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

CMS Collaboration; Amsler, C; Chiochia, V; Kilminster, B; et al

DOI: https://doi.org/10.1016/j.physletb.2013.02.003

Posted at the Zurich Open Repository and Archive, University of Zurich
ZORA URL: https://doi.org/10.5167/uzh-75837
Journal Article

Originally published at:
CMS Collaboration; Amsler, C; Chiochia, V; Kilminster, B; et al (2013). Search for heavy narrow dilepton resonances in pp collisions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 8$ TeV. Physics Letters B, 720(1-3):63-82.
DOI: https://doi.org/10.1016/j.physletb.2013.02.003
Search for heavy narrow dilepton resonances in pp collisions at $\sqrt{s} = 7\text{ TeV}$ and $\sqrt{s} = 8\text{ TeV}$

The CMS Collaboration

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 $\sqrt{s} = 7\text{ TeV}$ and $8\text{ TeV}$ at the LHC, with integrated luminosities of up to 5.3 and 4.1 $\text{fb}^{-1}$, 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 $Z'_{\text{SSM}}$ resonance lighter than 2590 GeV, a superstring-inspired $Z'_{\psi}$ lighter than 2260 GeV, and Kaluza–Klein gravitons lighter than 2390 (2030) GeV, assuming that the coupling parameter $k/M_{\text{Pl}}$ is 0.10 (0.05). These are the most stringent limits to date.

Submitted to Physics Letters B

―See Appendix for the list of collaboration members
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 $k/M_{Pl}$, where $k$ is the curvature of the extra dimension and $M_{Pl}$ 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 $Z'_\psi$ masses are 2330 GeV and 2000 GeV [6], respectively. The best previous direct limits on RS graviton ($G_{KK}$) production are 2160 GeV for $k/M_{Pl} = 0.1$ [7] and 1810 GeV for $k/M_{Pl} = 0.05$ [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 ($R_{\sigma}$) 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.

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 76000 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, $\theta$ is the polar angle with respect to the direction of the counterclockwise proton beam.
We use $\phi$ 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].

# 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 $|\eta| < 2.1$. Di-electron 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 5$^\text{th}$ 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 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 $\Delta R$ 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
to 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 photodiodes (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 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 $\chi^2$ 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 \( t\bar{t}, tW, Z \to \tau^+\tau^- \), 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 \( \eta \), 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 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 \( R_{\sigma} \) 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 ±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
Figure 1: The invariant mass spectrum of $\mu^+\mu^-$ (left) and ee (right) 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.

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          | Dimuon sample | Dielectron sample |
|-----------------|---------------|-------------------|
|                 | (120–200) GeV | >200 GeV          |
|                 | (120–200) GeV | >200 GeV          |
| Data            | 1381          | 3503              |
| Total background| 13010 ± 590   | 3630 ± 160        |
| $Z/\gamma^*$    | 11700 ± 570   | 2920 ± 140        |
| $t\bar{t}$ + others | 1280 ± 150 | 698 ± 78          |
| Jets            | 26 ± 3        | 10 ± 1            |

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 $R_\gamma$ at 8 TeV, $R_{\gamma,8\text{TeV}}$, 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 with our understanding of the selection efficiency and detector acceptance ratio for $Z'$ bosons relative to the $Z$, denoted $R_\epsilon$. The uncertainty in the total lepton selection efficiency at high mass dominates the $R_\epsilon$ 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 $R_\epsilon$ 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 $R_\gamma$ 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 $R_\gamma$ 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 $Z'_{\psi}$ with a relative width of 0.6% is therefore considered narrow. A wider resonance, such as the $Z'_{\text{SSM}}$ 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 gg 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 gg and q\bar{q} cross sections scale differently with \sqrt{s}. For the spin-1 case, no gg 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].

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

Figure 2: Upper limits on the ratio \(R_\sigma\) 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 gg coupling as an RS graviton. For the spin-1 case no gg coupling is considered. Shaded bands identified in the legend correspond to the 68% and 95% quantiles for the expected limits, respectively.

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
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    |
| $Z'_{\psi}$    |                   | 2000  | 2110  | 2270    |
| $G_{KK} (k/\bar{M}_{Pl} = 0.1)$ |       | 2140  | 2260  | 2390    |
| $G_{KK} (k/\bar{M}_{Pl} = 0.05)$ |       | 1810  | 1900  | 2030    |

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 $Z'_{\psi}$ below 2260 GeV. An RS graviton with $k/\bar{M}_{Pl}$ 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 centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWF and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPEMIG (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).

References

[1] L. Evans and P. Bryant (editors), “LHC machine”, JINST 3 (2008) S08001, doi:10.1088/1748-0221/3/08/S08001.

[2] G. Altarelli, B. Mele, and M. Ruiz-Altaba, “Searching for new heavy vector bosons in p$\bar{p}$ colliders”, Z. Phys. C 45 (1989) 109, doi:10.1007/BF01556677.
[3] A. Leike, “The phenomenology of extra neutral gauge bosons”, *Phys. Rept.* 317 (1999) 143, [doi:10.1016/S0370-1573(98)00133-1](http://dx.doi.org/10.1016/S0370-1573(98)00133-1) [arXiv:hep-ph/9805494](http://arxiv.org/abs/hep-ph/9805494).

[4] L. Randall and R. Sundrum, “An alternative to compactification”, *Phys. Rev. Lett.* 83 (1999) 4690, [doi:10.1103/PhysRevLett.83.4690](http://dx.doi.org/10.1103/PhysRevLett.83.4690) [arXiv:hep-th/9906064](http://arxiv.org/abs/hep-th/9906064).

[5] L. Randall and R. Sundrum, “Large Mass Hierarchy from a Small Extra Dimension”, *Phys. Rev. Lett.* 83 (1999) 3370, [doi:10.1103/PhysRevLett.83.3370](http://dx.doi.org/10.1103/PhysRevLett.83.3370) [arXiv:hep-ph/9905221](http://arxiv.org/abs/hep-ph/9905221).

