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Search for narrow resonances in dilepton mass spectra in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$ and combination with 8 TeV data

The CMS Collaboration*

Abstract

A search for narrow resonances in dielectron and dimuon invariant mass spectra has been performed using data obtained from proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$ collected with the CMS detector. The integrated luminosity for the dielectron sample is $2.7\,\text{fb}^{-1}$ and for the dimuon sample $2.9\,\text{fb}^{-1}$. The sensitivity of the search is increased by combining these data with a previously analysed set of data obtained at $\sqrt{s} = 8\,\text{TeV}$ and corresponding to a luminosity of $20\,\text{fb}^{-1}$. No evidence for non-standard-model physics is found, either in the 13 TeV data set alone, or in the combined data set. Upper limits on the product of production cross section and branching fraction have also been calculated in a model-independent manner to enable interpretation in models predicting a narrow dielectron or dimuon resonance structure. Limits are set on the masses of hypothetical particles that could appear in new-physics scenarios. For the Z'_{SSM} particle, which arises in the sequential standard model, and for the superstring inspired Z'_{ψ} particle, 95% confidence level lower mass limits for the combined data sets and combined channels are found to be 3.37 and 2.82 TeV, respectively. The corresponding limits for Kaluza–Klein gravitons arising in the Randall–Sundrum model of extra dimensions with coupling parameters 0.01 and 0.10 are 1.46 and 3.11 TeV, respectively. These results significantly extend previous limits.

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*See Appendix A for the list of collaboration members

1 Introduction

The observation of a new narrow resonance in the invariant mass spectrum of lepton pairs would provide compelling evidence for physics beyond the standard model (SM). Many models designed to address the shortcomings of the SM [1] predict such resonances at the TeV scale. Examples include a new heavy Z boson-like particle such as the Z'_{SSM} boson of the sequential standard model [2]; the Z'_{ψ} boson inspired by superstring models [3, 4]; and the Kaluza–Klein graviton (G_{KK}) of the Randall–Sundrum (RS) model of extra dimensions [5, 6].

This Letter describes a search for such narrow resonances in dielectron and dimuon mass spectra based on proton-proton (pp) collision data collected at $\sqrt{s} = 13\,\mathrm{TeV}$ in 2015 by the CMS experiment at the CERN LHC. The data correspond to integrated luminosities of 2.7 and 2.9 fb^{-1} for the dielectron and dimuon channels, respectively. The ATLAS and CMS Collaborations have previously reported searches in these channels [7, 8] based on approximately 20 fb^{-1} of pp collisions at $\sqrt{s} = 8\,\mathrm{TeV}$ in each experiment. These results each exclude a Z'_{SSM} with a mass less than 2.90 TeV, and also exclude a Z'_{ψ} with a mass less than 2.51 TeV for ATLAS and 2.57 TeV for CMS. The data-taking and data-analysis methods for the 13 TeV data follow closely those for the 8 TeV data [7], with some differences due to data-taking conditions and refinements noted below. This Letter presents the search results from the 13 TeV data, followed by results from combining the CMS data sets at 8 and 13 TeV; the latter have only slightly more power, as most of the sensitivity at high mass comes from the higher $\sqrt{s}$. As in previous searches, the dimuon selection requires opposite sign charge for the muons, while the dielectron selection has no sign requirement.

The primary results of the analysis are expressed in terms of the ratio of the product of production cross section and branching fraction for a possible new resonance to that for the Z boson. To determine this ratio, the measured lepton pair invariant mass distributions are fit to models that contain signal and background processes and incorporate the ratio of efficiencies including the experimental acceptance. This approach reduces the impact of many experimental and theoretical systematic uncertainties. Furthermore, the analysis is designed to be largely independent of specific model assumptions, enabling the results to be interpreted in the context of any model that includes a narrow spin-1 or spin-2 resonance decaying to an electron or muon pair. Here we present lower limits on the masses of hypothetical particles that are derived from cross sections calculated in the context of certain specific models.

2 The CMS detector

The central feature of the CMS detector is a superconducting solenoid providing an axial magnetic field of 3.8 T and enclosing an inner tracker, an electromagnetic calorimeter (ECAL), and a hadron calorimeter (HCAL). The inner tracker is composed of a silicon pixel detector and a silicon strip tracker, and measures charged-particle trajectories in the pseudorapidity range $|\eta| < 2.5$. The ECAL and HCAL, each composed of a barrel and two endcap sections, extend over the range $|\eta| < 3.0$. The finely segmented ECAL consists of nearly 76 000 lead tungstate crystals while the HCAL is constructed from alternating layers of brass and scintillator. Forward hadron calorimeters encompass $3.0 < |\eta| < 5.0$. The muon detection system covers $|\eta| < 2.4$ with up to four layers of gas-ionization chambers installed outside the solenoid and sandwiched between the layers of the steel flux-return yoke. Additional detectors and upgrades of electronics were installed before the beginning of the 13 TeV data collection period in 2015, yielding improved reconstruction performance for muons relative to the 8 TeV data collection period in 2012. A more detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in Ref. [9].

The CMS experiment has a two-level trigger system. The level-1 (L1) trigger [10], composed of custom hardware processors, selects events of interest using information from the calorimeters and muon detectors and reduces the readout rate from the 40 MHz bunch-crossing frequency to a maximum of 100 kHz. The software based high-level trigger (HLT) [11] uses the full event information, including that from the inner tracker, to reduce the event rate to the 1 kHz that is recorded.

