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Search for new massive resonances in dilepton mass spectra in *p-p* collisions with Run I and Run II data at CMS

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A search for new massive resonances in the dielectron and dimuon decay channels has been performed combining 2015 data collected by the CMS experiment in proton - proton collisions at a center of mass energy of 13 TeV (corresponding to an integrated luminosity of 2.9 fb^{-1}) with a previous analysed set of data obtained at 8 TeV (corresponding to 20 fb^{-1}). The analysis has been updated with data collected during Run II in 2016 at 13 TeV (13 fb^{-1}). In the absence of a significant deviation from the standard model predictions, 95% confidence level limits are set on the ratio of the production cross section times branching fraction for possible new high-mass resonances to that for the Z boson. Limits are set on the masses of hypothetical particles that could appear in new-physics scenarios.

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1. Introduction

The dilepton (ee or $\mu\mu$) final state signature is a key search channel for various new phenomena expected in theories that go beyond the Standard Model (SM). One of the cleanest signatures would be the observation of a narrow resonance in the invariant mass spectrum of lepton pairs, predicted by many models at the TeV scale. Examples include models described with extended gauge groups, featuring additional U(1) symmetries such as the Sequential Standard Model (SSM) that includes a Z'_{SSM} boson with SM-like couplings and the Grand Unification Theories (GUT) inspired models, based on E_6 gauge group, with a Z'_ψ boson. This search channel benefits from high signal selection efficiencies and relatively small, well-understood, backgrounds.

2. The CMS detector

CMS (Compact Muon Solenoid) is one of the most important detector at the LHC [1]. Its name is due to the superconducting solenoid providing an axial magnetic field of 3.8 T: it encloses an inner tracker, an electromagnetic calorimeter (ECAL) and a hadron calorimeter (HCAL). The muon detection system consists of up to four layers of gas-ionization chambers installed outside the solenoid and sandwiched between the layers of the steel flux return yoke. The CMS experiment uses a two-level trigger system: the former, L1, selects events of interest using information from the calorimeters and muon detectors; the second, the high level trigger (HLT), uses software algorithms accessing the full event information.

3. Event selection

The event selection requires particular conditions on the final state object: at trigger level, electron candidates are selected with transverse energy (E_T) above 33 GeV while muons with traverse momentum (p_T) above 50 GeV. Then electrons are reconstructed associating tracks in the inner detector with calorimeter deposits; in the dimuon channel instead the tracks from the inner detector are associated with that of the muon system: for high-p_T (1TeV) muons, a particular algorithm has been developed to assign the correct p_T. A dedicated high-E_T (high-p_T) selection has been developed to select electrons (muons) that must be also isolated. In the dimuon channel it is required that muons must have opposite charge (this condition is not present in the dielectron channel due to large charge misidentification for TeV electrons). For dielectron channel, due to high multi jets background, at least one electron must lie in the barrel region.

4. Background

The dominant and irreducible SM background arises from Drell-Yan (DY) production (Z/γ^*) of e^+e^- and $\mu^+\mu^-$ pairs. Additional sources of background are top - antitop quark ($t\bar{t}$) and single top quark (tW), Drell-Yan $\tau^+\tau^-$ and diboson (WW, ZZ, WZ), in which the two prompt leptons are from different particles. These processes are estimated using Monte Carlo (MC) simulated events at the next-to-leading order (NLO) and corrected to the next-to-next-to-leading order (NNLO). Events in which at least one lepton candidate is a misidentified jet (W+jets, γ +jets and multijets) contribute a small background, mainly in the electron channel, in the mass region of interest. These contributions are estimated from data. In Figure 1, the invariant mass spectrum, together with the predicted SM backgrounds, is shown for both leptons channels. No evidence for a signal deviation from the SM expectations is observed.

