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Search for narrow trijet resonances in proton-proton collisions at $\sqrt{s} = 13\,\mathrm{TeV}$

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Abstract

The first search for narrow resonances decaying to three well-separated hadronic jets is presented. The search uses proton-proton collision data corresponding to an integrated luminosity of $138\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 13\,\mathrm{TeV}$, collected at the CERN LHC. No significant deviations from the background predictions are observed between 1.75–9.00 TeV. The results provide the first mass limits on a right-handed boson Z_R decaying to three gluons, an excited quark decaying via a vector boson to three quarks, as well as updated limits on a Kaluza–Klein gluon decaying via a radion to three gluons.

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The standard model (SM) of particle physics has several well-established shortcomings, notably lacking explanations for the nonzero neutrino masses, the issue of dark matter, the matter-antimatter asymmetry of the universe, the hierarchy problem, and the proliferation of quarks and leptons. These shortcomings have motivated a comprehensive program of searches for beyond-the-SM physics at high-energy colliders. Searches for new particles coupled to quarks and/or gluons are especially compelling at hadron colliders, such as the CERN LHC, since these particles could potentially be produced with significant cross sections. Searches for new particles decaying to two hadronic jets (dijets) have been performed numerous times at past and current colliders [1–11]. Hadronic resonances with more complicated signatures have also been explored, including searches for the pair production of resonances decaying to two or more jets [12–19] and a search for resonances decaying to a jet and a boosted dijet resonance [20].

In this Letter, we present the first generic search for singly-produced resolved three-jet (trijet) resonances using proton-proton (pp) collision data recorded by the CMS experiment from 2016 to 2018 at a center-of-mass energy of 13 TeV, corresponding to an integrated luminosity of 138 fb^{-1}. Following techniques established by dijet resonance searches, the trijet invariant mass (m_{jjj}) spectrum is scrutinized for narrow excesses compatible with new resonances decaying to three hadronic jets. No assumptions are made on the structure of the decay, except for the requirement that the final state contain three resolved jets with large transverse momentum (p_{T}). The SM background consists of events containing three or more jets produced exclusively through quantum chromodynamics (QCD), and is estimated from data by fitting the m_{jjj}spectrum with smoothly falling empirical functions. New resonances (X) from three signal models that could potentially address the above-mentioned SM shortcomings are considered: a right-handed Z boson, Z_{R}, decaying directly to three gluons (g) [21]; a Kaluza–Klein excitation of a gluon, G_{KK}, decaying via an intermediate radion to three gluons [22, 23]; and an excited quark, q^{*}, decaying via an intermediate beyond-the-SM vector boson to three quarks (q) [24]. The latter two scenarios, which involve an initial resonance (X) and an intermediate resonance (Y), are referred to as cascade decays and are characterized by the mass ratio $\rho_{\mathrm{m}} = m_{\mathrm{Y}}/m_{\mathrm{X}}$. Values of ρ_{m}between 0.2 and 0.8 that could lead to the resolved trijet signature are considered. At values of ρ_{m}lower than 0.2, the Y is produced with significant transverse momentum, and its decay products are reconstructed as a single jet; this scenario was explored in Ref. [20]. Tabulated results are provided as a HEPData record for this analysis [25].

The CMS apparatus [26] is a multipurpose, nearly hermetic detector, designed to trigger on [27, 28] and identify electrons, muons, photons, and charged and neutral hadrons [29–31]. The "particle-flow" algorithm [32] aims to reconstruct all individual particles in an event, combining information provided by the all-silicon inner tracker, the crystal electromagnetic calorimeters (ECAL), and the brass-scintillator hadron calorimeters (HCAL), all operating inside a 3.8 T superconducting solenoid, with data from the gas-ionization muon detectors embedded in the flux-return yoke outside the solenoid. The reconstructed particles are used to build τ leptons, jets, and missing transverse momentum [33–35].

Events of interest are selected using a two-tiered trigger system. The first level, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select events at a rate of around 100 kHz within a fixed latency of about 4 μs [27]. The second level, known as the high-level trigger, consists of a farm of processors running a version of the full event reconstruction software optimized for fast processing, and reduces the event rate to around 1 kHz before data storage [28].

The primary vertex is taken to be the vertex corresponding to the hardest scattering in the event, evaluated using tracking information alone [36]. The energy of photons is obtained from the ECAL measurement. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the corresponding corrected ECAL and HCAL energies.