3 Event selection

3.1 Triggers

The event selection and reconstruction algorithms employed are refined versions of those used for previous high-mass dilepton searches [7]. The transverse energy of a localized ECAL energy deposit ("cluster") is defined as $E_T = E \sin\theta$, with θ the polar angle relative to the beam axis, where the cluster energy E includes deposits consistent with bremsstrahlung emission. The selection of electrons begins with the L1 trigger, where electron candidates are defined as ECAL clusters with $E_T > 25$ GeV. In the HLT, electron candidates are defined as ECAL clusters with $E_T > 33$ GeV that are matched to a track reconstructed in the inner tracker. To suppress hadrons misidentified as electrons in the barrel (endcaps), the energy deposited in the HCAL in a cone of radius $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.14$ around the electron candidate must be less than 15 (10)% of the ECAL cluster energy, where ϕ is the azimuthal angle. In the HLT, events with at least two electron candidates are selected.

Muon candidates are identified with the L1 trigger by requiring each track segment reconstructed in the muon detectors to have transverse momentum p_T above 16 GeV. In the HLT, muon candidates are defined by fitting hits from track segments in the muon detectors with hits from segments in the inner tracker, with a p_T threshold on the track that depended on the instantaneous luminosity and reached as high as 50 GeV for unprescaled triggers. The HLT muon candidates must have a distance of closest approach to the beam axis less than 0.1 cm in the plane perpendicular to that axis. In the HLT, events with at least one muon candidate are selected. To allow the normalization of rates, Z boson events are obtained via a prescaled trigger that is identical to the primary analysis trigger except that the p_T requirement is lowered to 27 GeV.

Trigger efficiencies are defined relative to the full analysis requirements described in Section 3.2, and are evaluated from data using high mass dilepton or high-p_T Z samples, free from background contributions. For electrons with $E_T > 45$ GeV, the trigger efficiency of an electron pair is 99.6% for events with both electrons in the ECAL barrel, and 99.2% for events with one electron in the ECAL barrel and the other in an ECAL endcap, and is consistent with being independent of E_T. For muons with $p_T > 53$ GeV, the trigger efficiency of a muon pair is 99.4% and is uniform in muon p_T.

3.2 Lepton reconstruction

The recorded events are processed with the CMS event reconstruction algorithms [12, 13].

Electron candidates are defined by associating tracks in the inner detector with ECAL clusters. The energy of the electron candidate is given by the energy of the associated cluster, which is adjusted through calibration and regression methods [7, 13, 14]. The associated tracks provide the angular information used to calculate the electron four-momentum. Each electron candidate must have $E_T > 35\,\text{GeV}$ and either $|\eta_C| < 1.44$ (barrel region) or $1.56 < |\eta_C| < 2.50$ (endcap region), where η_C is the pseudorapidity of the cluster with respect to the nominal centre of the CMS detector. The electron reconstruction efficiency is around 93% [13] for electrons within the acceptance region of the analysis. At least two electron candidates are required in an event, at least one of which must lie in the barrel region.

Muon candidate track segments are reconstructed separately in the muon detector and inner tracker. Hits from a muon detector track segment and from a compatible track segment in the inner tracker are fitted under a global muon track hypothesis that incorporates information from the entire CMS detector. Dedicated algorithms [12], developed for high-p_T (of the order of 1 TeV) muon reconstruction are used to ensure the quality of the hits contributing to the fit, as well as the quality of the fit itself. Events are required to contain at least two muon candidates, each with $p_T > 53\,\text{GeV}$, slightly above the corresponding HLT requirement, and to appear within $|\eta| < 2.4$. The muon reconstruction efficiency for muons within this region is above 98%.

3.3 Lepton identification

Electron candidates are required to satisfy dedicated high-E_T selection criteria [7]. The energy deposited in the HCAL in a cone of radius $\Delta R = 0.14$ around the direction of the electron candidate must be less than 5% of the energy of the electron measured in the ECAL.

Muon candidates are required to satisfy standard CMS muon selection criteria, with modifications for high-p_T muon identification [7] that emphasize information from the muon detectors in order to improve the muon p_T resolution above 200 GeV. Each pair of muon candidates is fitted to a common vertex, with a requirement that the resulting value of the χ^2 per degree of freedom be less than 20. This selection is designed to have an efficiency close to 100% and to reject pairs formed from mismatched muons. To suppress background from cosmic ray muons that pass near the interaction point, the three-dimensional angle between the two track momentum vectors is required to be less than $\pi - 0.02$.

Finally, we impose isolation requirements to suppress jets misidentified as leptons, and leptons from hadron decays. Electrons are considered to be isolated if the p_T sum of tracks within a cone of radius $\Delta R = 0.3$ around the direction of the candidate is less than 5 GeV and if the E_T sum of energy deposits within this same cone less than 3% of the candidate's E_T value, once corrected for the contributions expected from detector noise and additional interactions in the event [7]. The majority of the dilepton events in the analysed data set contain between 7 and 12 additional interactions. Similarly, muons are considered to be isolated if the p_T sum of tracks within a cone of radius $\Delta R = 0.3$ around the candidate direction is less than 10% of the p_T of the candidate. The sums exclude the lepton candidate under consideration.

The electron candidates in a dielectron event are not required to have opposite charges because the charge misidentification rate is non-negligible for high-p_T electrons. In contrast, we require muon candidates in a dimuon event to have opposite charge because in this case a charge mismeasurement, while rare, implies a large p_T mismeasurement. If there are more than two electron candidates selected in the event, the two highest-p_T electrons are used to construct the pair. This procedure is also used when constructing a dimuon pair.

