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Search for BSM Physics in High-Mass Diphoton Events at CMS

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We present the results from an extensive search for BSM particles in 'high-mass diphoton events', a distinctive phase-space indicative of various SM extensions such as Supersymmetry, extra dimensions, and non-minimal Higgs sectors. The searches for both spin-0 and spin-2 particles in resonant as well as non-resonant scenarios were carried out using the full luminosity of the LHC Run-II in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the CMS detector. We place constraints on the production of heavy Higgs bosons and the continuum clockwork mechanism, setting the most stringent limits to date on ADD extra dimensions and RS gravitons, excluding coupling parameters greater than 0.1.

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Search for BSM Physics in High-Mass Diphoton Events at CMS

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Abstract. We present the results from an extensive search for BSM particles in 'high-mass diphoton events', a distinctive phase-space indicative of various SM extensions such as Supersymmetry, extra dimensions, and non-minimal Higgs sectors. The searches for both spin-0 and spin-2 particles in resonant as well as non-resonant scenarios were carried out using the full luminosity of the LHC Run-II in proton-proton collisions at $\sqrt{s} = 13$ TeV with the CMS detector. We place constraints on the production of heavy Higgs bosons and the continuum clockwork mechanism, setting the most stringent limits to date on ADD extra dimensions and RS gravitons, excluding coupling parameters greater than 0.1.

Keywords: BSM Physics, Diphoton Signatures, CMS Experiment

1 Introduction

The search for new physics beyond the Standard Model (BSM) remains a central pursuit in contemporary particle physics, driving the exploration of new particles and interactions. Several BSM theories addressing SM limitations predict high-mass states decaying to photon pairs. In this note, we present the results for Spin-0/2 particle searches in both resonant and non-resonant scenarios. For the resonant case, we consider benchmarks like non-minimal Higgs sectors and the Randall-Sundrum (RS1) graviton with a single extra warped dimension. For the non-resonant case, we explore models like the Arkani-Hamed, Dimopoulos, Dvali (ADD) graviton with large extra dimensions and the clockwork mechanism.

2 Analysis strategy

The analysis uses the p-p collision data at $\sqrt{s} = 13$ TeV collected by the CMS experiment during 2016–18, corresponding to an integrated luminosity of 138 fb^{-1} [1]. To search for both resonant and nonresonant deviations from the SM, two complementary background estimation techniques are employed. For resonant searches, the diphoton spectrum is fit with a parameterized function based on data while for nonresonant excesses related to ADD and clockwork models, we use an NNLO QCD calculation of the SM diphoton background and estimate misidentified jet backgrounds with control samples from data. This analysis also improves upon previous CMS result [2] by using enhanced photon identification, better background modeling, and refined statistical inference methods.

2.1 Event selection and reconstruction

Photons are reconstructed by clustering spatially correlated energy deposits in the electromagnetic calorimeter (ECAL), with calibration and correction methods detailed in Ref. [3]. To reduce backgrounds from jets and electrons, additional criteria based on shower shape and surrounding activity are applied. Photon energy scale and resolution are determined using $Z \to e^+e^-$ events. The per photon reconstruction efficiency is approximately 90% (82%) in the EB (EE) and depends minimally on the photon p_T in the signal region. The trigger requires at least two photons with p_T above 60 GeV (2016) or 70 GeV (2017-2018), achieving nearly 100% efficiency for offline photons with $p_T > 125$ GeV. The diphoton invariant mass is required to be above 500 GeV, and photon pairs must satisfy $\Delta R_{\gamma\gamma} > 0.45$. The interaction vertex is selected with a multivariate algorithm, achieving 90% accuracy in correct vertex assignment for the signal events. Two event categories are used: (1) both photons in the EB ($|\eta| < 1.44$, EBEB) and (2) one photon in EB and one in EE ($1.57 < |\eta| < 2.50$, EBEE).

2.2 Signal simulation

In the resonant analysis, two intrinsic spin values are considered: a spin-0 ($J = 0$), representing a heavy SM-like Higgs boson, and a spin-2 ($J = 2$), representing an RS graviton from the warped extra dimension model. For each spin, three signal widths are analyzed: narrower than, comparable to, and wider than the detector resolution. For $J = 0$, the widths are $\Gamma_X/m_X = 1.4 \times 10^{-4}$, 1.4×10^{-2}, and 5.6×10^{-2} (where Γ_X is the natural width of the resonance, and m_X is the resonance mass). For $J = 2$, they correspond to $\tilde{k} = 0.01$, 0.1, and 0.2 (with $\tilde{k} = \sqrt{8\pi k/M_{\rm Pl}}$). Events are generated across mass points using $m_{\gamma\gamma}$ binned histograms as shape templates. Linear interpolation of cumulative distribution functions of $m_{\gamma\gamma}$ shapes are used for interpolation between generated points.

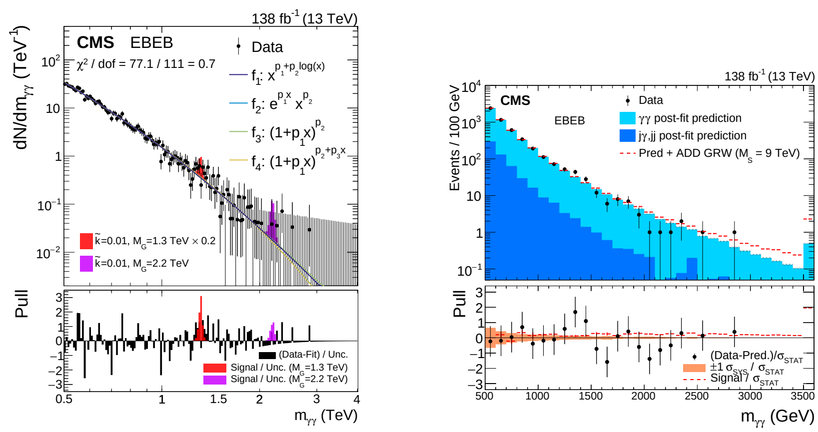
In the nonresonant analysis, ADD signals are generated at LO together with the SM diphoton process to account for the interference effects. The ADD model is defined by the scale M_S, an ultraviolet cutoff for virtual graviton exchange in the GRW convention, with translations performed for the Hewett and HLZ conventions. The clockwork model can reinterpret ADD signals by considering the on-shell, narrow KK modes.