For each event, hadronic jets are clustered from these reconstructed particles using the infrared- and collinear-safe anti-k_{T} algorithm [37, 38] with a distance parameter of 0.4. Jet momentum is determined as the vectorial sum of all particle momenta in the jet, and is found from simulation to be, on average, within 5 to 10% of the true momentum over the entire p_{T} spectrum and detector acceptance. Additional pp interactions within the same or nearby bunch crossings (pileup) can contribute additional tracks and calorimetric energy depositions to the jet momentum. To mitigate this effect, charged particles identified to be originating from pileup vertices are discarded, and an offset correction is applied to correct for remaining contributions. Jet energy corrections are derived from simulation to bring the measured response of jets to that of particle level jets on average. In situ measurements of the momentum balance in dijet, photon + jet, Z + jet, and multijet events are used to account for any residual differences in the jet energy scale between data and simulation [34]. The jet energy resolution amounts typically to 15–20% at 30 GeV, 10% at 100 GeV, and 5% at 1 TeV [34]. Additional selection criteria are applied to each jet to remove jets potentially dominated by anomalous contributions from various subdetector components or reconstruction failures [39]. Jets with $p_{\mathrm{T}} < 50\,\mathrm{GeV}$ are further required to pass a multivariate pileup jet rejection algorithm, which has 99% efficiency for jets originating from the primary vertex of interest [40].

To mitigate the loss of resolution from QCD radiation outside the jet boundaries, a "wide–jet" algorithm introduced for previous CMS dijet searches [41] is used. Using the three leading jets with $p_{\mathrm{T}} > 100\,\mathrm{GeV}$ as seeds, the four-vectors of additional jets in the event with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ are added to the nearest seed jet within an optimized distance of $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 1.1$, where η is the pseudorapidity and ϕ is the azimuthal angle in radians. The trijet invariant mass, m_{jjj}, is defined as the invariant mass of the three wide jets obtained with this algorithm.

Monte Carlo (MC) simulation is used to model the contributions from the production of new resonances that assume the Breit–Wigner line shape. The $\mathrm{Z_R} \to \mathrm{ggg}$ process is simulated at leading order (LO) in QCD with PYTHIA 8.242 [42]. Two width scenarios are simulated: the nominal left-right symmetric scenario from Ref. [21] assuming SM-like couplings with a width of $\Gamma_{\mathrm{Z_R}}/m_{\mathrm{Z_R}} \sim 3\%$, and a narrow-width scenario with $\Gamma_{\mathrm{Z_R}}/m_{\mathrm{Z_R}} \sim 0.01\%$ that represents the cases where the width is negligible with respect to the jet energy resolution. The $\mathrm{G_{KK}}$ process is modeled at LO with MADGRAPH5_aMC@NLO 2.7.3 [43], interfaced with PYTHIA for the parton shower. The excited quark process is also modeled at LO in QCD with PYTHIA. Simulated samples are also produced for the background QCD process, using MADGRAPH5_aMC@NLO 2.6.5 at LO with up to four partons at the matrix element level. These background samples are used only for the development of the analysis strategy; the background estimation is performed using collision data. The NNPDF3.1 [44] parton distribution function (PDF) set at next-to-next-to-LO accuracy is used for all processes, along with the parton shower tune CP5 [45]. The interaction of particles with the detector is simulated using the GEANT4 toolkit [46]. The effects of pileup are incorporated by overlaying minimum bias events, simulated with PYTHIA, on the hard scattering interactions, with the multiplicity distribution matching that observed in data.

In the MC simulations, only signal events with a generated resonance mass greater than 85% of the mass point under consideration are used. This requirement helps in avoiding sensitivity to the modeling of far-off-shell low-mass tails that are subject to large uncertainties originating from the choice of PDF, the assumption of resonance width, and the exact description of the relativistic Breit-Wigner line shape. The acceptance of this requirement, which depends on the width of the resonance, is denoted by $\mathcal{A}$.