The efficiency to select signal events, accounting for the effects of event reconstruction, lepton identification and, in the case of muons, the effect of the trigger, is determined from Monte Carlo (MC) simulations. Details of the simulation are given in Section 4. Methods relying primarily on data, such as the use of control samples of high-p_T Z bosons decaying to e^+e^- and $\mu^+\mu^-$ pairs, are employed to validate the simulation up to muon $p_T = 300\,\mathrm{GeV}$. The simulated and measured efficiencies generally agree within about 1%, for both single electrons and muons. High mass dilepton or high-p_T Z samples, where background sources are subtracted using MC information, are used to extend the validation up to $p_T \approx 1\,\mathrm{TeV}$. Differences between data and simulation up to around 5% (2.5%) for single electrons (muons) are found for large E_T (p_T) values. The signal efficiency within the acceptance of the analysis is found to be $(75 \pm 8)\%$ and $(70 \pm 10)\%$, respectively, for a barrel-barrel and barrel-endcap electron pair of 1 TeV mass. For a muon pair with a mass of 1 TeV, the corresponding efficiency is $91^{+1}_{-5}\%$. The uncertainties in the efficiency values account for the statistical precision and for the systematic uncertainty in the extrapolation of the data-simulation differences to high p_T. The acceptances are derived from simulation and rise with increasing mass. In the dimuon channel the probability for a produced boson with 400 GeV mass to decay within the detector acceptance is close to 40% while for a 3 TeV mass it is greater than 90%. The acceptance is slightly lower in the dielectron channel since endcap-endcap events are not considered.

3.4 Mass resolution and scale

The shape of the signal distribution in the dilepton mass is described by the convolution of a Breit–Wigner (BW) function, describing the intrinsic signal shape, and a Gaussian distribution, describing the experimental resolution. Note that for a resonance mass of 2.5 TeV, the intrinsic widths of the Z'_{SSM} and Z'_{ψ} resonances are 80 and 14 GeV, respectively. For this same mass value, the intrinsic width of the G_{KK} resonance is 0.35 GeV for a coupling parameter $k/\overline{M}_{Pl}$ [3, 4] equal to 0.01, and 35 GeV for a coupling parameter equal to 0.10, where k is the warp factor of 4-dimensional anti-de Sitter space and $\overline{M}_{Pl}$ is the reduced Planck scale. The resolution is determined from simulation as a function of the generated dilepton mass. The resulting resolution function is validated with data, using Z boson events for the dielectron sample and cosmic ray events for the dimuon sample. The dielectron resolution function is adjusted on the basis of this comparison to agree with the measured result. The experimental mass resolution, defined as the standard deviation of the Gaussian function divided by its most probable value, is 1.4% (1.8%) for barrel-barrel (barrel-endcap) dielectron pairs with a mass of 1 TeV. The resolution for dimuon pairs with a mass of 1 TeV is 3.2%.

The response of the detector to leptons may evolve as the dilepton mass increases. For electrons this could arise from a nonlinear response of the readout electronics. However, with the current data set there is no evidence for such an effect and the energy scale of electrons above 500 GeV is validated at the 1–2% level [13]. As the muon p_T increases, its measurement becomes increasingly sensitive to the detector alignment. New methods have been developed for the 2015 data to determine a potential bias from this source. The curvature distributions of positive and negative muons in data are compared to those obtained in simulation for different η and ϕ ranges. The effects of misalignment not already included in simulation are modelled with additional smearing applied to the dimuon mass resolution. This is particularly important for muons with $|\eta| > 0.9$, since their p_T measurement in this region cannot be validated with cosmic rays. The resulting resolution for a dimuon pair with mass 1 TeV is increased from 3.2% to 3.8% in order to account for a potential misalignment in the muon system. Finally, for dimuon pairs, an additional 1% uncertainty is assigned in the position of the mass peak to account for other possible sources of scale bias such as detector movement due to magnet cycles.

4 Background estimation

The principal SM background arises from Drell–Yan (DY) production (Z/γ^*) of e^+e^- and $\mu^+\mu^-$ pairs. Additional sources of background are top quark-antiquark ($t\bar{t}$), single top quark (tW), diboson (WW, WZ, and ZZ), and DY $\tau^+\tau^-$ production, although the relative contributions of these sources diminish with increasing dilepton mass. Events in which at least one electron candidate is a misidentified jet contribute a small background in the mass region of interest. The multijet background is negligible in the dimuon channel where it is found to be less than 0.2% for masses above 200 GeV, as for the previous 8 TeV analysis [7]. The contribution of cosmic ray events is also negligible. An additional SM source of e^+e^- and $\mu^+\mu^-$ pairs comes from the photon-induced process $\gamma\gamma \to \ell^+\ell^-$ [15], where ℓ is an electron or muon. The theoretical predictions at TeV mass scales for this process have a significant uncertainty, with some predictions indicating that the photon-induced process is the dominant source of dilepton pairs with masses above 3 TeV. Even if the relative contribution of this process to background at such high masses is large, the absolute contribution is small and, as noted below, the potential effect on the derived limits is negligible.

The background from DY, $t\bar{t}$, tW, and diboson events is evaluated from simulation. Direct DY, $t\bar{t}$, and tW production are simulated with the POWHEG v2 [16–21] next-to-leading order (NLO) event generator, with parton showering and hadronization described by PYTHIA 8.2 [22]. Diboson processes are simulated at leading order (LO) with PYTHIA, and DY $\tau^+\tau^-$ production at NLO with MADGRAPH 5_aMC@NLO 2.2.2 [23] interfaced with PYTHIA. The NNPDF2.3LO [24] parton distribution functions (PDFs) are used for the diboson samples and the NNPDF3.0NLO [25] PDFs are used for the rest of the samples. The PDFs are evaluated using the LHAPDF library [26–28]. The detector response is simulated with the GEANT4 [29] package.

Over the full DY spectra multiplicative corrections are computed with FEWZ 3.1 [30] to take into account missing contributions like QCD effects at next-to-next-to-leading order (NNLO), electroweak effects at NLO in addition to pure QED effects, and photon-induced lepton pair production. These corrections have a negligible impact on the final results. The data and MC backgrounds are normalized to the event yield in the Z boson peak region, so that the resulting normalization is independent of the detector luminosity calibration. For $t\bar{t}$, tW, diboson, and DY $\tau^+\tau^-$ production, the produced number of $e\mu$ final states should be equal to the sum of ee and $\mu\mu$ final states. This feature is used to compare the $e\mu$ spectrum with suitably scaled MC predictions. The resulting scale factors are all consistent with unity and are not applied in the analysis.