[6] CMS Collaboration, “Search for narrow resonances in dilepton mass spectra in pp collisions at $\sqrt{s} = 7$ TeV”, *Phys. Lett. B* 714 (2012) 158, [doi:10.1016/j.physletb.2012.06.051](http://dx.doi.org/10.1016/j.physletb.2012.06.051) [arXiv:1206.1849](http://arxiv.org/abs/1206.1849).

[7] ATLAS Collaboration, “Search for high-mass resonances decaying to dilepton final states in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector”, *JHEP* 11 (2012) 138, [doi:10.1007/JHEP11(2012)138](http://dx.doi.org/10.1007/JHEP11(2012)138) [arXiv:1209.2535](http://arxiv.org/abs/1209.2535).

[8] CDF Collaboration, “Search for High-Mass $e^+e^-$ Resonances in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* 102 (2009) 031801, [doi:10.1103/PhysRevLett.102.031801](http://dx.doi.org/10.1103/PhysRevLett.102.031801) [arXiv:0810.2059](http://arxiv.org/abs/0810.2059).

[9] CDF Collaboration, “Search for High-Mass Resonances Decaying to Dimuons at CDF”, *Phys. Rev. Lett.* 102 (2009) 091805, [doi:10.1103/PhysRevLett.102.091805](http://dx.doi.org/10.1103/PhysRevLett.102.091805) [arXiv:0811.0053](http://arxiv.org/abs/0811.0053).

[10] D0 Collaboration, “Search for Randall-Sundrum Gravitons in the Dielectron and Diphoton Final States with 5.4 fb$^{-1}$ of Data from $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Rev. Lett.* 104 (2010) 241802, [doi:10.1103/PhysRevLett.104.241802](http://dx.doi.org/10.1103/PhysRevLett.104.241802) [arXiv:1004.1826](http://arxiv.org/abs/1004.1826).

[11] D0 Collaboration, “Search for a heavy neutral gauge boson in the dielectron channel with 5.4 fb$^{-1}$ of $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV”, *Phys. Lett. B* 695 (2011) 88, [doi:10.1016/j.physletb.2010.10.059](http://dx.doi.org/10.1016/j.physletb.2010.10.059) [arXiv:1008.2023](http://arxiv.org/abs/1008.2023).

[12] CDF Collaboration, “Search for new dielectron resonances and Randall-Sundrum gravitons at the Collider Detector at Fermilab”, *Phys. Rev. Lett.* 107 (2011) 051801, [doi:10.1103/PhysRevLett.107.051801](http://dx.doi.org/10.1103/PhysRevLett.107.051801) [arXiv:1103.4650](http://arxiv.org/abs/1103.4650).

[13] CDF Collaboration, “Search for high mass resonances decaying to muon pairs in $\sqrt{s} = 1.96$ TeV p$\bar{p}$ collisions”, *Phys. Rev. Lett.* 106 (2011) 121801, [doi:10.1103/PhysRevLett.106.121801](http://dx.doi.org/10.1103/PhysRevLett.106.121801) [arXiv:1101.4578](http://arxiv.org/abs/1101.4578).

[14] OPAL Collaboration, “Tests of the standard model and constraints on new physics from measurements of fermion-pair production at 189–209 GeV at LEP”, *Eur. Phys. J. C* 33 (2004) 173, [doi:10.1140/epjc/s2004-01595-9](http://dx.doi.org/10.1140/epjc/s2004-01595-9) [arXiv:hep-ex/0309053](http://arxiv.org/abs/hep-ex/0309053).

[15] DELPHI Collaboration, “Measurement and interpretation of fermion-pair production at LEP energies above the Z resonance”, *Eur. Phys. J. C* 45 (2006) 589, [doi:10.1140/epjc/s2005-02461-0](http://dx.doi.org/10.1140/epjc/s2005-02461-0) [arXiv:hep-ex/0512012](http://arxiv.org/abs/hep-ex/0512012).

[16] L3 Collaboration, “Measurement of hadron and lepton-pair production in $e^+e^-$ collisions at $\sqrt{s} = 192–208$ GeV at LEP”, *Eur. Phys. J. C* 47 (2006) 1, [doi:10.1140/epjc/s2006-02539-1](http://dx.doi.org/10.1140/epjc/s2006-02539-1) [arXiv:hep-ex/0603022](http://arxiv.org/abs/hep-ex/0603022).
[17] ALEPH Collaboration, “Fermion pair production in $e^+e^-$ collisions at 189–209 GeV and constraints on physics beyond the standard model”, *Eur. Phys. J. C* 49 (2007) 411, doi:10.1140/epjc/s10052-006-0156-8, arXiv:hep-ex/0609051.

[18] R. Gavin et al., “FEWZ 2.0: A code for hadronic Z production at next-to-next-to-leading order”, *Comput. Phys. Commun.* 182 (2011) 2388, doi:10.1016/j.cpc.2011.06.008, arXiv:1011.3540.

[19] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[20] CMS Collaboration, “The TriDAS Project Technical Design Report, volume I: The trigger systems”, CMS TDR CERN/LHCC 2000-038, CERN, (2000).

[21] CMS Collaboration, “The TriDAS Project Technical Design Report, volume II: Data acquisition and high-level trigger”, CMS TDR CERN/LHCC 2002-026, CERN, (2002).

[22] CMS Collaboration, “Measurements of inclusive $W$ and $Z$ cross sections in pp collisions at $\sqrt{s} = 7$ TeV”, *JHEP* 01 (2011) 080, doi:10.1007/JHEP01(2011)080, arXiv:1012.2466.

[23] CMS Collaboration, “Performance of CMS muon reconstruction in pp collision events at $\sqrt{s} = 7$ TeV”, *JINST* 7 (2012) P10002, doi:10.1088/1748-0221/7/10/P10002, arXiv:1206.4071.

[24] CMS Collaboration, “Electron Reconstruction and Identification at $\sqrt{s} = 7$ TeV”, CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).