5. Efficiency, Resolution and Scale

The trigger efficiency, evaluated from data (simulation), is greater than 99% in electron (muon) channel and is uniform in E_T (p_T). Event reconstruction and selection efficiency, within the acceptance, determined from MC, corresponds to (75 $\pm$ 8)% for 1 TeV electron pair mass, with both leptons in the Barrel (Barrel - Barrel, BB), and (70 $\pm$ 10)% for an electron in the Barrel and the other in the Endcap (Barrel - Endcap, BE). For a 1 TeV muon pair mass it corresponds to (91 $\pm$ 5)%, and is independent of η. The acceptances rise with increasing mass. The resolutions are predicted by MC as a function of generated dilepton mass and validated with data. For 2 TeV dielectron (dimuon) pairs they correspond to 1% (5.5%) for BB pairs, 1.5% (8.5)% for BE pairs. The response of the detector to leptons may evolve as the dilepton mass increases, mainly for muons. For electrons the energy scale above 500 GeV is validated at 1-2% level. For muons the effect of misalignment, not already included in simulation, are modelled with additional smearing applied to the dimuon mass resolution. 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.

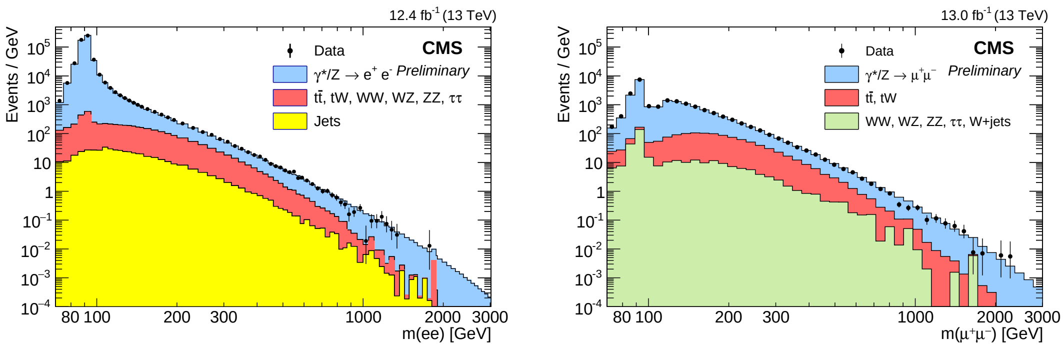

Figure 1: The invariant mass spectrum, together with the predicted SM backgrounds, for the ee channel on the left and $\mu\mu$ channel on the right. [2]. No evidence for a signal deviation from the SM expectations is observed.

6. Analysis strategy and results

Using a Bayesian approach with an unbinned extended likelihood function, limits are derived for the production of a narrow spin 1 (Z'_{SSM}, Z'_{ψ}) and spin 2 (G_{KK}) heavy resonance - see Figure 2. The likelihood function is based on probability density functions that describes the signal and the background contributions to the invariant mass spectra:

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- Signal: parametrized by the convolution of a Breit-Wigner (describing the intrinsic signal shape) and a Gaussian distribution (describing the experimental resolution)
- Background: parametrization obtained by fitting the SM simulated background distribution.

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. The Poisson mean of the signal yield is $\mu_s = R_\sigma \mu_Z R_\varepsilon$, 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 $Z > ll$ events. 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. The observed limits are robust and do not significantly change for reasonable variations in the limit-setting procedure (mass intervals, background shape).