Events are selected using a set of triggers requiring large hadronic activity, based on either the p_{T} of a single jet or the event H_{T}, defined as the scalar sum of jet p_{T} for all jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ and $|\eta| < 3.0$. The typical thresholds deployed for H_{T} triggers were 900 (1050) GeV and 360 (500) GeV for the p_{T} triggers in 2016 (2017–2018). To avoid the phase space where the trigger is inefficient, we apply a selection of $m_{\mathrm{jjj}} > 1.50\,\mathrm{TeV}$ (2016) or $m_{\mathrm{jjj}} > 1.76\,\mathrm{TeV}$ (2017–2018). The trigger and m_{jjj}thresholds for 2016 data are lower because of the lower instantaneous luminosity. The fully reconstructed events are required to have at least three reconstructed jets with $p_{\mathrm{T}} > 100\,\mathrm{GeV}$ and $|\eta| < 2.5$, prior to the application of the wide–jet algorithm. The aforementioned jet identification criteria, which have an efficiency of more than 98–99%, are applied to each jet used to construct the wide jet. Since the QCD background tends to have jets with higher values of $|\eta|$ than the signal processes, the sensitivity of the analysis is improved by requiring that the maximum difference in η between any two of the three wide jets, $\Delta\eta_{\mathrm{max}}$, be less than 1.6. Similarly, the maximum difference in ΔR between any two jets must be less than 3.0. The efficiencies of the above selection requirements are calculated in simulation to be $\sim$30% for the $\mathrm{Z_R}$ process and between 23–35% (26–37%) for the $\mathrm{G_{KK}}$ (q^*) process between 2.0 and 9.0 TeV. For resonance masses below $\sim$2 TeV, the efficiencies decrease because the signal peaks are truncated by the lower m_{jjj}threshold, reaching $\sim$20% for the $\mathrm{Z_R}$ process, $\sim$15% for the $\mathrm{G_{KK}}$ process, and $\sim$25% for the q^* process.

The background, dominantly arising from the QCD multijet process, is modeled by fitting the m_{jjj}distribution with smoothly falling, empirical functions that have been used in previous searches [19, 20]. Three families of functions are considered:

$$
\begin{aligned}
f_A(x;N) &= p_0 \frac{(1-x)^{p_1}}{x^{\sum_{i=2}^{N} p_i \log^{i-2}(x)}},\\
f_B(x;N) &= p_0 \frac{\mathrm{e}^{-p_1 x}}{x^{\sum_{i=2}^{N} p_i \log^{i-2}(x)}},\\
f_C(x;N) &= p_0 x^{\sum_{i=1}^{N} p_i \log^{i-1}(x)},
\end{aligned}
\tag{1}
$$

where $x = m_{\mathrm{jjj}}/\sqrt{s}$, $p_i (i = 0, 1, \ldots, N)$ are free parameters, and N is the order of the fit function, which is determined using a Fisher F-test [47]. It is found that the third order yields the best fits to the data for all three families of functions. The signal is extracted using a binned maximum-likelihood fit based on a profile likelihood ratio test statistic [48], with variable bin size approximating the m_{jjj} resolution. The signal component of the fit is taken from binned templates derived from simulation, while the background component corresponds to the integral of the fit function across each bin. The three fit functions are incorporated into a single likelihood using a discrete nuisance parameter [49]. This parameter is profiled in an analogous way to continuous nuisance parameters to consider the extra uncertainty brought by the various possible choices of the background functional form. The background parameters are included as freely floating nuisance parameters. The three data-taking years are treated separately in the fit, in particular with independent background parameterizations for each year,

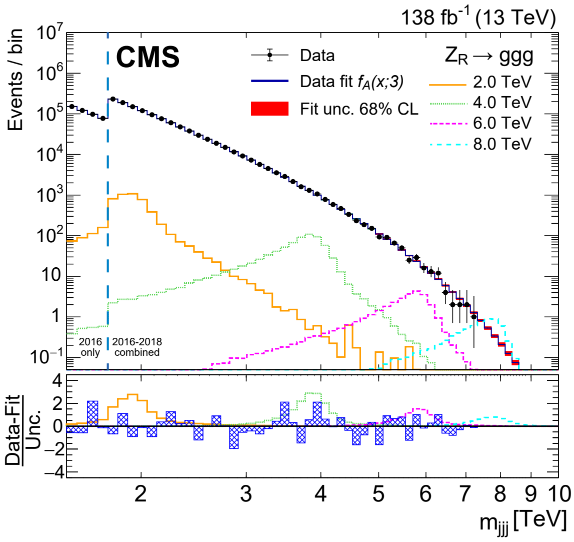

Figure 1: The observed m_{jjj} distribution and the background-only fit to the data using the f_A fit function. Uncertainties in the fit that correspond to the 68% confidence level are depicted with the red band. The expected m_{jjj} distributions for $\mathrm{Z_R}$ signal masses of 2.0, 4.0, 6.0, and 8.0 TeV, with nominal width of $\sim$3%, are also shown. For illustration purposes, the normalizations correspond to $\sigma\mathcal{B}$ values of 200, 50, 20, and 20 fb, respectively. Only 2016 data are shown for $m_{\mathrm{jjj}} < 1.76$ TeV because of the higher trigger thresholds in 2017 and 2018. In the bottom panel, the blue hatched bars show the difference between the observed data and the background prediction divided by the statistical uncertainty, along with expectations for the example $\mathrm{Z_R}$ signal points.

and are combined statistically into a single likelihood. The combined result of the background-only fits with the function $f_A(x; 3)$ is shown in Fig. 1 as an example.

