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Search for heavy resonances decaying into W, Z, H bosons at CMS

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Summary. — A summary of searches for heavy resonances decaying in dibosons is presented, performed on data produced by LHC p-p collisions at $\sqrt{s} = 13\,\text{TeV}$ and collected with the CMS detector during 2016. The common feature of these analyses is the boosted topology: the decay products of the considered bosons (both electroweak (W, Z) bosons and the Higgs boson) are expected to be highly energetic and close in angle, leading to a non-trivial identification of the particles involved in the final state (quarks). The background estimation technique is data driven. Results are interpreted in the context of theories beyond the Standard Model.

1. – Introduction

Many Beyond Standard Model (BSM) theories foresee the existence of new heavy resonances (at TeV scale), as a consequence of the enlargement of the SM symmetry group, that represents a tentative solution to the open questions of the theory.

The Heavy Vector Triplet (HVT) model [1] is a general framework that encloses many other BSM theories. It introduces a triplet of neutral and charged heavy vector bosons (X^0, X^+, X^-): in the so-called HVT-A scenario, the fermionic decays of the triplet dominate, whilst in the HVT-B scenario, the decays into vector and scalar bosons is preferred.

In this document, searches for heavy diboson resonances performed with 2016 data provided by LHC proton-proton collisions and collected by the CMS detector, for an integrated luminosity of $\mathcal{L} = 35.9\,\text{fb}^{-1}$, are presented. Two possible resonances are probed: a couple of vector bosons (VV) decaying hadronically, or a vector boson and a Higgs boson (VH), decaying into quarks (V) and into a couple of b quarks (H). Dealing with heavy particles (over 1 TeV) means that the decay products have a large Lorentz boost, hence the couples of quarks coming from bosons are expected to be collimated. Each boson is therefore reconstructed as a large-cone jet. Jet substructure techinques are exploited in order to discriminate the V or the H boson from the dominant multijet background. A detailed description of the CMS detector can be found in [2].

2. – Event reconstruction and boson tagging

Given the boosted topology of the decay products, a pair of large-cone jets is requested, clustered with anti-k_T algorithm in a cone $\Delta R = 0.8$ and with high transverse momenta ($> 200\,\mathrm{GeV}$). Events with charged leptons and neutrinos (reconstructed as missing transverse momentum) are rejected.

An interplay of two grooming algorithms is applied to jet candidates: the PUPPI algorithm [3] is designed to subtract the pile-up contributions from the jet (namely, energy deposits coming from spectator events, not involved in the primary interaction producing the heavy resonance), along with the soft-drop algorithm [4], that removes the soft radiation contributions. Exclusive categories of the groomed jet mass (m_j) define the boson type and hence the signal regions of the analyses: if it lies in the window $65 < m_j < 85\,\mathrm{GeV}$, the jet is tagged as W boson; if $85 < m_j < 105\,\mathrm{GeV}$ it is a Z; if $105 < m_j < 135\,\mathrm{GeV}$ it is a Higgs boson (fig. 1, left).

The τ_{21} subjettiness [5] is a powerful variable to exploit the jet substructure: it compares the 2-prong jet substructure hypotesis (typical of hadronically decaying electroweak bosons) *vs.* the 1-prong hypotesis (that is peculiar of multijet QCD events). Signal events are expected to lie mainly at low τ_{21}, whilst the dominant QCD background tends to higher values (fig. 1, center). Two exclusive categories are defined: high-purity category (low background contribution but few events) when $0 < \tau_{21} < 0.35$, and low purity when $0.35 < \tau_{21} < 0.75$ (QCD contamination but higher efficiency).

Higgs bosons are identified through their most probable decay ($b\bar{b}$). The double b-tagger algorithm tags the presence of a pair of b-quarks in a large jet, by combining information about displaced tracks and secondary vertices with MVA techniques. Two exclusive categories are set: loose operating point, namely the lower tail of the distribution, where background contamination is expected, and tight operating point, mainly populated by genuine Higgs boson events (fig. 1, right).

When a heavy particle decays into a couple of electroweak bosons, 6 categories are defined, depending on the bosons flavour (WW, WZ, ZZ) and their purity categorization (τ_{21}). For the VH resonances, 8 categories are defined, additionally considering the b-tagging working point. For each category, the search for local excess in data is performed by looking at the invariant mass spectra of the two most energetic large-cone jets, falling into the required criteria.

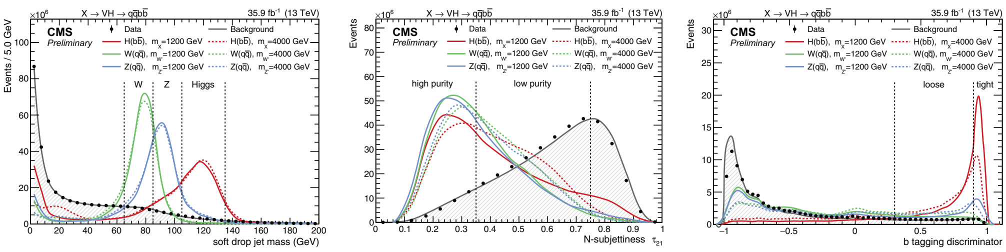

Fig. 1. – Significant variables used to discriminate signal events (coloured curves) with regards to multijet background (in shaded grey): the jet mass (left) defines the signal regions (W in green, Z in blue, H in red); τ_{21} subjettiness (center) defines the purity categories for electroweak bosons; the double b-tagger algorithm outcome (right) defines the categorization when a jet is identified as Higgs boson.

3. – Background estimation and statistical analysis

Since multijet background is poorly modelled by Monte Carlo simulations, a data-driven approach is adopted: fits to data are performed in the signal region with power law or exponentially falling functions, with a variable number of parameters (2 to 5). A 10% confidence level Fisher test is used to determine the best choice. Signal shapes are fitted as crystal ball functions (namely, a Gaussian core with power law asymmetric tails) in Monte Carlo signal simulations, in the narrow-width approximation: the intrinsic width of the resonance is negligible (0.1%) when compared to the detector resolution.

In both VV and VH analyses, uncertainties assigned to the background shapes come from the covariance matrix of the function fits.

For the VV analysis, the most relevant uncertainty sources impacting on Monte Carlo signal samples are related to the τ_{21} tagging efficiency (up to 33%). In VH analysis, the largest uncertainties depend on V-tagging (up to 20%) and H-tagging (up to 8%). The mass resolution of the jet has different impacts (up to 36% in VV, 10% in VH). Minor uncertainties come from luminosity measurement, jet momentum resolution and energy corrections.

4. – Results and conclusions

The signal hypoteses are tested against the background-only hypotesis via the modified frequentist prescription (asymptotic CL_S method). Limits on the production cross-section of the resonances times the branching ratios in the respective decay channels (VV, VH) are computed using a shape analysis of the di-jet invariant mass spectrum. Systematic uncertainties are treated as log-normal nuisance parameters and profiled in the statistical interpretation.

No excess is observed in data with regards to predictions. In the context of the HVT-B scenario, W' and Z' with masses below 3.6 TeV and 2.7 TeV are excluded by [6]. In the HVT-A scenario, W' and Z' with masses below 3.1 TeV and 2.5 TeV are excluded by [7]. Upper limits on the cross-section times branching ratio are set in the range 0.8–50 fb, as a function of the resonance mass.

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