[25] CMS Collaboration, “Measurement of the charge ratio of atmospheric muons with the CMS detector”, *Phys. Lett. B* 692 (2010) 83, doi:10.1016/j.physletb.2010.07.033, arXiv:1005.5332.

[26] M. Cacciari and G. P. Salam, “Pileup subtraction using jet areas”, *Phys. Lett. B* 659 (2008) 119, doi:10.1016/j.physletb.2007.09.077, arXiv:0707.1378.

[27] D. A. Petyt, “Anomalous APD signals in the CMS Electromagnetic Calorimeter”, *Nucl. Instr. Meth. A* 695 (2012) 293, doi:10.1016/j.nima.2011.10.025.

[28] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 physics and manual”, *JHEP* 05 (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.

[29] J. Alwall et al., “MadGraph 5: Going Beyond”, *JHEP* 06 (2011) 128, doi:10.1007/JHEP06(2011)128, arXiv:1106.0522.

[30] P. Nason, “A new method for combining NLO QCD with shower Monte Carlo algorithms”, *JHEP* 11 (2004) 040, doi:10.1088/1126-6708/2004/11/040, arXiv:hep-ph/0409146.

[31] S. Frixione, P. Nason, and C. Oleari, “Matching NLO QCD computations with parton shower simulations: the POWHEG method”, *JHEP* 11 (2007) 070, doi:10.1088/1126-6708/2007/11/070, arXiv:0709.2092.

[32] S. Alioli et al., “A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX”, *JHEP* 06 (2010) 043, doi:10.1007/JHEP06(2010)043, arXiv:1002.2581.
[33] E. Re, “Single-top Wt-channel production matched with parton showers using the POWHEG method”, *Eur. Phys. J. C* 71 (2011) 1547, doi:10.1140/epjc/s10052-011-1547-z, arXiv:1009.2450.

[34] J. Pumplin et al., “New Generation of Parton Distributions with Uncertainties from Global QCD analysis”, *JHEP* 07 (2002) 012, doi:10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.

[35] A. D. Martin et al., “Parton distributions for the LHC”, *Eur. Phys. J. C* 63 (2009) 189, doi:10.1140/epjc/s10052-009-1072-5, arXiv:0901.0002.

[36] E. Accomando et al., “Z’ physics with early LHC data”, *Phys. Rev. D* 83 (2011) 075012, doi:10.1103/PhysRevD.83.075012, arXiv:1010.6058.

[37] R. Hamberg, W. L. van Neerven, and T. Matsuura, “A complete calculation of the order $\alpha_s^2$ correction to the Drell–Yan $K$ factor”, *Nucl. Phys. B* 359 (1991) 343, doi:10.1016/0550-3213(91)90064-5, Erratum: – ibid. B 644 (2002) 403.

[38] W. L. van Neerven and E. B. Zijlstra, “The O($\alpha_s^2$) corrected Drell–Yan $K$-factor in the DIS and $\overline{\text{MS}}$ schemes”, *Nucl. Phys. B* 382 (1992) 11, doi:10.1016/0550-3213(92)90078-P, Erratum – ibid. B 680 (2004) 513.

[39] P. Mathews, V. Ravindran, and K. Sridhar, “NLO-QCD corrections to dilepton production in the Randall-Sundrum model”, *JHEP* 10 (2005) 031, doi:10.1088/1126-6708/2005/10/031, arXiv:hep-ph/0506158.
A 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, E. Aguilo, T. Bergauer, M. Dragicevic, J. Erö, C. Fabjan, M. Friedl, R. Frühwirth, V.M. Ghete, N. Hörmann, J. Hrubec, M. Jeitler, W. Kiesenhofer, V. Knünz, M. Krammer, I. Krätschmer, D. Liko, I. Mikulec, M. Pernicka, D. Rabady, B. Rahbaran, C. Rohringer, H. Rohringer, R. Schönbeck, J. Strauss, A. Taurok, W. Waltenberger, C.-E. Wulz

National Centre for Particle and High Energy Physics, Minsk, Belarus
V. Mossolov, N. Shumeiko, J. Suarez Gonzalez

Universiteit Antwerpen, Antwerpen, Belgium
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

Vrije Universiteit Brussel, Brussel, 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, J. Orloff, J. Roche, R. Rougny, M. Selvaggi, H. Van Haevermaet, E. Yazgan, N. Zaganidis

Université Libre de Bruxelles, Bruxelles, 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

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, M. Sigamani, N. Strobbe, F. Thyssen, M. Tytgat, S. Walsh, E. Yazgan, N. Zaganidis

Université Catholique de Louvain, Louvain-la-Neuve, Belgium
S. Basegmez, G. Bruno, R. Castello, L. Ceard, C. Delaere, T. du Pree, D. Favart, L. Forthomme, A. Giammanco, J. Hollar, V. Lemaître, J. Liao, O. Militaru, C. Nuttens, D. Pagano, A. Pin, K. Piotrzkowski, J.M. Vizan Garcia

Université de Mons, Mons, Belgium
N. Beliy, T. Caebbers, E. Daubie, G.H. Hammad

Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
G.A. Alves, M. Correa Martins Junior, 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, 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. Szajder, A. Vilela Pereira

Universidade Estadual Paulista \textsuperscript{a}, Universidade Federal do ABC \textsuperscript{b}, São Paulo, Brazil
T.S. Anjos, C.A. Bernardes, F.A. Dias, T.R. Fernandez Perez Tomei, E.M. Gregores, C. Lagana, F. Marinho, P.G. Mercadante, S.F. Novaes, Sandra S. Padula

Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria
V. Genchev, P. Iaydjiev, 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,
X. Wang, Z. Wang, H. Xiao, M. Xu, J. Zang, Z. Zhang

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

Universidad de Los Andes, Bogota, Colombia
C. Avila, C.A. Carrillo Montoya, J.P. Gomez, B. Gomez Moreno, A.F. Osorio Oliveros,
J.C. Sanabria

Technical University of Split, Split, Croatia
N. Godinovic, D. Lelas, R. Plestina, D. Polic, I. Puljak