The background from jets misidentified as electrons is evaluated from multijet data control samples. The method is the same as that described in Ref. [7], except that data sidebands, rather than MC predictions, are used to evaluate the contributions to the control samples from genuine electrons and photons misidentified as electrons. The method takes into account the different ways in which one or two misidentified jets, in possible conjunction with other particles, can satisfy the selection criteria for dielectron events.

5 Statistical analysis and results

The observed invariant mass spectra of the dielectron and dimuon events are presented in Fig. 1. No evidence for a significant deviation from the SM expectations is observed. The highest mass event observed is in the electron channel and has a mass of 2.9 TeV. The estimated probability of observing a background event with a mass at least this large is a few per cent in each channel.

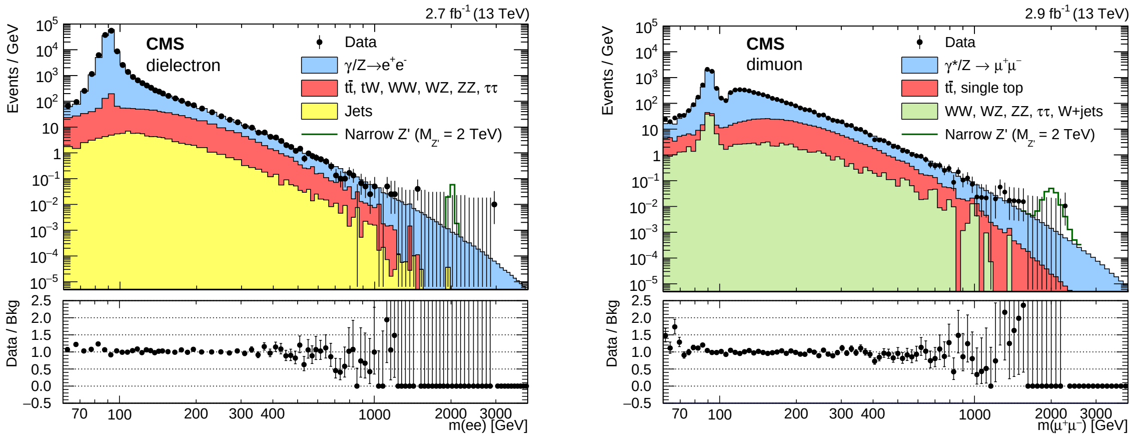


Figure 1: The invariant mass spectrum of (left) dielectron and (right) dimuon events at $\sqrt{s} = 13\,\text{TeV}$. The points with error bars represent the data. The histograms represent the expectations from SM processes. The bins have equal width in logarithmic scale but the width in GeV becomes larger with increasing mass. Example signal shapes for a narrow resonance with a mass of 2 TeV are shown by the stacked open histograms.

Using a Bayesian approach with an unbinned extended likelihood function [7], limits are derived for the production of a narrow spin-1 or spin-2 heavy resonance. The likelihood function is based on probability density functions (pdf) that describe the signal and background contributions to the invariant mass spectra. The signal distribution is parametrized by the convolution of BW and Gaussian functions discussed in Section 3.4. This analysis is designed for scenarios in which the BW intrinsic width Γ is small compared to the detector resolution, and variations in Γ therefore typically have little effect on the derived limits. At high masses, however, the dielectron mass resolution is comparable with the intrinsic width of the Z' in some of the models described in section 3.4, and the limits can exhibit some dependence on the assumed width. Therefore results are presented for different choices of the signal intrinsic width: 0.0, 0.6, and 3.0% of the resonance mass.

The functional form of the background pdf is given in Ref. [7] and is chosen to describe the complete background representation produced using SM MC generators and the background arising from misidentified jets deduced from the data. For each channel, the parameters of the background pdfs are obtained by fitting the background distribution for masses above 400 GeV.

The limits are set on the parameter R_σ, which is the ratio of the cross section for dilepton production through a Z' boson to the cross section for dilepton production through a Z boson:

$$R_\sigma = \frac{\sigma(\mathrm{pp} \to \mathrm{Z}' + \mathrm{X} \to \ell\ell + \mathrm{X})}{\sigma(\mathrm{pp} \to \mathrm{Z} + \mathrm{X} \to \ell\ell + \mathrm{X})}. \tag{1}$$

The Poisson mean of the signal yield is $\mu_\mathrm{S} = R_\sigma \mu_\mathrm{Z} R_\epsilon$, where R_ϵ is the ratio of the selection efficiency times detector acceptance for the Z' decay relative to that for the Z boson decay, and μ_Z is the Poisson mean of the number of $\mathrm{Z} \to \ell\ell$ events. The value of μ_Z is estimated from the number of dilepton pairs in a $\pm 30\,\text{GeV}$ window around the Z boson mass, where the contributions of other processes are predicted to be small ($\approx$0.5% in simulation). The quantities μ_Z and R_ϵ are obtained separately for the dimuon and dielectron channels. By performing a measurement relative to the Z boson cross section, the uncertainty in the integrated luminosity is removed and uncertainties in other quantities, such as in the experimental acceptance, trigger, and reconstruction efficiencies, become relative rather than absolute.

The Bayesian limit-setting procedure follows closely that described for the 8 TeV data in Ref. [7]. The prior pdf for the signal cross section is positive and uniform, as this is known to result in good frequentist coverage properties. Log-normal functions are used to describe the systematic uncertainties. Limits on R_σ are evaluated for scenarios in which the hypothetical particle is either a spin-1 or a spin-2 resonance. The limits are sensitive to the number of signal events relative to the number of background events, and to some extent to the signal widths. Three classes of dilepton events are used to set the limits: both electrons in the barrel section of the ECAL, one electron in the barrel and the other in the endcap, and dimuons. To obtain the limit for a dilepton mass point, the amplitude of the background shape function is constrained using data within a mass window ± 6 times the mass resolution about the mass point. If fewer than 100 events in the 13 TeV data lie within this window (rather than 400 used in the 8 TeV data), the window is symmetrically expanded until this number is reached. This procedure sets the level of the statistical uncertainty in the local background amplitude, and the level is chosen to dominate expected systematic uncertainties in the background shape at high mass. The uncertainties are larger in the 13 TeV data because of the reduction in the number of calibration events due to the lower integrated luminosity, and because of the higher mass ranges probed. The observed limits are robust and do not significantly change for reasonable variations in the limit-setting procedure, such as modifications of the mass intervals used in the fit or changes in the assumed background shape.

