, J. Berryhill, P.C. Bhat, 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, J. Hanlon, R.M. Harris, J. Hirschauer, B. Hooberman, S. Jindariani, M. Johnson, U. Joshi, B. Klima, S. Kunori, S. Kwan, C. Leonidopoulos⁵³, J. Linacre, D. Lincoln, R. Lipton, J. Lykken, K. Maeshima, J.M. Marraffino, V.I. Martinez Outschoorn, S. Maruyama, D. Mason, P. McBride, K. Mishra, S. Mrenna, Y. Musienko⁵⁴, C. Newman-Holmes, V. O'Dell, O. Prokofyev, E. Sexton-Kennedy, S. Sharma, W.J. Spalding, L. Spiegel, L. Taylor, S. Tkaczyk, N.V. Tran, L. Uplegger, E.W. Vaandering, R. Vidal, J. Whitmore, W. Wu, F. Yang, J.C. Yun

Fermi National Accelerator Laboratory, Batavia, USA

D. Acosta, P. Avery, D. Bourilkov, M. Chen, T. Cheng, 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. Milenovic⁵⁵, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

University of Florida, Gainesville, USA

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

Florida International University, Miami, USA

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

Florida State University, Tallahassee, USA

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

Florida Institute of Technology, Melbourne, USA

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

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

U. Akgun, E.A. Albayrak, B. Bilki⁵⁶, W. Clarida, F. Duru, S. Griffiths, J.-P. Merlo, H. Mermerkaya⁵⁷, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok⁵⁸, S. Sen, P. Tan, E. Tiras, J. Wetzel, T. Yetkin, K. Yi

The University of Iowa, Iowa City, USA

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

Johns Hopkins University, Baltimore, USA

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

The University of Kansas, Lawrence, USA

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

Kansas State University, Manhattan, USA

J. Gronberg, D. Lange, F. Rebassoo, D. Wright

Lawrence Livermore National Laboratory, Livermore, USA

A. Baden, 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, K. Pedro, A. Peterman, A. Skuja, J. Temple, M.B. Tonjes, S.C. Tonwar

University of Maryland, College Park, USA

A. Apyan, G. Bauer, J. Bendavid, W. Busza, E. Butz, I.A. Cali, M. Chan, V. Dutta, G. Gomez Ceballos, M. Goncharov, Y. Kim, M. Klute, K. Krajczar⁵⁹, A. Levin, P.D. Luckey, T. Ma, S. Nahn, C. Paus, D. Ralph, C. Roland, G. Roland, M. Rudolph, G.S.F. Stephans, F. Stöckli, K. Sumorok, K. Sung, D. Velicanu, E.A. Wenger, R. Wolf, B. Wyslouch, M. Yang, Y. Yilmaz, A.S. Yoon, M. Zanetti, V. Zhukova

Massachusetts Institute of Technology, Cambridge, USA

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

University of Minnesota, Minneapolis, USA

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

University of Mississippi, Oxford, USA

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

University of Nebraska-Lincoln, Lincoln, USA

A. Godshalk, I. Iashvili, S. Jain, A. Kharchilava, A. Kumar, S. Rappoccio, Z. Wan

State University of New York at Buffalo, Buffalo, USA

G. Alverson*, E. Barberis, D. Baumgartel, M. Chasco, J. Haley, D. Nash, T. Orimoto, D. Trocino, D. Wood, J. Zhang

Northeastern University, Boston, USA

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

Northwestern University, Evanston, USA

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

University of Notre Dame, Notre Dame, USA

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

The Ohio State University, Columbus, USA

E. Berry, P. Elmer, V. Halyo, P. Hebda, J. Hegeman, A. Hunt, P. Jindal, S.A. Koay, 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, S.C. Zenz, A. Zuranski

Princeton University, Princeton, USA

E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

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

S. Guragain, N. Parashar

Purdue University Calumet, Hammond, USA

A. Adair, B. Akgun, C. Boulahouache, K.M. Ecklund, F.J.M. Geurts, W. Li, B.P. Padley, R. Redjimi, J. Roberts, J. Zabel

Rice University, Houston, USA

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

University of Rochester, Rochester, USA

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

The Rockefeller University, New York, 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, A. Lath, S. Panwalkar, M. Park, R. Patel, V. Rekovic, J. Robles, K. Rose, S. Salur, S. Schnetzer, C. Seitz, S. Somalwar, R. Stone, S. Thomas, M. Walker

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

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

University of Tennessee, Knoxville, USA

R. Eusebi, W. Flanagan, J. Gilmore, T. Kamon⁶⁰, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safonov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas A&M University, College Station, USA

N. Akchurin, J. Damgov, C. Dragoiu, P.R. Duderø, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, I. Volobouev

Texas Tech University, Lubbock, USA

E. Appelt, A.G. Delannoy, C. Florez, S. Greene, A. Gurrola, W. Johns, P. Kurt, C. Maguire, A. Melo, M. Sharma, P. Sheldon, B. Snook, S. Tuo, J. Velkovska

Vanderbilt University, Nashville, USA

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

University of Virginia, Charlottesville, USA

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

Wayne State University, Detroit, USA

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

University of Wisconsin, Madison, USA

* Corresponding author.