University of Split, Split, Croatia
Z. Antunovic, M. Kovac

Institute Rudjer Boskovic, Zagreb, Croatia
V. Brigljevic, S. Duric, K. Kadija, J. Luetic, D. Mekterovic, S. Morovic, L. Tikvica

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, S. Elgammal, A. Ellithi Kamel, A.M. Kuotb Awad, M.A. Mahmoud, A. Radi

National Institute of Chemical Physics and Biophysics, Tallinn, Estonia
M. Kadastik, M. Müntel, M. Murumaa, M. Raidal, L. Rebane, A. Tiko

Department of Physics, University of Helsinki, Helsinki, Finland
P. Eerola, G. Fedi, M. Voutilainen

Helsinki Institute of Physics, Helsinki, Finland
J. Härkönen, A. Heikkinen, V. Karimäki, R. Kinnunen, M.J. Korvelainen, 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
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, M. Titov

Laboratoire Leprince-Ringuet, Ecole Polytechnique, IN2P3-CNRS, Palaiseau, France
S. Baffioni, F. Beaudette, L. Benhabib, L. Bianchini, M. Blujić, P. Busson, C. Charlot, N. Daci,
T. Dahms, M. Dalchenko, L. Dobrzynski, A. Florent, R. Granier de Cassagnac, M. Haguenaier,
Institut Pluridisciplinaire Hubert Curien, Université de Strasbourg, Université de Haute Alsace Mulhouse, CNRS/IN2P3, Strasbourg, France

Jean-Luc Agram, Jean-André Andrea, Didier Bloch, Didier Bodin, Jean-Marc Brom, Maria Cardaci, Éric Chabert, Emile Collard, Emmanuelle Conte, Florence Drouhin, Jean-Claude Fontaine, Dominique Géle, Uwe Goerlach, Philippe Juillot, Anne-Catherine Le Bihan, Philippe Van Hove

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

Sébastien Beauceron, Nicolas Beaupère, Olivier Bondu, Sylvain Boudoul, Stéphane Brochet, Jean Chasserat, Raphaël Chierici, David Contardo, Pierre Depasse, Hany El Mamouni, Jean-François Gay, Stéphane Gascón, Muriel Gouzevitch, Bertrand Ille, Thomas Kurca, Martin Lethuiller, Luc Mirabetto, Séverine Perries, Laura Sgandurra, Vincent Sordini, Yannick Tschudi, Pierre Verdier, Stéphane Viret

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

Z. Tsamalaidze

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

C. Autermann, S. Beranek, Benjamin Calpas, Markus Edelhoff, Lukas Feld, Nicolas Heracleous, Oliver Hindrichs, Roland Jussen, Kevin Klein, Johannes Merz, Anton Ostapchuk, Alin Perieanu, Frank Raupach, Jochen Sammet, Stefan Schael, Dipl.-Phys. Sören Sprenger, Dipl.-Phys. Johannes Weber, Bernd Wittmer, Valeriy Zhukov

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

Michael Ata, Cédric Caudron, Dietrich-Laursonn, Dennis Duchess, Michael Erdmann, Rolf Fischer, Andreas Guth, Tobias Hebbeker, Christian Heidemann, Klaus Hoepfner, Klaus Klingebiel, Peter Kreuzer, Michael Merschmeyer, Mareike Meyer, Malte Olschewski, Pierre Papacz, Heike Pieta, Reinhart Reithler, Silke Schmitz, Leonie Sonnenschein, Jochen Steggemann, Dipl.-Phys. Dennis Teyssié, Dipl.-Phys. Silvia Thüer, Michael Weber

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

Mirko Bontenackels, Victor Cherepanov, Yalçın Erdogan, Sebastian Flügge, Heiner Geenen, Matthias Geisler, Wissam Haj Ahmad, Florian Hoehle, Benjamin Kargoll, Thomas Kress, Yves Kuessel, Jochen Lingemann, A. Nowack, laptopin, O. Pooth, Dipl.-Phys. Pål Sauerland, Dipl.-Phys. Alexander Staahl

Deutsches Elektronen-Synchrotron, Hamburg, Germany

María Aldaya Martín, Johann Behr, Wolfgang Behrenhoff, Ulrike Behrens, Michael Bergholz, A. Bethani, Kevin Borras, Andreas Burgmeier, Arix Cakir, Luis Calligaris, Alastair Campbell, Eike Castro, François Costanza, Daniel Dammann, Christian Diez Pardos, T. Dorland, Georg Eckerlin, David Eckstein, Marcus Flucke, Andreas Geiser, Ilya Glushkov, Pasquale Gunnellini, Sahab Habib, Johann Hauk, Gerhard Hellwig, Jürgen Jung, Martin Kasemann, Patrick Katsas, Cornelia Kleinwort, Helga Kluge, Andreas Knutsson, Michael Krämer, Dirk Krücker, Evgeny Kuznetsova, Joachim Lange, Jean Leonard, Wolfgang Lohmann, Boris Lutz, Roland Mankel, Ivo Marfin, Maximilian Marienfeld, Ibrahim Melzer-Pellmann, Andrew Meyer, Michael Mnič, Alexander Mussigiller, Stefan Naumann-Emme, Oksana Novgorodova, Finn Nowak, Olaf Olzem, Harald Perrey, Andrey Petruchkin, David Pitzl, Ales Raspereza, Pedro Ribeiro Cipriano, C. Riedl, Erik Ron, Marc Rosin, Jochen Salfeld-Nebgen, Roland Schmidt, Schoerner-Sadenius, Nitin Sen, Spiridon Spiridonov, Michael Stein, Robert Walsh, Christopher Wisser