The limits obtained correspond to on-shell cross sections and do not include model-dependent interference effects or enhancements at low mass values related to the PDFs. The limits are sensitive to the fraction of events in each of three channels and so only apply to models that contain a particle with the same spin as the particle in the reference model, produced via a similar production mechanism. The limits are also only applicable to resonances with widths of the order of a few per cent of the resonance mass, with the limits becoming less applicable as the width increases. Within these constraints, the limits are, to a good approximation, model independent and can be interpreted in the context of models not explicitly addressed in this Letter. A recipe to convert the cross sections obtained from MC event generators such as PYTHIA, which include off-shell effects, to the on-shell cross sections presented here is provided in Ref. [31].

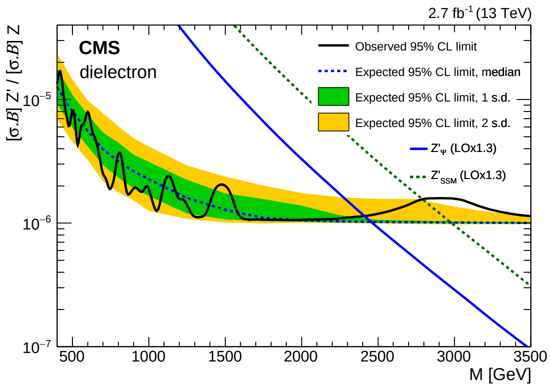
5.1 Combination of 8 and 13 TeV data sets

The 13 TeV data set is combined with the 2012 data set at $\sqrt{s} = 8$ TeV [7], corresponding to integrated luminosities of 19.7 and 20.6 fb^{-1} for the dielectron and dimuon channels, respectively. For the combination, these luminosities must be rescaled to match the equivalent 13 TeV luminosities. This scaling depends on the mass of the resonance, with the effective luminosity of the 8 TeV data sample decreasing with increasing resonance mass. The scaling was determined by comparing Z′ and $\mathrm{G_{KK}}$ cross sections calculated by PYTHIA using the NNPDF2.3LO PDF set at $\sqrt{s} = 8$ and 13 TeV. This cross section ratio depends on the PDF set used and different choices of PDF set can change the resulting limits by a few per cent. The scaling also depends on the production mechanism of the new boson, and therefore the value used to combine the data sets depends on the properties of the particular model under consideration.

The dominant uncertainty in this analysis is in the parameter R_ϵ. Its uncertainty is 8% for the dielectron barrel-barrel channel, 10% for the dielectron barrel-endcap channel, and $^{+1}_{-5}$% for the dimuon channel. The background from misidentified jets in the electron analysis is a small fraction of the total background; therefore, although the uncertainty in this background is large, its impact on the limit determination is negligible. The uncertainty in the background shape is, as noted above, dominated by the statistical uncertainty in the background amplitude estimate, which arises from uncertainties in the PDFs, in the contributions of the photon-induced processes, and in the NNLO corrections to the cross sections. Possible photon-induced contributions are studied using the MRST2004QED and NNPDF PDFs, which include photons, and are found to have a negligible effect on the derived mass limits. The uncertainty due to the PDFs is assessed using the PDF4LHC15 prescription [32] and is found to vary from 2% to 7% as the dilepton mass increases from 1 to 4 TeV. Varying the numbers of background events within their total uncertainties is found to have a negligible impact on the derived limits. Common systematic uncertainties are taken to be fully correlated in the calculation of combined limits. A relative mass scale calibration uncertainty of 1% is included when extracting the combined limits using the 8 and 13 TeV data. The uncertainties on the electron and muon efficiency at high p_T are taken to be uncorrelated between 8 and 13 TeV data, as most of these uncertainties have their origin in calibration measurements made with different data sets (with some variation as well in reconstruction and identification variables used).

5.2 Limits

The 95% confidence level (CL) upper limits on R_σ for the 13 TeV data are shown in Fig. 2 for both the dielectron and dimuon channels. The resonance peak width for these results is taken to be 0.6% of the assumed mass value. Results for widths equal to 0.0, 0.6, and 3% of the resonance mass are shown in Fig. 3. Figure 4 shows the 95% CL upper limits on R_σ for the combination of the two channels (assuming universality of electron and muon couplings) at 13 TeV (left), and the corresponding effects of varying the signal width (right).



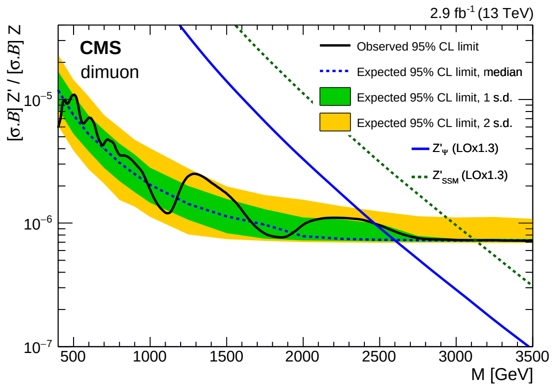


Figure 2: The 95% CL upper limits on the product of production cross section and branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the product of production cross section and branching fraction for a Z boson, for the (left) dielectron and (right) dimuon channels in the 13 TeV data. The shaded bands correspond to the 68 and 95% quantiles for the expected limits. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_ψ resonances are shown for comparison.