† Deceased.

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

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

³ Also at National Institute of Chemical Physics and Biophysics, Tallinn, Estonia.

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 Zewail City of Science and Technology, Zewail, Egypt.

⁸ Also at Cairo University, Cairo, Egypt.

⁹ Also at Fayoum University, El-Fayoum, Egypt.

¹⁰ Also at British University in Egypt, Cairo, Egypt.

¹¹ Now at Ain Shams University, Cairo, Egypt.

¹² Also at National Centre for Nuclear Research, Swierk, Poland.

¹³ Also at Université de Haute-Alsace, Mulhouse, France.

¹⁴ Also at Joint Institute for Nuclear Research, Dubna, Russia.

¹⁵ Also at Moscow State University, Moscow, Russia.

¹⁶ Also at Brandenburg University of Technology, Cottbus, Germany.

¹⁷ Also at The University of Kansas, Lawrence, USA.

¹⁸ Also at Institute of Nuclear Research ATOMKI, Debrecen, Hungary.

¹⁹ Also at Eötvös Loránd University, Budapest, Hungary.

²⁰ Also at Tata Institute of Fundamental Research – HECR, Mumbai, India.

²¹ Now at King Abdulaziz University, Jeddah, Saudi Arabia.

²² Also at University of Visva-Bharati, Santiniketan, India.

²³ Also at Sharif University of Technology, Tehran, Iran.

²⁴ Also at Isfahan University of Technology, Isfahan, Iran.

²⁵ Also at Shiraz University, Shiraz, Iran.

²⁶ Also at Plasma Physics Research Center, Science and Research Branch, Islamic Azad University, Tehran, Iran.

²⁷ Also at Facoltà Ingegneria, Università di Roma, Roma, Italy.

²⁸ Also at Università degli Studi Guglielmo Marconi, Roma, Italy.

²⁹ Also at Università degli Studi di Siena, Siena, Italy.

³⁰ Also at University of Bucharest, Faculty of Physics, Bucuresti-Magurele, Romania.

³¹ Also at Faculty of Physics of University of Belgrade, Belgrade, Serbia.

³² Also at University of California, Los Angeles, USA.

³³ Also at Scuola Normale e Sezione dell'INFN, Pisa, Italy.

- ³⁴ Also at INFN Sezione di Roma, Roma, Italy.
- ³⁵ Also at University of Athens, Athens, Greece.
- ³⁶ Also at Rutherford Appleton Laboratory, Didcot, United Kingdom.
- ³⁷ Also at Paul Scherrer Institut, Villigen, Switzerland.
- ³⁸ Also at Institute for Theoretical and Experimental Physics, Moscow, Russia.
- ³⁹ Also at Albert Einstein Center for Fundamental Physics, Bern, Switzerland.
- ⁴⁰ Also at Gaziosmanpasa University, Tokat, Turkey.
- ⁴¹ Also at Adiyaman University, Adiyaman, Turkey.
- ⁴² Also at Izmir Institute of Technology, Izmir, Turkey.
- ⁴³ Also at The University of Iowa, Iowa City, USA.
- ⁴⁴ Also at Mersin University, Mersin, Turkey.
- ⁴⁵ Also at Ozyegin University, Istanbul, Turkey.
- ⁴⁶ Also at Kafkas University, Kars, Turkey.
- ⁴⁷ Also at Suleyman Demirel University, Isparta, Turkey.
- ⁴⁸ Also at Ege University, Izmir, Turkey.
- ⁴⁹ Also at Kahramanmaraş Sütcü Imam University, Kahramanmaraş, Turkey.
- ⁵⁰ Also at School of Physics and Astronomy, University of Southampton, Southampton, United Kingdom.
- ⁵¹ Also at INFN Sezione di Perugia; Università di Perugia, Perugia, Italy.
- ⁵² Also at Utah Valley University, Orem, USA.
- ⁵³ Now at University of Edinburgh, Scotland, Edinburgh, United Kingdom.
- ⁵⁴ Also at Institute for Nuclear Research, Moscow, Russia.
- ⁵⁵ Also at University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia.
- ⁵⁶ Also at Argonne National Laboratory, Argonne, USA.
- ⁵⁷ Also at Erzincan University, Erzincan, Turkey.
- ⁵⁸ Also at Mimar Sinan University, Istanbul, Istanbul, Turkey.
- ⁵⁹ Also at KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary.
- ⁶⁰ Also at Kyungpook National University, Daegu, Republic of Korea.