University of Hamburg, Hamburg, Germany

Vladimir Blobel, Helmut Enderle, Jochen Erfle, Ulrike Gebbert, Michael Görner, Andreas Gosselink, Jan Haller, Thomas Herrmanns, Rolf-Hotz Höing, Karsten Kaschube, Gunter Kaussen, Hans Kirschenmann, Roman Klanner, Joachim Lange, Tilman Peiffer, Norbert Pietsch, Dieter Rathjens, Carsten Sander, Harald Schettler, Patrick Schleper, Eva Schlieckau, Andreas Schmidt, Mathias Schröder, Tilman Schumacher, Michael Seidel, Jörg Sibille, Vincenzo Sola, Hartwig Stadie, Gerald Steinbrück, Jesper Thomsen, Lars Vanelderen
Institut für Experimentelle Kernphysik, Karlsruhe, Germany
C. Barth, J. Berger, C. Böser, T. Chwalek, W. De Boer, A. Descroix, A. Dierlamm, M. Feindt, M. Guthoff, C. Hackstein, F. Hartmann, T. Hauth, M. Heinrich, H. Held, K.H. Hoffmann, U. Husemann, I. Katkov, 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. Ratinikov, N. Ratinikova, 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

Institute of Nuclear Physics “Demokritos”, Aghia Paraskevi, Greece
G. Anagnostou, G. Daskalakis, T. Geralis, V.A. Giakoumopoulou, S. Kesisoglou, A. Kyriakis, D. Loukas, I. Manolakos, A. Markou, C. Markou, 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, P. Kokkas, N. Manthos, I. Papadopoulos

KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
G. Bencze, C. Hajdu, P. Hidas, D. Horvath, F. Sikler, V. Veszpremi, G. Vesztergombi, A.J. Zsigmond

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. Kaur, M.Z. Mehta, M. Mittal, N. Nishu, L.K. Saini, A. Sharma, J.B. Singh

University of Delhi, Delhi, India
A. Abdulsalam, D. Dutta, S. Kailas, V. Kumar, A.K. Mohanty, L.M. Pant, P. Shukla

Tata Institute of Fundamental Research - EHEP, Mumbai, India
T. Aziz, R.M. Chatterjee, S. Ganguly, M. Guchait, A. Gurtu, M. Maity, K. Mazumdar, G.B. Mohanty, B. Parida, K. Sudhakar, N. Wickramage

Tata Institute of Fundamental Research - HECR, Mumbai, India
S. Banerjee, D. Dugad

Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
H. Arfaei, H. Bakhshiansohi, S.M. Etesami, A. Fahim, M. Hashemi, H. Hesari, A. Jafari, M. Khakzad, M. Mohammadi Najafabadi, S. Paktinat Mehdibadi, B. Safarzadeh, M. Zeinali

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

INFN Sezione di Bologna \textsuperscript{a}, Università di Bologna \textsuperscript{b}, Bologna, Italy
G. Abbieni\textsuperscript{a}, A.C. Benvenuti\textsuperscript{a}, D. Bonacorsi\textsuperscript{a,b}, S. Braibant-Giacomelli\textsuperscript{a,b}, L. Brigliadori\textsuperscript{a,b}, P. Capiluppi\textsuperscript{a,b}, A. Castro\textsuperscript{a,b}, F.R. Cavallo\textsuperscript{a}, M. Cuffiani\textsuperscript{a,b}, G.M. Dallavalle\textsuperscript{a}, F. Fabbri\textsuperscript{a}, A. Fanfani\textsuperscript{a,b}, D. Fasanella\textsuperscript{a,b}, P. Giacomelli\textsuperscript{a}, C. Grandi\textsuperscript{a}, L. Guiducci\textsuperscript{a,b}, S. Marcellini\textsuperscript{a}, G. Masetti\textsuperscript{a}, M. Meneghelli\textsuperscript{a,b,2}, A. Montanari\textsuperscript{a}, F.L. Navarria\textsuperscript{a,b}, F. Odorici\textsuperscript{a}, A. Perrotta\textsuperscript{a}, F. Primavera\textsuperscript{a,b}, A.M. Rossi\textsuperscript{a,b}, T. Rovelli\textsuperscript{a,b}, G.P. Siroli\textsuperscript{a,b}, N. Tosi, R. Travaglini\textsuperscript{a,b}

INFN Sezione di Catania \textsuperscript{a}, Università di Catania \textsuperscript{b}, Catania, Italy
S. Albergo\textsuperscript{a,b}, G. Cappello\textsuperscript{a,b}, M. Chiorboli\textsuperscript{a,b}, S. Costa\textsuperscript{a,b}, R. Potenza\textsuperscript{a,b}, A. Tricomi\textsuperscript{a,b}, C. Tuve\textsuperscript{a,b}

INFN Sezione di Firenze \textsuperscript{a}, Università di Firenze \textsuperscript{b}, Firenze, Italy
G. Barbagli\textsuperscript{a}, V. Ciulli\textsuperscript{a,b}, C. Civinini\textsuperscript{a}, R. D’Alessandro\textsuperscript{a,b}, E. Focardi\textsuperscript{a,b}, S. Frosati\textsuperscript{a,b}, G. Gallo\textsuperscript{a}, S. Gonzi\textsuperscript{a,b}, M. Meschini\textsuperscript{a}, S. Paolotti\textsuperscript{a}, G. Sguazzoni\textsuperscript{a}, A. Tropiano\textsuperscript{a,b}

INFN Laboratori Nazionali di Frascati, Frascati, Italy
L. Benussi, S. Bianco, S. Colafranceschi\textsuperscript{27}, F. Fabbri, D. Piccolo

INFN Sezione di Genova \textsuperscript{a}, Università di Genova \textsuperscript{b}, Genova, Italy
P. Fabbricatore\textsuperscript{a}, R. Musenich\textsuperscript{a}, S. Tosi\textsuperscript{a,b}