The 95% CL upper limits on R_σ for the combined 8 and 13 TeV data are shown in Fig. 5 for the individual dielectron and dimuon channels, and in Fig. 6 (left) for the combination of the two channels. Figure 6 (right) shows the 95% CL upper limits on the product of production cross section and branching fraction for an RS graviton, normalized to the same quantity for the Z boson, for the combination of the 8 and 13 TeV data and of the two dilepton channels.

The 95% CL lower limits on the masses of the Z'_{SSM} and Z'_ψ bosons are presented in Table 1, along with the expected results. Table 2 presents the corresponding limits for an RS graviton with coupling parameters 0.01 and 0.10. In each case the limit appropriate to the width of the boson is used. For example the Z'_{SSM} boson mass limits are calculated using a width of 3%.

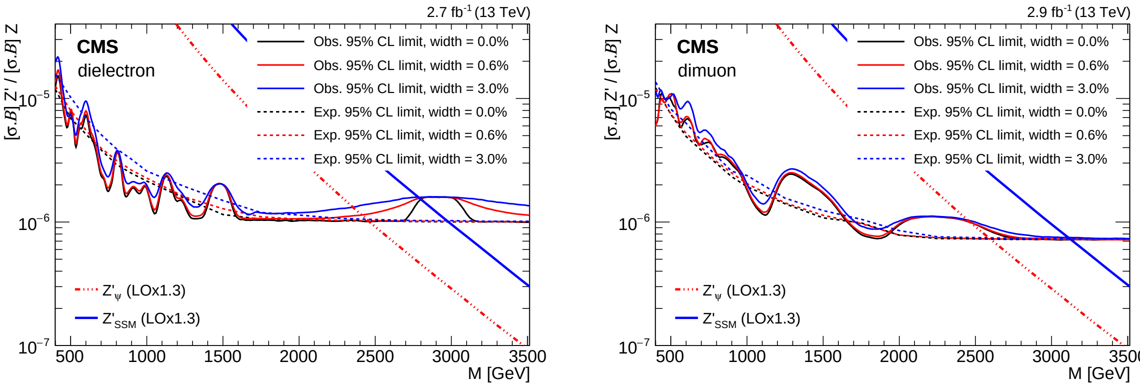


Figure 3: The 95% CL upper limits on the product of production cross section and branching fraction for a spin-1 resonance for widths equal to 0, 0.6, and 3.0% of the resonance mass, relative to the product of production cross section and branching fraction for a Z boson, for the (left) dielectron and (right) dimuon channels in the 13 TeV data. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_{ψ} resonances are also shown.

The cross section as a function of mass is calculated at LO using the PYTHIA 8.2 program with the NNPDF2.3 PDFs. As the limits in this Letter are obtained on the on-shell cross section and the PYTHIA event generator includes off-shell effects, the cross section is calculated in a mass window of $\pm 5\%\ \sqrt{s}$ centred on the resonance mass, following the advice of Ref. [31]. To account for NLO effects, the cross sections are multiplied by a K-factor of 1.3 for Z' models and 1.6 for RS graviton models [33], with the K-factor for Z' models obtained by comparing POWHEG and PYTHIA cross sections for SM Drell–Yan production. These same comments apply for the theoretical predictions shown in Figs. 2–6. For the Z'_{SSM} and Z'_{ψ} bosons, we obtain lower mass limits of 3.37 and 2.82 TeV, respectively. The lower mass limit obtained for the RS graviton is 1.46 (3.11) TeV for a coupling parameter of 0.01 (0.10).

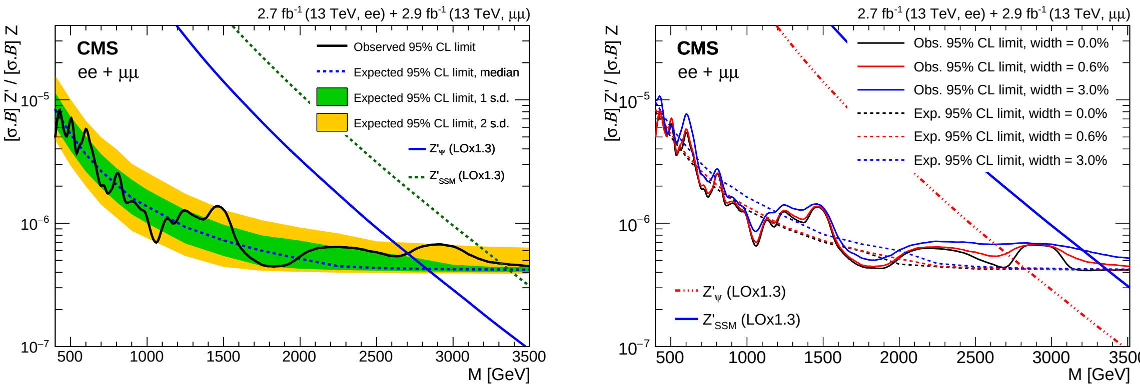


Figure 4: The 95% CL upper limits on the product of production cross section and branching fraction for a spin-1 resonance, relative to the product of production cross section and branching fraction for a Z boson, for the combined dielectron and dimuon channels in the 13 TeV data, (left) for a resonance width equal to 0.6% of the resonance mass and (right) for resonance widths equal to 0, 0.6, and 3.0% of the resonance mass. The shaded bands correspond to the 68 and 95% quantiles for the expected limits. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_{ψ} resonances are also shown.