To gauge the systematic biases in the signal extraction, bias tests are performed using pseudo-data produced from the background-only fits with injected signal events. The bias is found to be negligible. Systematic uncertainties in the signal are incorporated in the likelihood as constrained nuisance parameters. The jet energy resolution and scale uncertainties translate to $\approx$10% and $\approx$1% uncertainties in the width and the position of the trijet mass shape for the signal, respectively. The integrated luminosities for the 2016, 2017, and 2018 data-taking years have 1.2–2.5% individual uncertainties [50–52], while the overall uncertainty for the 2016–2018 period is 1.6%. Finally, the uncertainty in the predicted signal yield that stems from the pileup reweighting procedure is $\approx$3% for the three years, and is uncorrelated between years. The most significant uncertainties are those associated with background fit parameters in the background prediction, which are evaluated to have an impact on the fitted signal strength by $\approx$10% over the entire search range.

No significant excesses compatible with the signal hypotheses are observed. For the $\mathrm{X} \rightarrow \mathrm{ggg}$ signal scenario, the largest deviation is observed at $m_{\mathrm{X}} = 4.1$ TeV, corresponding to local significance values of 2.1 and 2.2 standard deviations for the nominal and narrow width hypotheses, respectively. Taking into account the look-elsewhere effect [53], the global significance values are 0.2 and 0.3 standard deviations, respectively. For the $\mathrm{X} \rightarrow \mathrm{Y(gg)g}$ cascade decay scenario, the largest deviation is observed for $\rho_{\mathrm{m}} = 0.3$ and $m_{\mathrm{X}} = 4.1$ TeV, with a local (global) significance of 2.2 (0.4) standard deviations. For the $\mathrm{X} \rightarrow \mathrm{Y(qq)q}$ cascade decay scenario, the largest deviation is observed at $\rho_{\mathrm{m}} = 0.7$ and $m_{\mathrm{X}} = 3.9$ TeV, and corresponds to a local (global) significance of 2.1 (0.3) standard deviations.

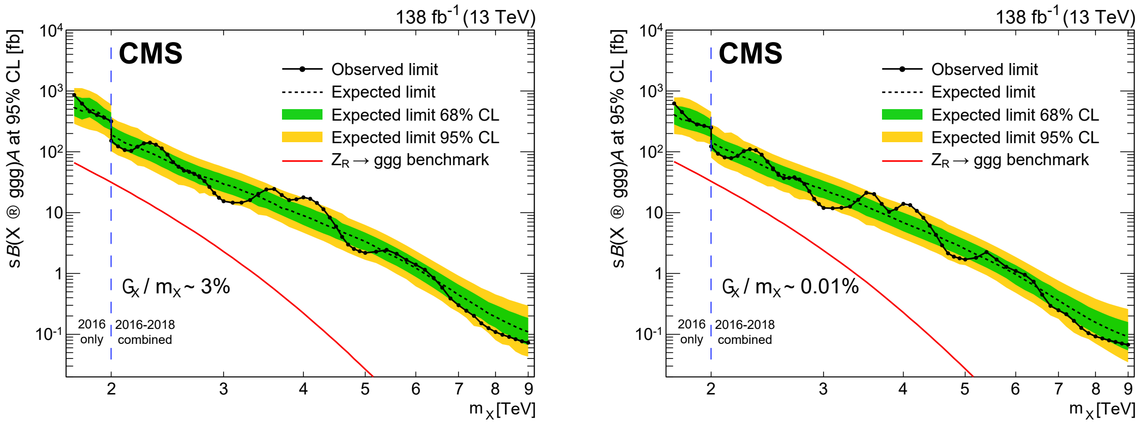

Figure 2: Limits at 95% CL on $\sigma\mathcal{B}(\mathrm{X} \to \mathrm{ggg})\mathcal{A}$ for the nominal (left) and narrow-width (right) scenarios. Only 2016 data are used to derive limits below 2.0 TeV because of the higher trigger thresholds in 2017 and 2018. Theoretical predictions assuming SM-like couplings are depicted with red curves.