INFN Sezione di Milano-Bicocca \textsuperscript{a}, Università di Milano-Bicocca \textsuperscript{a}, Milano, Italy
A. Benaglia\textsuperscript{a}, F. De Guio\textsuperscript{a,b}, L. Di Matteo\textsuperscript{a,b,2}, E. Fiore\textsuperscript{a,b}, S. Gennai\textsuperscript{a,b}, A. Ghezzi\textsuperscript{a,b}, S. Malvezzi\textsuperscript{a}, R.A. Manzoni\textsuperscript{a,b}, A. Martelli\textsuperscript{a,b}, A. Massironi\textsuperscript{a,b}, D. Menasce\textsuperscript{a}, L. Moroni\textsuperscript{a}, M. Paganoni\textsuperscript{a,b}, D. Pedrini\textsuperscript{a}, S. Ragazzi\textsuperscript{a,b}, S. Redaelli\textsuperscript{a}, T. Tabarelli de Fatis\textsuperscript{a,b}

INFN Sezione di Napoli \textsuperscript{a}, Università di Napoli T’Federico II’ \textsuperscript{b}, Università della Basilicata (Potenza) \textsuperscript{c}, Università G. Marconi (Roma) \textsuperscript{d}, Napoli, Italy
S. Buontempo\textsuperscript{a}, N. Cavallo\textsuperscript{a,c}, A. De Cos	extsuperscript{a,b,2}, O. Dogangun\textsuperscript{a,b}, F. Fabozzi\textsuperscript{a,c}, A.O.M. Iorio\textsuperscript{a,b}, L. Lista\textsuperscript{a}, S. Meola\textsuperscript{a,d,28}, M. Merola\textsuperscript{b}, P. Paolucci\textsuperscript{a,2}

INFN Sezione di Padova \textsuperscript{a}, Università di Padova \textsuperscript{b}, Università di Trento (Trento) \textsuperscript{c}, Padova, Italy
P. Azzi\textsuperscript{a}, N. Bacchetta\textsuperscript{a,2}, A. Branca\textsuperscript{a,b,2}, R. Carlin\textsuperscript{a,b}, P. Checchia\textsuperscript{a}, T. Dorigo\textsuperscript{a}, F. Gasparini\textsuperscript{a,b}, U. Gasparini\textsuperscript{a,b}, A. Gozzelino\textsuperscript{a}, K. Kanischchev\textsuperscript{a,c}, S. Lacaprara\textsuperscript{a}, I. Lazzizzera\textsuperscript{a,c}, M. Margoni\textsuperscript{a,b}, A.T. Meneguzzo\textsuperscript{a,b}, F. Montecassiano\textsuperscript{a}, P. Pazzi\textsuperscript{a,b}, N. Pozzobon\textsuperscript{a,b}, P. Ronchese\textsuperscript{a,b}, F. Simonetto\textsuperscript{a,b}, E. Torassa\textsuperscript{a}, M. Tosi\textsuperscript{a,b}, S. Vanini\textsuperscript{a,b}, P. Zotto\textsuperscript{a,b}, A. Zucchetta\textsuperscript{a,b}, G. Zumerle\textsuperscript{a}

INFN Sezione di Pavia \textsuperscript{a}, Università di Pavia \textsuperscript{b}, Pavia, Italy
M. Gabusi\textsuperscript{a,b}, S.P. Ratti\textsuperscript{a,b}, C. Riccardi\textsuperscript{a,b}, P. Torre\textsuperscript{a,b}, P. Vitulo\textsuperscript{a,b}

INFN Sezione di Perugia \textsuperscript{a}, Università di Perugia \textsuperscript{b}, Perugia, Italy
M. Biasin\textsuperscript{a,b}, G.M. Bilei\textsuperscript{a}, L. Fanò\textsuperscript{a,b}, P. Lariccia\textsuperscript{a,b}, G. Mantovani\textsuperscript{a,b}, M. Menichelli\textsuperscript{a}, A. Nappi\textsuperscript{a,b}, F. Romeo\textsuperscript{a,b}, A. Saha\textsuperscript{a}, A. Santocchia\textsuperscript{a,b}, A. Spiezia\textsuperscript{a,b}, S. Taroni\textsuperscript{a,b}

INFN Sezione di Pisa \textsuperscript{a}, Università di Pisa \textsuperscript{b}, Scuola Normale Superiore di Pisa \textsuperscript{c}, Pisa, Italy
P. Azzurri\textsuperscript{a,c}, G. Bagliesi\textsuperscript{a}, J. Bernardini\textsuperscript{a}, T. Boccoli\textsuperscript{a}, G. Broccolo\textsuperscript{a,c}, R. Castaldi\textsuperscript{a}, R.T. D’Agno\textsuperscript{a,c,2}, R. Dell’Orso\textsuperscript{a}, F. Fiori\textsuperscript{a,b,2}, L. Foà\textsuperscript{a,c}, A. Giassi\textsuperscript{a}, A. Kraan\textsuperscript{a}, F. Ligabue\textsuperscript{a,c}, T. Lomtadze\textsuperscript{a}, L. Martini\textsuperscript{a,29}, A. Messineo\textsuperscript{a,b}, F. Palla\textsuperscript{a}, A. Rizzi\textsuperscript{a,b}, A.T. Serban\textsuperscript{a,30}, P. Spagnolo\textsuperscript{a}, P. Squillacioti\textsuperscript{a,2}, R. Tenchini\textsuperscript{a}, G. Tonelli\textsuperscript{a,b}, A. Venturi\textsuperscript{a}, P.G. Verdini\textsuperscript{a}
A. The CMS Collaboration

INFN Sezione di Roma $^a$, Università di Roma $^b$, Roma, 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$^{a,b}$

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$^a$, 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$^a$

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

Kangwon National University, Chunchon, Korea
T.Y. Kim, S.K. Nam

Kyungpook National University, Daegu, Korea
S. Chang, D.H. Kim, G.N. Kim, D.J. Kong, H. Park, D.C. Son, T. Son

Chonnam National University, Institute for Universe and Elementary Particles, Kwangju, Korea
J.Y. Kim, Zero J. Kim, S. Song

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, Y. Roh

University of Seoul, Seoul, Korea
M. Choi, J.H. Kim, C. Park, I.C. Park, S. Park, G. Ryu

Sungkyunkwan University, Suwon, Korea
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, J. Martínez-Ortega, A. Sanchez-Hernandez, 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, J. Butt, H.R. Hoorani, S. Khalid, W.A. Khan, T. Khurshid, S. Qazi, M.A. Shah, M. Shoaib