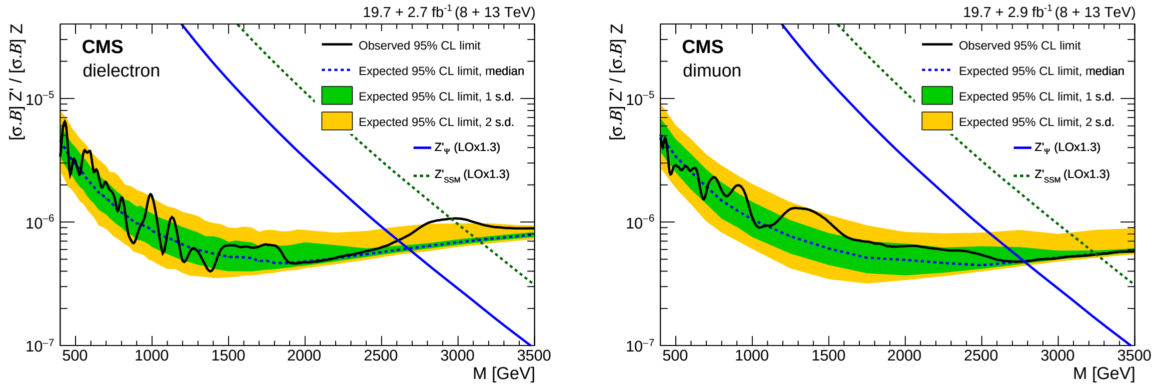


Figure 5: The 95% CL upper limits on the product of production cross section and branching fraction for a spin-1 resonance with a width equal to 0.6% of the resonance mass, relative to the product of production cross section and branching fraction for a Z boson, for the combined 8 and 13 TeV data in the (left) dielectron and (right) dimuon channel. The shaded bands correspond to the 68 and 95% quantiles for the expected limits. Theoretical predictions for the spin-1 Z'_{SSM} and Z'_{ψ} resonances are also shown.

Table 1: The observed and expected 95% CL lower limits on the masses of spin-1 Z'_{SSM} and Z'_{ψ} bosons for the combination of the 8 and 13 TeV data, assuming a signal width of 0.6% of the resonance mass for Z'_{ψ} and 3% for Z'_{SSM}.

Channel	Z'_{SSM}		Z'_{ψ}	
	Obs. (TeV)	Exp. (TeV)	Obs. (TeV)	Exp. (TeV)
ee	2.95	3.11	2.60	2.67
$\mu^+\mu^-$	3.22	3.23	2.77	2.77
ee + $\mu^+\mu^-$	3.37	3.45	2.82	2.98
ee + $\mu^+\mu^-$ 13 TeV only	3.18	3.35	2.70	2.82

Table 2: The observed and expected 95% CL lower limits on the masses of spin-2 Kaluza–Klein gravitons in the Randall–Sundrum model, for two values of the coupling parameter, $k/\overline{M}_{Pl}$.

Channel	G_{KK} ($k/\overline{M}_{Pl} = 0.01$)		G_{KK} ($k/\overline{M}_{Pl} = 0.10$)	
	Obs. (TeV)	Exp. (TeV)	Obs. (TeV)	Exp. (TeV)
ee	1.46	1.48	2.78	2.93
$\mu^+\mu^-$	1.26	1.41	3.03	3.03
ee + $\mu^+\mu^-$	1.46	1.61	3.11	3.23
ee + $\mu^+\mu^-$ 13 TeV only	1.38	1.45	2.98	3.15

6 Summary

A search for narrow resonances in dielectron and dimuon invariant mass spectra has been performed using data obtained from proton-proton collisions at $\sqrt{s} = 13$ TeV. The integrated luminosity for the dielectron sample is 2.7 fb^{-1} and for the dimuon sample 2.9 fb^{-1}. The sensitivity of the search is increased by combining these data with a previously analysed set of data obtained at $\sqrt{s} = 8$ TeV and corresponding to a luminosity of 20 fb^{-1}. No evidence for non-standard-model physics is found, either in the 13 TeV data set alone, or in the combined data set. Upper limits at 95% confidence level on the product of production cross section and branching fraction have also been calculated in a model-independent manner to enable interpretation in models predicting a narrow dielectron or dimuon resonance structure.

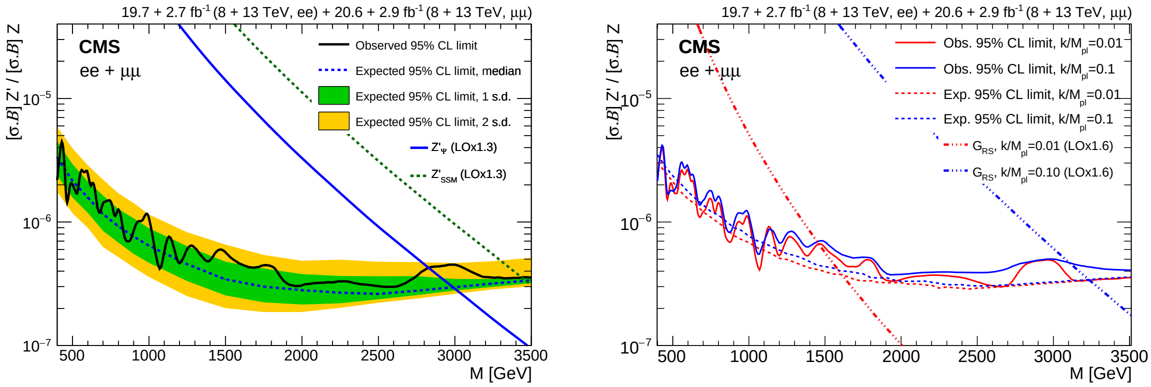


Figure 6: The 95% CL upper limits on the product of production cross section and branching fraction for (left) a spin-1 resonance with a width equal to 0.6% of the resonance mass and (right) for a spin-2 RS graviton, both relative to the product of production cross section and branching fraction for a Z boson, for the combined dielectron and dimuon channels and combined 8 and 13 TeV data. For the spin-1 results (left plot), the shaded bands correspond to the 68 and 95% quantiles for the expected limits, and theoretical predictions are shown for the spin-1 Z'_{SSM} and Z'_{ψ} resonances. For the spin-2 results (right plot), observed limits, expected limits, and theoretical predictions are shown for values of the coupling parameter $k/\overline{M}_{Pl} = 0.01$ and 0.10.