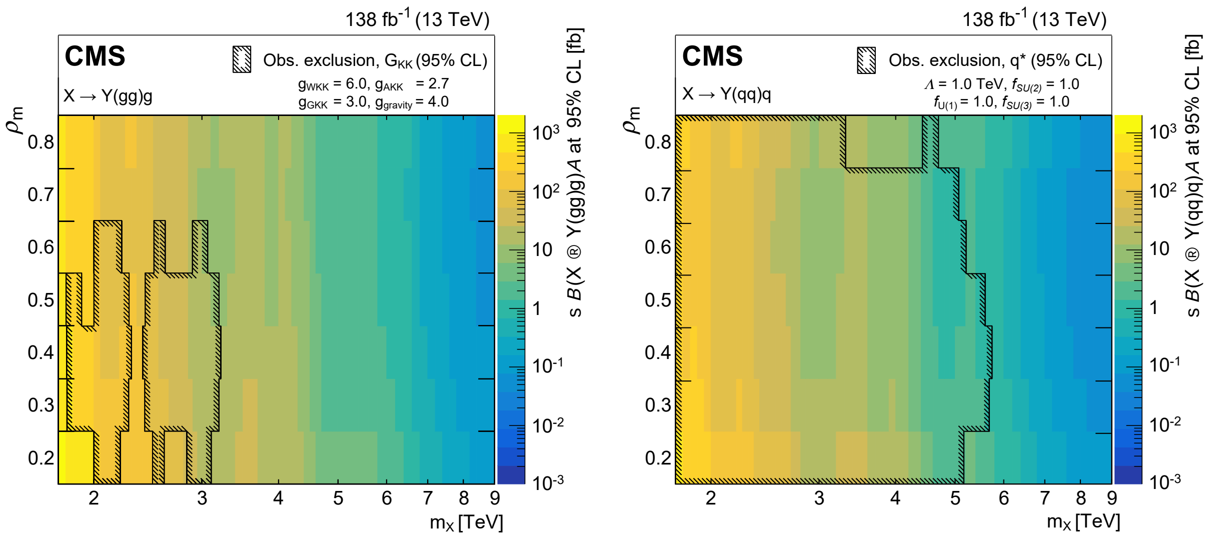

Figure 3: Observed limits at 95% CL as a function of m_X and ρ_m on $\sigma\mathcal{B}(\mathrm{X} \to \mathrm{Y}(\mathrm{gg})\mathrm{g})\mathcal{A}$ (left) and $\sigma\mathcal{B}(\mathrm{X} \to \mathrm{Y}(\mathrm{qq})\mathrm{q})\mathcal{A}$ (right). Only 2016 data are used to derive limits below 2.0 TeV because of the higher trigger thresholds in 2017 and 2018. The legend shows the model parameters for the chosen benchmark [23, 24], and their corresponding mass exclusion ranges are depicted with areas inside the black hatched contours.

Limits are set for the first time at 95% confidence level (CL) on the product of the signal process production cross section, branching fraction, and acceptance ($\sigma\mathcal{BA}$) to three resolved jets using the asymptotic $\mathrm{CL_s}$ procedure [54–56] in the mass range between 1.75 TeV and 9.00 TeV. Only 2016 data are used to derive limits below 2.0 TeV because of the higher trigger thresholds deployed in 2017 and 2018. Limits are shown in Fig. 2 for the three-body decay of new resonances, ranging from 0.073 (0.067) fb to 0.86 (0.62) pb for the nominal (narrow) width hypotheses. Theoretical predictions of $\sigma\mathcal{BA}$ assuming SM-like couplings are depicted with red curves. The current data set does not provide sufficient sensitivity to constrain the $\mathrm{Z_R}$ model. Limits on the cascade decay of new resonances into ggg (qqq) are presented in Fig. 3, which range from 0.061 (0.047) fb to 1.2 (0.49) pb. Benchmark model coupling parameters [23, 24] are shown in the legend, and their corresponding mass exclusion ranges are depicted with areas inside the black hatched contours. At $\rho_\mathrm{m} = 0.2$, this search achieves a similar level of sensitivity to that of the previous search [20] for the ggg decay mode.