National Centre for Nuclear Research, Swierk, Poland
H. Bialkowska, B. Boimska, T. Frueboes, M. Górski, M. Kazana, K. Nawrocki, K. Romanowska-Rybinska, M. Szleper, G. Wrochna, P. Zalewski

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, M. Misiura

Laboratório de Instrumentação e Física Experimental de Partículas, Lisboa, Portugal
N. Almeida, P. Bargassa, A. David, P. Faccioli, P.G. Ferreira Parracho, M. Gallinaro, J. Seixas, J. Varela, P. Vischia

Joint Institute for Nuclear Research, Dubna, Russia
I. Belotelov, P. Bunin, M. Gavrilenko, I. Golutvin, I. Gorbunov, A. Kamenev, V. Karjavin, G. Kozlov, A. Laine, A. Malakhov, P. Moisenz, V. Palichik, V. Perelygin, S. Shmatov, V. Smirnov, A. Volodko, A. Zarubin

Petersburg Nuclear Physics Institute, Gatchina (St. Petersburg), Russia
S. Evtusyukhin, 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. Deremen, S. Gniwenko, N. Golubev, M. Kirsanov, N. Krasnikov, V. Matveev, A. Pashenkov, D. Trilov, A. Toropin

Institute for Theoretical and Experimental Physics, Moscow, Russia
V. Epshteyn, M. Erofeeva, V. Gavrilov, M. Kossov, N. Lychkovskaya, V. Popov, G. Safronov, S. Semenov, I. Shreyber, V. Stolin, E. Vlaskov, A. Zhokin

Moscow State University, Moscow, Russia
A. Belyaev, E. Boos, V. Bunichev, M. Dubinin, L. Dudko, A. Ershov, V. Klyukhin, O. Kodolova, I. Lokhtin, A. Markina, S. Obraztsov, M. Perfilov, S. Petrushenko, A. Popov, 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, V. Kachanov, D. Konstantinov, V. Krychkine, V. Petrov, R. Ryutin, A. Sobol, L. Tourchanovitch, S. Troshin, N. Tyurin, A. Uzunian, A. Volkov

University of Belgrade, Faculty of Physics and Vinca Institute of Nuclear Sciences, Belgrade, Serbia
P. Adzic, M. Djordjevic, M. Ekmedjian, D. Krpic, 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, D. Domínguez Vázquez, C. Fernandez
Bedoya, J.P. Fernández Ramos, A. Ferrando, J. Flix, M.C. Fouz, P. García-Abia, O. González Lopez, S. Goy Lopez, J.M. Hernandez, M.I. Josa, G. Merino, J. Puerta Pelayo, A. Quintario Olmeda, I. Redondo, L. Romero, J. Sántaolalla, M.S. Soares, C. Willmott

**Universidad Autónoma de Madrid, Madrid, Spain**
C. Albajar, G. Codispoti, J.F. de Trocóniz

**Universidad de Oviedo, Oviedo, Spain**
H. Brun, J. Cuevas, J. Fernandez Menendez, S. Folgueras, I. Gonzalez Caballero, L. Lloret Iglesias, J. Piedra Gomez

**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, 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. Rodriguez-Marrero, A. Ruiz-Jimeno, L. Scodellaro, I. Vila, R. Vilar Cortabitarte

**CERN, European Organization for Nuclear Research, Geneva, Switzerland**
D. Abbaneo, E. Auffray, G. Auzinger, M. Bachts, P. Baillon, A.H. Ball, D. Barney, J.F. Benitez, C. Bernet, G. Bianchi, P. Bloch, A. Bocci, A. Bonato, C. Botta, H. Breuker, T. Camporesi, G. Cerminara, T. Christiansen, J.A. Coarasa Perez, D. D’Enterría, 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, V. Hinzmann, E. Innocente, P. Janot, K. Kaadze, E. Karavakis, K. Kousouris, P. Lecoq, J.Y. 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. Rolandi, C. Rovelli, M. Rovere, H. Sakulin, E. Santanastasio, C. Schäfer, C. Schwik, I. Segoni, S. Sekmen, A. Sharma, P. Siegrist, P. Silva, M. Simon, P. Spificas, D. Spiga, A. Tsirou, G.I. Veres, J.R. Vlimant, H.K. Wöhri, S.D. Worm, 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

**Institute for Particle Physics, ETH Zurich, Zurich, Switzerland**
F. Bachmair, L. Bäni, P. Bortignon, M.A. Buchmann, B. Casal, N. Chanon, A. Deisher, G. Distrorti, M. Dittmar, M. Donegà, M. Dünser, P. Eller, J. Eurgster, K. Freudenreich, C. Grab, D. Hits, P. Lecomte, W. Lüstermann, A.C. Marini, P. Martinez Ruiz del Arbol, N. Mohr, F. Moortgat, C. Nägele, P. Nef, F. Nessi-Tedaldi, F. Pandolfi, L. Pape, P. Pauss, M. Peruzzi, F.J. Ronga, M. Rossini, L. Sala, A.K. Sanchez, A. Starodumov, 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**
C. Amsler, V. Chiochia, S. De Visscher, C. Favaro, M. Ivova Rikova, B. Kilminster, B. Millan Mejias, P. Otiougozva, P. Robmann, H. Snoek, S. Tuppiti, M. Verzetti

**National Central University, Chung-Li, Taiwan**
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 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, X. Wan, M. Wang

Chulalongkorn University, Bangkok, Thailand
B. Asavapibhop, N. Srimanobhas, N. Suwonjandee

Cukurova University, Adana, Turkey
A. Adiguzel, M.N. Bakirci, C. Cerci, C. Dozen, I. Dumanoglu, E. Eskut, S. Girgis, G. Gokbulut, E. Gurpinar, I. Hos, E.E. Kangal, T. Karaman, G. Karapinar, A. Kayis Topaksu, G. Onengut, K. Ozdemir, S. Ozturk, A. Polatoz, K. Sogut, D. Sunar Cerci, B. Tali, H. Topakli, 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
E. Gülmez, B. Isildak, M. Kaya, O. Kaya, S. Ozkorucuklu, N. Sonmez

