Search for high-mass resonances $g_{KK} \to gR \to gWW$

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Abstract

A search for high-mass resonances decaying into a gluon, g, and two W bosons is presented. A Kaluza-Klein gluon, g_{KK}, decaying in cascade via a scalar radion R, $g_{KK} \to gR \to gWW$, is considered. The final state consists of three large-radius jets, two of which contain the products of hadronically decaying W bosons, and the third one the hadronization products of the gluon. The analysis is performed using proton-proton collision data at $\sqrt{s} = 13$ TeV collected by the CMS experiment at the CERN LHC during 2016–2018, corresponding to an integrated luminosity of 138 fb^{-1}. The masses of the g_{KK} and R candidates are reconstructed as trijet and dijet masses, respectively. These are used for event categorization and signal extraction. No excess of data events above the standard model background expectation is observed. Upper limits are set on the product of the g_{KK} production cross section and its branching fraction via a radion R to gWW. This is the first analysis examining the resonant WW+jet signature and setting limits on the two resonance masses in an extended warped extra-dimensional model.

1. Introduction

This study presents a search for a Kaluza–Klein excited gluon (g_{KK}) and a scalar radion (R) in proton-proton collisions at $\sqrt{s} = 13$ TeV using 138 fb^{-1} of CMS data from the LHC (2016–2018). The signal process $g_{KK} \to gR \to gWW$ is investigated in fully hadronic final states with three large-radius (AK8) jets, targeting resolved $R \to WW$ decays. The analysis focuses on the **extended warped extra-dimensional (EWED) model**'s QCD sector, probing high-mass regions $1.25 \leq m_{g_{KK}} \leq 4.5$ TeV and 180 GeV $\leq m_R \leq 0.9 m_{g_{KK}}$. Machine learning (via ParticleNet) is employed for W-jet tagging to suppress QCD backgrounds, with resonance mass reconstruction and kinematic fitting used for signal discrimination. Results are interpreted within EWED phenomenology constraints, accounting for experimental resolution effects ($|\Gamma_{\mathrm{res}}| \ll \Delta m_{\mathrm{det}}$).

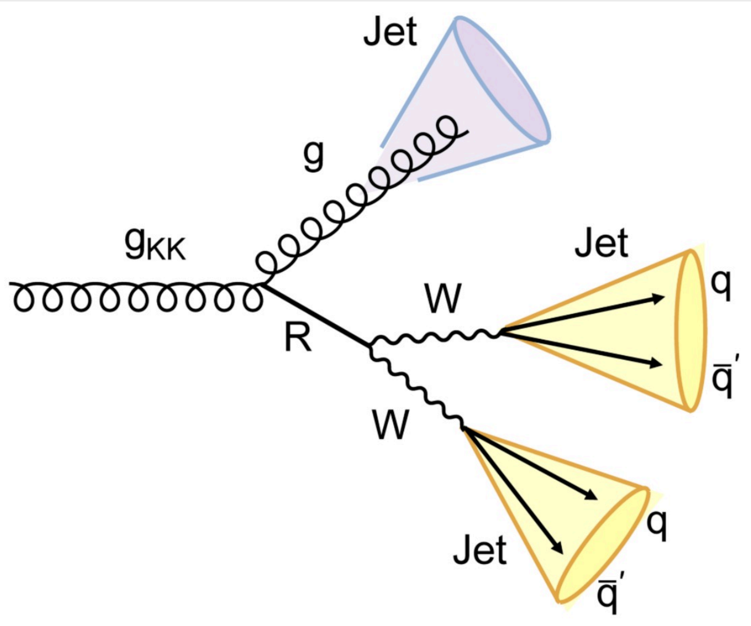

Fig. 1: Feynman-like diagram of the decay of a Kaluza–Klein g_{KK} resonance into two resolved Ws bosons and a gluon.

2. Analysis strategy

The event selection strategy targets fully hadronic decays of $g_{KK} \to gR \to gWW$ in proton-proton collisions at $\sqrt{s} = 13$ TeV (138 fb^{-1} CMS data) are as follows.

Preselection: Baseline cuts requiring: $N_\ell = 0$ (veto isolated leptons); Trijet topology: $N_{\mathrm{AK8}} = 3$ with $p_T(j_1) > 400$ GeV, $p_T(j_{2,3}) > 200$ GeV, $|\eta_j| < 2.4$; Soft-drop jet masses $m_{j_a}, m_{j_b} > 50$ GeV; HT > 1100 GeV (trigger efficiency optimization)