In summary, the first generic search for new particles decaying to three hadronic jets has been presented. The search uses proton-proton collision data at $\sqrt{s} = 13\,\mathrm{TeV}$ recorded by the CMS experiment in 2016–2018, corresponding to an integrated luminosity of $138\,\mathrm{fb^{-1}}$. The three-jet invariant mass spectrum is scanned for narrow peaks corresponding to new particles. No significant excesses above the standard model background expectations are observed. Limits are set on the product of the production cross section, branching fraction, and acceptance to three resolved jets. The results are interpreted in the context of a new right-handed boson $\mathrm{Z_R}$ decaying to three gluons, a Kaluza–Klein gluon $\mathrm{G_{KK}}$ decaying via an intermediate radion to three gluons (ggg), and an excited quark decaying via a vector boson to three quarks (qqq). This is the first search for the three-body decay of high-mass resonances (X) into three resolved jets at the LHC, and also the first search for X that decays into three resolved jets through an intermediate resonance (Y) with a mass ratio $m_\mathrm{Y}/m_\mathrm{X}$ between 0.3–0.8 for the ggg decay mode and 0.2–0.8 for the qqq decay mode, significantly extending the model parameter space explored by a previous search [20].

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References

[1] R. M. Harris and K. Kousouris, "Searches for Dijet Resonances at Hadron Colliders", *Int. J. Mod. Phys. A* **26** (2011) 5005, doi:10.1142/S0217751X11054905, arXiv:1110.5302.

[2] UA1 Collaboration, "Two-jet mass distributions at the CERN proton-antiproton collider", *Phys. Lett. B* **209** (1988) 127, doi:10.1016/0370-2693(88)91843-6.

[3] UA2 Collaboration, "A search for new intermediate vector mesons and excited quarks decaying to two jets at the CERN $\overline{\mathrm{p}}\mathrm{p}$ collider", *Nucl. Phys. B* **400** (1993) 3, doi:10.1016/0550-3213(93)90395-6.

[4] CDF Collaboration, "Search for new particles decaying into dijets in proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. D* **79** (2009) 112002, doi:10.1103/PhysRevD.79.112002, arXiv:0812.4036.

[5] D0 Collaboration, "Search for new particles in the two-jet decay channel with the D0 detector", *Phys. Rev. D* **69** (2004) 111101(R), doi:10.1103/PhysRevD.69.111101, arXiv:hep-ex/0308033.

[6] ATLAS Collaboration, "Search for new resonances in mass distributions of jet pairs using 139 fb^{-1} of pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *JHEP* **03** (2020) 145, doi:10.1007/JHEP03(2020)145, arXiv:1910.08447.

[7] ATLAS Collaboration, "Search for light resonances decaying to boosted quark pairs and produced in association with a photon or a jet in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Phys. Lett. B* **788** (2019) 316, doi:10.1016/j.physletb.2018.09.062, arXiv:1801.08769.

[8] ATLAS Collaboration, "Search for resonances in the mass distribution of jet pairs with one or two jets identified as b-jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Phys. Rev. D* **98** (2018) 032016, doi:10.1103/PhysRevD.98.032016, arXiv:1805.09299.

[9] CMS Collaboration, "Search for high mass dijet resonances with a new background prediction method in proton-proton collisions at $\sqrt{s} = 13$ TeV", *JHEP* **05** (2020) 033, doi:10.1007/JHEP05(2020)033, arXiv:1911.03947.

[10] CMS Collaboration, "Search for low mass vector resonances decaying into quark-antiquark pairs in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. D* **100** (2019) 112007, doi:10.1103/PhysRevD.100.112007, arXiv:1909.04114.

[11] CMS Collaboration, "Search for narrow resonances in the b-tagged dijet mass spectrum in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. D* **108** (2023) 012009, doi:10.1103/PhysRevD.108.012009, arXiv:2205.01835.

[12] CDF Collaboration, "First search for multijet resonances in $\sqrt{s} = 1.96$ TeV $\mathrm{p}\overline{\mathrm{p}}$ collisions", *Phys. Rev. Lett.* **107** (2011) 042001, doi:10.1103/PhysRevLett.107.042001, arXiv:1105.2815.

[13] CDF Collaboration, "Search for pair production of strongly interacting particles decaying to pairs of jets in $p\overline{p}$ collisions at $\sqrt{s} = 1.96\,\text{TeV}$", *Phys. Rev. Lett.* **111** (2013) 031802, doi:10.1103/PhysRevLett.111.031802, arXiv:1303.2699.