Istanbul Technical University, Istanbul, Turkey
H. Bahtiyar, E. Barlas, K. Cankocak, Y.O. Günaydin, F.I. Vardarlı, M. Yücel

National Scientific Center, Kharkov Institute of Physics and Technology, Kharkov, Ukraine
L. Levchuk

University of Bristol, Bristol, United Kingdom
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, K. Nirunpong, A. Poll, S. Senkin, V.J. Smith, T. Williams

Rutherford Appleton Laboratory, Didcot, United Kingdom
L. Basso, K.W. Bell, A. Belyaev, 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, J. Pela, M. Pesaresi, K. Petridis, M. Pioppi, 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

Brunel University, Uxbridge, 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

Baylor University, Waco, USA
K. Hatakeyama, H. Liu, T. Scarbroough

The University of Alabama, Tuscaloosa, USA
O. Charaf, 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, 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

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

University of California, Los Angeles, 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, Riverside, Riverside, USA
J. Bab, R. Clare, M.E. Dinardo, J. Ellison, J.W. Gary, F. Giordano, G. Hanso, 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, A. Holzner, R. Kelley, M. Lebourgeois, J. Letts, I. Macneill, B. Mangano, S. Padhi, C. Palmer, G. Petrueciani, M. Pieri, M. Sani, V. Sharma, S. Simon, E. Sudano, M. Tadel, Y. Tu, A. Vartak, S. Wasserbaech, 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, C. George, F. Golf, J. Incandela, C. Justus, P. Kalavase, D. Kovalskyi, V. Krutelyov, S. Lowette, R. Magana Villalba, N. Mccoll, V. Pavlunin, 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, M. Spiropulu, V. Timciuc, J. Veverka, R. Wilkinson, S. Xie, Y. Yang, R.Y. Zhu

Carnegie Mellon University, Pittsburgh, USA
V. Azzolini, A. Calamba, 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, W.T. Ford, A. Gaz, E. Luiggi Lopez, J.G. Smith, K. Stenson, K.A. Ulmer, S.R. Wagner

Cornell University, Ithaca, 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

Fairfield University, Fairfield, USA
D. Winn
Fermi National Accelerator Laboratory, Batavia, USA
S. Abdullin, M. Albrow, J. Anderson, L.A.T. Bauerick, 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. Leonidopoulos, 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. Musienko, 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

University of Florida, Gainesville, 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. Milenovic, G. Mitselmakher, L. Muniz, M. Park, R. Remington, A. Rinkevicius, P. Sellers, N. Skhirtladze, M. Snowball, J. Yelton, M. Zakaria

Florida International University, Miami, USA
V. Gaultney, S. Hewamanage, 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, F. Yumiceva

University of Illinois at Chicago (UIC), Chicago, USA
M.R. Adams, I.M. Anghel, L. Apanasevich, Y. Bai, V.E. Bazterra, R.R. Betts, I. Bucinskaite, J. Callner, R. Cavannaugh, 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

The University of Iowa, Iowa City, USA
U. Akgun, E.A. Albayrak, B. Bilki, W. Clarida, F. Duru, S. Griffiths, J-P. Merlo, H. Mermerkaya, A. Mestvirishvili, A. Moeller, J. Nachtman, C.R. Newsom, E. Norbeck, Y. Onel, F. Ozok, S. Sen, P. Tan, 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, M. Swartz, A. Whitbeck

The University of Kansas, Lawrence, USA
P. Baringer, A. Bean, G. Benelli, R.P. Kenny Iii, M. Murray, D. Noonan, S. Sanders, R. Stringer, G. Tinti, J.S. Wood

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, F. Rebassoo, D. Wright

University of Maryland, College Park, 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

**Massachusetts Institute of Technology, Cambridge, 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. Krajczar\(^{39}\), 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

**University of Minnesota, Minneapolis, 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 Mississippi, Oxford, USA**
L.M. Cremaldi, R. Kroeger, L. Perera, R. Rahmat, D.A. Sanders

**University of Nebraska-Lincoln, Lincoln, 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

**State University of New York at Buffalo, Buffalo, 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

**The Ohio State University, Columbus, USA**
L. Antonelli, B. Bylsma, L.S. Durkin, C. Hill, R. Hughes, K. Kotov, T.Y. Ling, D. Puigh, M. Rodenburg, C. Vuosalto, G. Williams, B.L. Winer

**Princeton University, Princeton, 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. Pirouë, X. Quan, A. Raval, H. Saka, D. Stickland, C. Tully, J.S. Werner, S.C. Zenz, A. Zuranski

**University of Puerto Rico, Mayaguez, USA**
E. Brownson, A. Lopez, H. Mendez, J.E. Ramirez Vargas

**Purdue University, West Lafayette, USA**
E. Alagöz, 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. Zabolocki, Y. Zheng
Purdue University Calumet, Hammond, USA
S. Guragain, N. Parashar

Rice University, Houston, 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

University of Rochester, Rochester, 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

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, 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

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, V. Khotilovich, R. Montalvo, I. Osipenkov, Y. Pakhotin, A. Perloff, J. Roe, A. Safronov, T. Sakuma, S. Sengupta, I. Suarez, A. Tatarinov, D. Toback

Texas Tech University, Lubbock, USA
N. Akchurin, J. Damgov, C. Dragoiu, P.R. Dudero, C. Jeong, K. Kovitanggoon, S.W. Lee, T. Libeiro, I. Volobouev

Vanderbilt University, Nashville, 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

University of Virginia, Charlottesville, USA
M.W. Arenton, M. Balazs, S. Boutle, B. Cox, B. Francis, J. Goodell, R. Hiosky, A. Ledovskoy, C. Lin, C. Neu, J. Wood

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, 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

†: 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 Kahramanmaras Sütçü Imam University, Kahramanmaras, 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, Korea