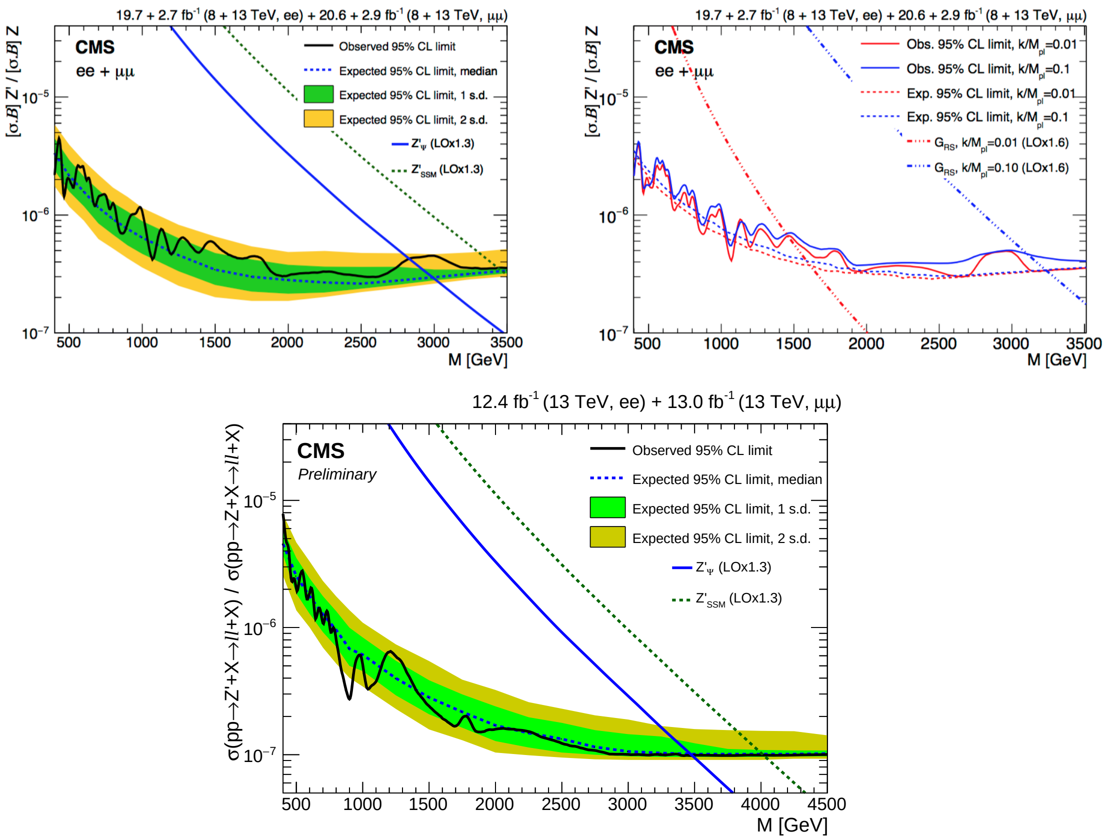

Figure 2: The 95% CL upper limits on the production cross section times branching fraction for a spin-1 (on top left) and for a spin-2 (on top right) resonance relative to the production cross section times branching fraction for a Z boson, for the combined dielectron and dimuon channels using data collected during Run I (20 fb^{-1}) and during 2015 Run II (2.9 fb^{-1}) [3]. On the bottom, the 95% CL upper limits for a spin-1 resonance for the combined dielectron and dimuon channels using data collected during Run II in 2016 (13 fb^{-1}) [2].

For the Z'_{SSM} particle and for the superstring inspired Z'_ψ particle, 95% confidence level lower mass limits are found to be 4.0 TeV and 3.5 TeV. The corresponding limits for Kaluza-Klein gravitons (G_{KK}) arising in the Randall - Sundrum model of extra dimensions with coupling parameters 0.01 and 0.1 are 1.46 and 3.11 TeV respectively.

References

[1] CMS Collaboration, *"The CMS experiment at the CERN LHC"*, JINST 3:S08004,2008

[2] CMS Collaboration, *"Search for a high-mass resonance decaying into a dilepton final state in 13 fb^{-1} of pp collisions at $\sqrt{s}$ = 13 TeV"*, http://cds.cern.ch/record/2205764.

[3] CMS Collaboration, *"Search for narrow resonances in dilepton mass spectra in proton-proton collisions at $\sqrt{s}$ = 13 TeV and combination with 8 TeV data"*, doi 10.1016/j.physletb.2017.02.010.