[14] ATLAS Collaboration, "A search for pair-produced resonances in four-jet final states at $\sqrt{s} = 13$ TeV with the ATLAS detector", *Eur. Phys. J. C* **78** (2018) 250, doi:10.1140/epjc/s10052-018-5693-4, arXiv:1710.07171.

[15] CMS Collaboration, "Search for pair-produced resonances decaying to quark pairs in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. D* **98** (2018) 112014, doi:10.1103/PhysRevD.98.112014, arXiv:1808.03124.

[16] CMS Collaboration, "Search for pair-produced resonances each decaying into at least four quarks in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. Lett.* **121** (2018) 141802, doi:10.1103/PhysRevLett.121.141802, arXiv:1806.01058.

[17] ATLAS Collaboration, "Search for R-parity-violating supersymmetric particles in multi-jet final states produced in p-p collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector at the LHC", *Phys. Lett. B* **785** (2018) 136, doi:10.1016/j.physletb.2018.08.021, arXiv:1804.03568.

[18] CMS Collaboration, "Search for pair-produced three-jet resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV", *Phys. Rev. D* **99** (2019) 012010, doi:10.1103/PhysRevD.99.012010, arXiv:1810.10092.

[19] CMS Collaboration, "Search for resonant and nonresonant production of pairs of dijet resonances in proton-proton collisions at $\sqrt{s}$ = 13 TeV", *JHEP* **07** (2023) 161, doi:10.1007/JHEP07(2023)161, arXiv:2206.09997.

[20] CMS Collaboration, "Search for high-mass resonances decaying to a jet and a Lorentz-boosted resonance in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$", *Phys. Lett. B* **832** (2022) 137263, doi:10.1016/j.physletb.2022.137263, arXiv:2201.02140.

[21] K. Huitu, J. Maalampi, A. Pietila, and M. Raidal, "Doubly charged higgs at lhc", *Nucl. Phys. B* **487** (1997) 27, doi:10.1016/S0550-3213(97)87466-4, arXiv:hep-ph/9606311.

[22] K. S. Agashe et al., "LHC signals from cascade decays of warped vector resonances", *JHEP* **05** (2017) 078, doi:10.1007/JHEP05(2017)078, arXiv:1612.00047.

[23] K. Agashe, M. Ekhterachian, D. Kim, and D. Sathyan, "LHC signals for KK graviton from an extended warped extra dimension", *JHEP* **11** (2020) 109, doi:10.1007/JHEP11(2020)109, arXiv:2008.06480.

[24] U. Baur, M. Spira, and P. M. Zerwas, "Excited-quark and -lepton production at hadron colliders", *Phys. Rev. D* **42** (1990) 815, doi:10.1103/PhysRevD.42.815.

[25] HEPData record for this analysis, 2023. doi:10.17182/hepdata.144165.

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

[27] CMS Collaboration, "Performance of the CMS Level-1 trigger in proton-proton collisions at $\sqrt{s} = 13\,\text{TeV}$", *JINST* **15** (2020) P10017, doi:10.1088/1748-0221/15/10/P10017, arXiv:2006.10165.

[28] CMS Collaboration, "The CMS trigger system", *JINST* **12** (2017) P01020, doi:10.1088/1748-0221/12/01/P01020, arXiv:1609.02366.

[29] CMS Collaboration, "Electron and photon reconstruction and identification with the CMS experiment at the CERN LHC", *JINST* **16** (2021) P05014, doi:10.1088/1748-0221/16/05/P05014, arXiv:2012.06888.

[30] CMS Collaboration, "Performance of the CMS muon detector and muon reconstruction with proton-proton collisions at $\sqrt{s} = 13$ TeV", *JINST* **13** (2018) P06015, doi:10.1088/1748-0221/13/06/P06015, arXiv:1804.04528.

[31] CMS Collaboration, "Description and performance of track and primary-vertex reconstruction with the CMS tracker", *JINST* **9** (2014) P10009, doi:10.1088/1748-0221/9/10/P10009, arXiv:1405.6569.

[32] CMS Collaboration, "Particle-flow reconstruction and global event description with the CMS detector", *JINST* **12** (2017) P10003, doi:10.1088/1748-0221/12/10/P10003, arXiv:1706.04965.

[33] CMS Collaboration, "Performance of reconstruction and identification of τ leptons decaying to hadrons and ν_τ in pp collisions at $\sqrt{s} = 13$ TeV", *JINST* **13** (2018) P10005, doi:10.1088/1748-0221/13/10/P10005, arXiv:1809.02816.