Limits are set on the masses of hypothetical particles that could appear in new-physics scenarios. For the Z'_{SSM} particle, which arises in the sequential standard model, and for the superstring inspired Z'_{ψ} particle, 95% confidence level lower mass limits for the combined data sets and combined channels are found to be 3.37 and 2.82 TeV, respectively. The corresponding limits for Kaluza–Klein gravitons arising in the Randall–Sundrum model of extra dimensions with coupling parameters 0.01 and 0.10 are 1.46 and 3.11 TeV, respectively. These results significantly extend previous limits.

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References

[1] J. Ellis, "Outstanding questions: physics beyond the Standard Model", *Phil. Trans. R. Soc. A* **370** (2012) 818, doi:10.1098/rsta.2011.0452.

[2] G. Altarelli, B. Mele, and M. Ruiz-Altaba, "Searching for new heavy vector bosons in $p\overline{p}$ 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, arXiv:hep-ph/9805494.

[4] J. L. Hewett and T. G. Rizzo, "Low-energy phenomenology of superstring-inspired E_6 models", *Phys. Rept.* **183** (1989) 193, doi:10.1016/0370-1573(89)90071-9.

[5] L. Randall and R. Sundrum, "An alternative to compactification", *Phys. Rev. Lett.* **83** (1999) 4690, doi:10.1103/PhysRevLett.83.4690, arXiv:hep-th/9906064.

[6] L. Randall and R. Sundrum, "A large mass hierarchy from a small extra dimension", *Phys. Rev. Lett.* **83** (1999) 3370, doi:10.1103/PhysRevLett.83.3370, arXiv:hep-ph/9905221.

[7] CMS Collaboration, "Search for physics beyond the standard model in dilepton mass spectra in proton-proton collisions at $\sqrt{s} = 8$ TeV", *JHEP* **04** (2015) 025, doi:10.1007/JHEP04(2015)025, arXiv:1412.6302.

[8] ATLAS Collaboration, "Search for high-mass dilepton resonances in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector", *Phys. Rev. D* **90** (2014) 052005, doi:10.1103/PhysRevD.90.052005, arXiv:1405.4123.

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

[10] CMS Collaboration, "The TriDAS Project Technical Design Report, volume I: The trigger systems", CMS TDR CERN/LHCC 2000-038, CERN, 2000.

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

[12] 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.

[13] CMS Collaboration, "Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at $\sqrt{s} = 8$ TeV", *JINST* **10** (2015) P06005, doi:10.1088/1748-0221/10/06/P06005, arXiv:1502.02701.

[14] 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.

[15] D. Bourilkov, "Photon-induced Background for Dilepton Searches and Measurements in pp Collisions at 13 TeV", (2016). arXiv:1606.00523.

[16] 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.

[17] 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.

[18] S. Alioli, P. Nason, C. Oleari, and E. Re, "A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX", *JHEP* **06** (2010) 043, doi:10.1007/JHEP06(2010)043, arXiv:1002.2581.

[19] S. Alioli, P. Nason, C. Oleari, and E. Re, "NLO vector-boson production matched with shower in POWHEG", *JHEP* **07** (2008) 060, doi:10.1088/1126-6708/2008/07/060, arXiv:0805.4802.

[20] S. Frixione, P. Nason, and G. Ridolfi, "A positive-weight next-to-leading-order Monte Carlo for heavy flavour hadroproduction", *JHEP* **09** (2007) 126, doi:10.1088/1126-6708/2007/09/126, arXiv:0707.3088.

[21] 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.

[22] T. Sjöstrand et al., "An Introduction to PYTHIA 8.2", *Comput. Phys. Commun.* **191** (2015) 159, doi:10.1016/j.cpc.2015.01.024, arXiv:1410.3012.

[23] J. Alwall et al., "The automated computation of tree-level and next-to-leading order differential cross sections and their matching to parton shower simulations", *JHEP* **07** (2014) 079, doi:10.1007/JHEP07(2014)079, arXiv:1405.0301.

[24] R. D. Ball et al., "Parton distributions with LHC data", *Nucl. Phys. B* **867** (2013) 244, doi:10.1016/j.nuclphysb.2012.10.003, arXiv:1207.1303.

[25] NNPDF Collaboration, "Parton distributions for the LHC Run II", *JHEP* **04** (2015) 040, doi:10.1007/JHEP04(2015)040, arXiv:1410.8849.

[26] M. R. Whalley, D. Bourilkov, and R. C. Group, "The Les Houches accord PDFs (LHAPDF) and LHAGLUE", in *HERA and the LHC: A Workshop on the implications of HERA for LHC physics. Proceedings, Part B*. 2005. arXiv:hep-ph/0508110.

[27] D. Bourilkov, R. C. Group, and M. R. Whalley, "LHAPDF: PDF use from the Tevatron to the LHC", (2006). arXiv:hep-ph/0605240.

[28] A. Buckley et al., "LHAPDF6: parton density access in the LHC precision era", *Eur. Phys. J. C* **75** (2015) 132, doi:10.1140/epjc/s10052-015-3318-8, arXiv:1412.7420.

[29] GEANT4 Collaboration, "GEANT4—a simulation toolkit", *Nucl. Instrum. Meth. A* **506** (2003) 250, doi:10.1016/S0168-9002(03)01368-8.

[30] Y. Li and F. Petriello, "Combining QCD and electroweak corrections to dilepton production in FEWZ", *Phys. Rev. D* **86** (2012) 094034, doi:10.1103/PhysRevD.86.094034, arXiv:1208.5967.

[31] E. Accomando et al., "Z′ at the LHC: Interference and Finite Width Effects in Drell-Yan", *JHEP* **10** (2013) 153, doi:10.1007/JHEP10(2013)153, arXiv:1304.6700.

[32] J. Butterworth et al., "PDF4LHC recommendations for LHC Run II", *J. Phys. G* **43** (2016) 023001, doi:10.1088/0954-3899/43/2/023001, arXiv:1510.03865.

[33] 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.

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