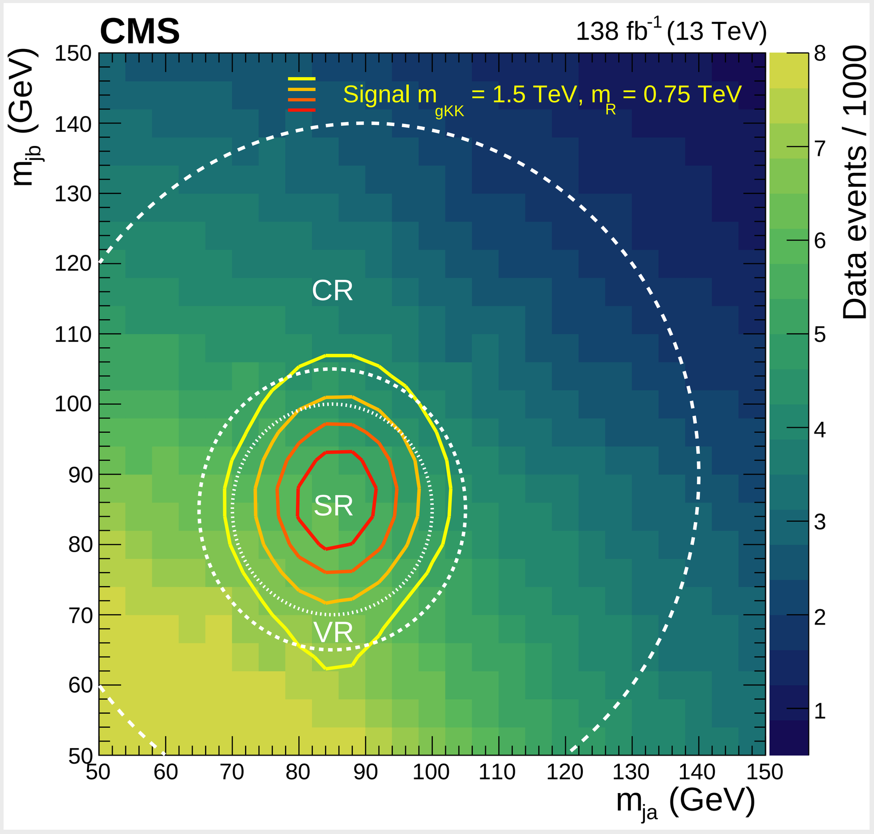

Fig. 2: Definition of SRs, CRs, and VRs.

Signal Region (SR) Definition: ParticleNet MD W-tagging applied to two leading-score jets (ja, jb), with SRa: Both W-tag scores > 0.9 and SRb: One tag > 0.9, other 0.8–0.9; Mass correction: $m_R = m_{jajb} - m_{j_a} - m_{j_b} + 170$ GeV and $m^*_{jjj} = m_{jjj} - m_{j_a} - m_{j_b} + 170$ GeV for improved resonance resolution.

Categorization: 10 orthogonal SRs (SR1a–5b) based on m_R/m^*_{jjj} ratio bins:

SR1: $[0, 0.28]$, SR2: $(0.28, 0.43]$, SR3: $(0.43, 0.57]$, SR4: $(0.57, 0.72]$, SR5: $(0.72, 1.0]$

; Additional cuts: $\Delta\eta^{\max}_{jj} < 3$ (QCD suppression), $N^T_b = 0$ (top background rejection).

Background Control: QCD multijet dominant in SRs, modeled via data-driven methods; Signal significance evaluated as $S/\sqrt{B}$ with optimal window scanning.

Statistical Analysis: 1D fits to m^*_{jjj} distributions in 10 SRs (Fig. 2); Signal efficiency: 12% (SRa), 22% (SRa+b) with $\sim 14\times$ significance gain over baseline.

3. Signal & Background modeling

The background estimation employs a data-driven approach for QCD multijet processes while utilizing corrected Monte Carlo (MC) simulations for subdominant contributions. Key components include:

QCD Multijet Prediction: We use 10 signal regions defined above; Transfer function derived from MC ratio:

$$\mathrm{Pred}^{QCD}_{SR} = [\mathrm{Data} - \mathrm{non\text{-}QCD}]_{CR} \times \frac{MC^{QCD}_{SR}}{MC^{QCD}_{CR}},$$

20% prefit uncertainty covers statistical limitations of transfer factors.