[34] CMS Collaboration, "Jet energy scale and resolution in the CMS experiment in pp collisions at 8 TeV", *JINST* **12** (2017) P02014, doi:10.1088/1748-0221/12/02/P02014, arXiv:1607.03663.

[35] CMS Collaboration, "Performance of missing transverse momentum reconstruction in proton-proton collisions at $\sqrt{s} = 13$ TeV using the CMS detector", *JINST* **14** (2019) P07004, doi:10.1088/1748-0221/14/07/P07004, arXiv:1903.06078.

[36] CMS Collaboration, "Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid", CMS Technical Proposal CERN-LHCC-2015-010, CMS-TDR-15-02, 2015.

[37] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_T jet clustering algorithm", *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

[38] M. Cacciari, G. P. Salam, and G. Soyez, "FastJet user manual", *Eur. Phys. J. C* **72** (2012) 1896, doi:10.1140/epjc/s10052-012-1896-2, arXiv:1111.6097.

[39] CMS Collaboration, "Jet algorithms performance in 13 TeV data", CMS Physics Analysis Summary CMS-PAS-JME-16-003, 2017.

[40] CMS Collaboration, "Pileup mitigation at CMS in 13 TeV data", *JINST* **15** (2020) P09018, doi:10.1088/1748-0221/15/09/P09018, arXiv:2003.00503.

[41] CMS Collaboration, "Search for resonances in the dijet mass spectrum from 7 TeV pp collisions at CMS", *Phys. Lett. B* **704** (2011) 123, doi:10.1016/j.physletb.2011.09.015, arXiv:1107.4771.

[42] 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.

[43] 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.

[44] NNPDF Collaboration, "Parton distributions from high-precision collider data", *Eur. Phys. J. C* **77** (2017) 663, doi:10.1140/epjc/s10052-017-5199-5, arXiv:1706.00428.

[45] CMS Collaboration, "Extraction and validation of a new set of CMS PYTHIA8 tunes from underlying-event measurements", *Eur. Phys. J. C* **80** (2020) 4, doi:10.1140/epjc/s10052-019-7499-4, arXiv:1903.12179.

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

[47] R. A. Fisher, "On the interpretation of χ^2 from contingency tables, and the calculation of P", *J. R. Stat. Soc.* **85** (1922) 87, doi:10.2307/2340521.

[48] ATLAS and CMS Collaborations, and LHC Higgs Combination Group, "Procedure for the LHC Higgs boson search combination in Summer 2011", Technical Report CMS-NOTE-2011-005, ATL-PHYS-PUB-2011-11, 2011.

[49] P. D. Dauncey, M. Kenzie, N. Wardle, and G. J. Davies, "Handling uncertainties in background shapes: the discrete profiling method", *JINST* **10** (2015) P04015, doi:10.1088/1748-0221/10/04/P04015, arXiv:1408.6865.

[50] CMS Collaboration, "Precision luminosity measurement in proton-proton collisions at $\sqrt{s} = 13$ TeV in 2015 and 2016 at CMS", *Eur. Phys. J. C* **81** (2021) 800, doi:10.1140/epjc/s10052-021-09538-2, arXiv:2104.01927.

[51] CMS Collaboration, "CMS luminosity measurement for the 2017 data-taking period at $\sqrt{s}$ = 13 TeV", CMS Physics Analysis Summary CMS-PAS-LUM-17-004, 2018.

[52] CMS Collaboration, "CMS luminosity measurement for the 2018 data-taking period at $\sqrt{s}$ = 13 TeV", CMS Physics Analysis Summary CMS-PAS-LUM-18-002, 2019.

[53] E. Gross and O. Vitells, "Trial factors for the look elsewhere effect in high energy physics", *Eur. Phys. J. C* **70** (2010) 525, doi:10.1140/epjc/s10052-010-1470-8, arXiv:1005.1891.

[54] A. L. Read, "Presentation of search results: The $\mathrm{CL_s}$ technique", *J. Phys. G* **28** (2002) 2693, doi:10.1088/0954-3899/28/10/313.

[55] T. Junk, "Confidence level computation for combining searches with small statistics", *Nucl. Instrum. Meth. A* **434** (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.

[56] G. Cowan, K. Cranmer, E. Gross, and O. Vitells, "Asymptotic formulae for likelihood-based tests of new physics", *Eur. Phys. J. C* **71** (2011) 1554, doi:10.1140/epjc/s10052-011-1554-0, arXiv:1007.1727. [Erratum: doi:10.1140/epjc/s10052-013-2501-z].

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