2.3 Background estimation

The two main backgrounds in this analysis are the irreducible SM diphoton production and a reducible background from jets that imitate prompt photons ("misID"). We use two different methods to estimate the SM background. For resonant background, a functional fit extracts the background shape, optimized for narrow resonance detection, with bias tests to assess parameterization effects. For nonresonant background, a combination of higher-order MC predictions and control samples from data is used, ideal for identifying nonresonant deviations in the distribution tail.

3 Results

For the resonant analysis, a composite hypothesis test is conducted that compares observed data against two hypotheses: the background-only (null) and the signal-plus-background (alternative). A simultaneous fit to the $m_{\gamma\gamma}$ spectrum is performed across six event categories, separating EBEB and EBEE, for each data-taking year. Fig. 1a shows the combined fit results for these data sets, using bin sizes suited to the narrow width hypothesis. In the nonresonant analysis, a Bayesian approach with a flat prior on signal strength, restricted to positive values, is applied, using a Markov chain Monte Carlo method to marginalize nuisance parameters. Fig. 1b shows data/bkg predictions after marginalization.

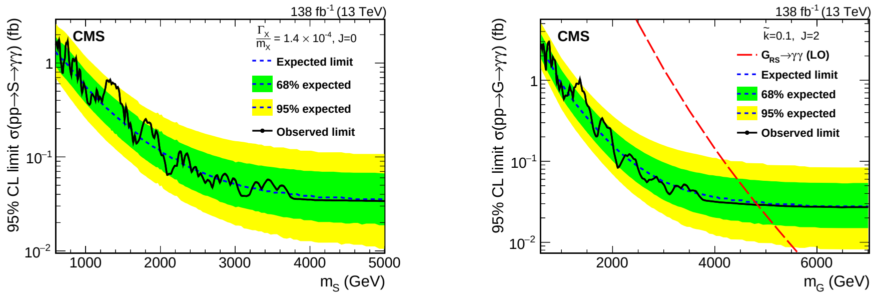


(a) (b)

Fig. 1: Observed $m_{\gamma\gamma}$ spectra and the bkg-only likelihood fit (Left). The "post-fit" $m_{\gamma\gamma}$ spectra and bkg prediction (right)

No significant excess is observed. Upper limits on the signal cross section are set at the 95% confidence level (CL) using the modified frequentist (CLs) method with asymptotic formulas. The upper limits on production cross sections by resonance mass are shown in Fig. 2. The largest deviation is observed at 1320 GeV with $\Gamma_X/m_X = 5.6 \times 10^{-2}$, having a local significance of 2.6 standard deviations (σ), while the global significance over the mass range of 0.6–2.5 TeV and widths of 1.4×10^{-4} to 5.6×10^{-2} is 0.8σ.

For the ADD model, 95% CL upper limits on signal strength translate into lower limits on the scale M_S, with exclusions between 7.1 and 11.1 TeV, depending on the convention (Table 1). The clockwork model uses a similar limit-setting approach as the ADD model. Fig. 3 presents the 95% CL exclusion limits in the k–M_5 plane, excluding M_5 values below 8.0 TeV for k in the range of 0.2 GeV to 2.0 TeV.



(a) RS graviton (b) heavy Higgs boson

Fig. 2: Expected and observed 95% CL upper limits (all plots in Ref. [4])

Table 1: The lower limits on M_S in TeV at the 95% CL for different theoretical conventions of the ADD model.

Signal	GRW	Hewett		HLZ (n_{ED})				
		Negative	Positive	$n = 3$	$n = 4$	$n = 5$	$n = 6$	$n = 7$
Expected	$8.7^{+0.7}_{-0.6}$	$7.3^{+0.3}_{-0.3}$	$7.8^{+0.6}_{-0.5}$	$10.3^{+0.8}_{-0.7}$	$8.7^{+0.7}_{-0.6}$	$7.9^{+0.6}_{-0.5}$	$7.3^{+0.6}_{-0.5}$	$6.9^{+0.6}_{-0.5}$
Observed	9.3	7.1	8.3	11.1	9.3	8.4	7.8	7.4

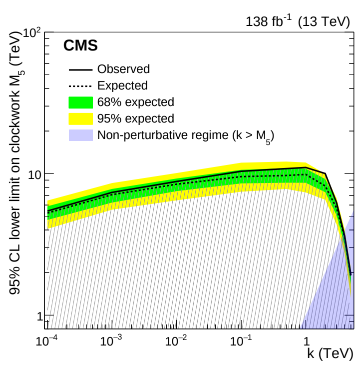


Fig. 3: Exclusion limit for the clockwork framework in the k–M_5 parameter space

4 Summary

Searches for new physics in high-mass diphoton events from 13 TeV proton-proton collisions at CMS are performed. Stringent constraints are placed on both resonant and non-resonant benchmark scenarios with the strongest limits to date on ADD extra dimensions and RS gravitons with $\tilde{k} \geq 0.1$. These results pave the way for future advancements using the latest data, with ongoing studies.

References

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