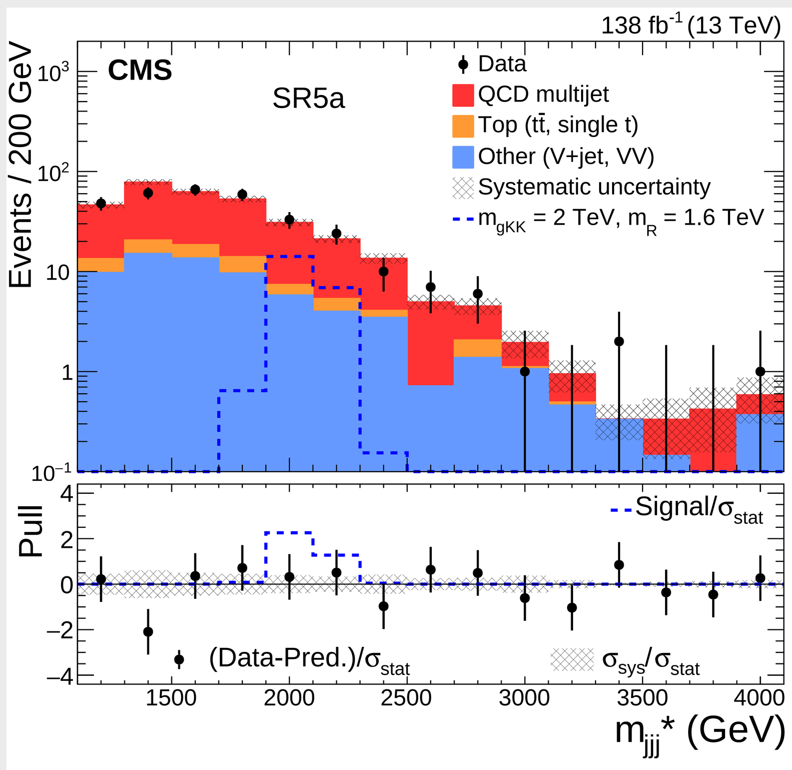

Fig. 3: The postfit plot in SR5a.

Top/W jets Backgrounds: Top: Validated via $N_b \geq 1$ regions, assigned 50% rate uncertainty; W jets + diboson: 30% rate uncertainty based on legacy analyses; Scale factors (SFs) applied for ParticleNet W-tagging efficiency.

Signal: We use signal MC for signal modeling generated from the benchmark model.

4. Conclusion and summary

A search for heavy resonances decaying, via an intermediate resonance, to a gluon and a pair of W bosons in the all-hadronic final states has been presented. A benchmark model, in which a Kaluza-Klein gluon decays into a radion and a gluon, $g_{KK} \to gR \to gWW$, has been considered.

The final states include three large-radius jets, at least two of which are required to be massive, containing the decay products of the hadronically decaying W bosons. In this analysis, a previously unexplored signature is probed using jet substructure techniques relying on deep learning. No resonant signal above the standard model background prediction is found in the data analyzed. Exclusion limits are set at 95% confidence level on the masses of the g_{KK} and R bosons, up to 3.55 and 2.18 TeV, respectively, and on the product of the production cross-section and the branching fraction to a gluon and two W bosons in an extended warped extra-dimensional model. This result is the first to analyze the resonant WW+jet signature and complements constraints set on similar scenarios.

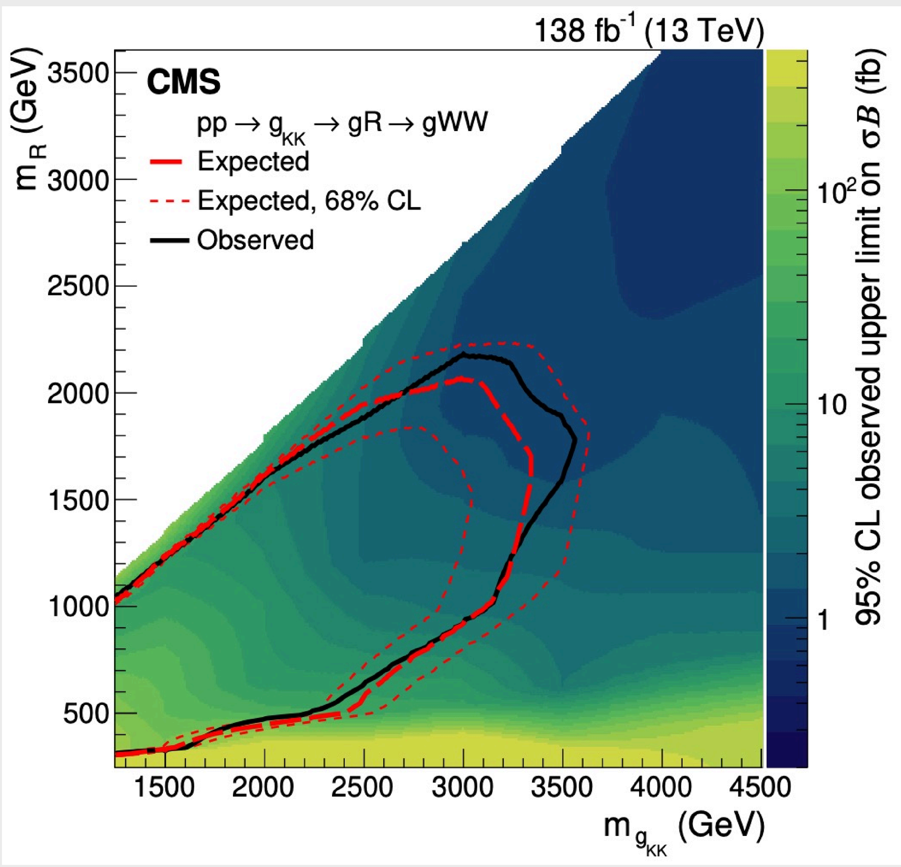

Fig. 4: The 95% CL upper limits on the production cross section times branching fraction B, for the process $pp \to gKK \to gR \to gWW$. The black solid (red dashed) line contour indicates the observed (expected) exclusion region of the gKK and R masses. The red dotted lines show the 68% CL band of the expected limit contour.

References

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[3] K. Agashe et al. "LHC Signals from Cascade Decays of Warped Vector Resonances". In: *JHEP* 1705 (2017), p. 078. DOI: doi:10.1007/JHEP05(2017)078.