## Exotica searches in CMS

D. del Re
*Università Sapienza, Rome and INFN Rome*

The CMS experiment collected 36 fb$^{-1}$ of pp collision data in 2016. Based on this statistics different searches for new physics in several final states have been conducted. We present the new results for final states with leptons and missing transverse energy, high momentum top quarks, and high mass dijets.

### 1 Introduction

The increase in center of mass energy, which is now at 13 TeV, and the large luminosity delivered by the LHC in 2016 allow for the search for new physics in an unexplored phase space. This is particularly important for both the searches for high mass new resonances and for analyses which require large statistics to better constraint systematic effects at lower masses. In this report we describe the new analyses presented by the CMS experiment [1] and based on 2016 statistics. They regard the searches involving leptons and missing transverse energy in the final states, predicted in seesaw models, searches with high momentum top quarks, predicted by Vector-like quark models, and searches for high mass resonances, in top-bottom and dijet final states, present in several beyond the standard model scenarios. All these searches supersede the previous results based on both the data collected at 8 TeV center of mass energy and at 13 TeV in 2015.

### 2 Search for New Physics in multileptons

The discovery of neutrino oscillations indicated that neutrinos are massive. Among the several extensions of the standard model to address neutrino masses, the seesaw mechanism is one of the most appealing possibility. In the type-III seesaw model the neutrino mass, which is a Majorana particle, arises via the mediation of new massive fermions, $\Sigma^{\pm}$ and $\Sigma^{0}$, which decay in Z, W and H bosons. In this analysis [2] these new fermions are produced in pairs and the final states with multileptons and missing transverse energy are studied.

The sample is divided in 6 categories, depending on the number of leptons and on the value of the reconstructed invariant mass of the dileptons present in the event, distinguishing the cases where the mass is on, below, or above the Z boson mass. The main discriminant variable used to check for the presence of the new massive fermions is the scalar sum of the transverse momentum of all leptons and the missing transverse energy. An example of such variable for the category with 3 leptons and a dilepton mass below the Z is shown in Fig.1. It can be noted that the main backgrounds are represented by dibosons and misidentified leptons and this is basically true for all categories. These backgrounds are extracted from control regions in data.

No significant excess is observed and upper limits on the production cross section and the mass of the massive fermions are set under the hypothesis that new heavy fermions are degenerate in mass and have the same couplings and branching ratios to leptons with different flavors. As shown in Fig.1 the limit on the mass of new heavy fermions corresponds to 850 GeV, with an improvements with respect to the previous 13 TeV limits of 400 GeV.

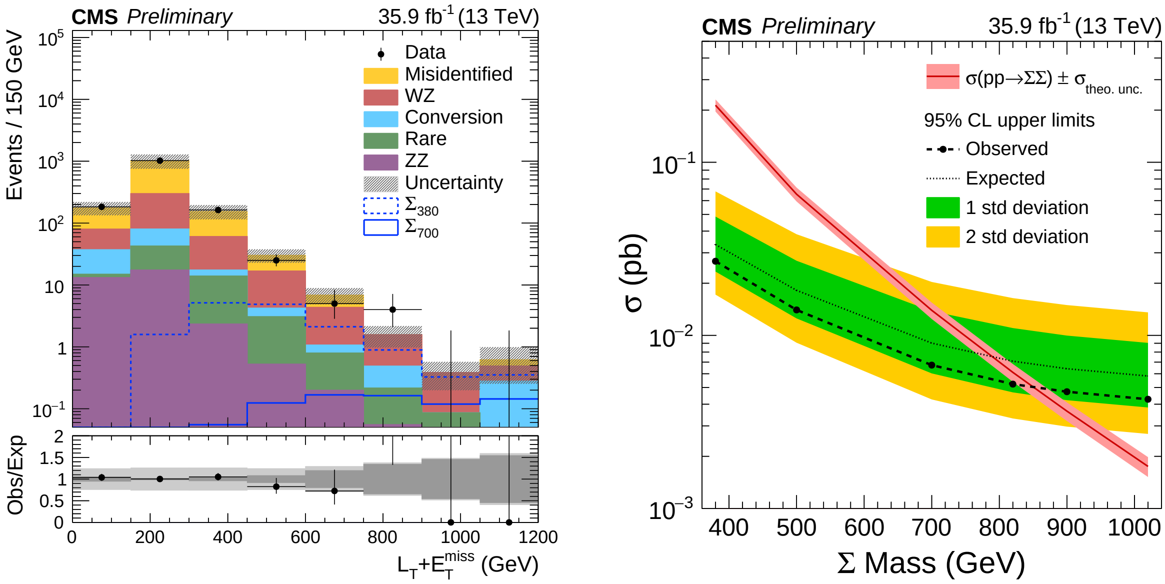


Figure 1 – Left: distribution of the scalar sum of leptons transverse momentum and missing transverse energy for events with three leptons and one lepton pair, with mass below-Z and $E_T^{miss} > 50$ GeV. The total standard model background is shown as a stack of all contributing processes. Right: 95% confidence level upper limits on the cross section for the production of heavy fermion pairs compared to the theoretical cross section.

## 3 Searches involving boosted tops

Many searches for new physics involve the reconstruction of top quark decays. In the high-energy regime, the event topology changes and top quark decay products become highly boosted, requiring the use of special identification algorithms. In the case the top decays fully hadronically, the decay products appear as a single and wide jet. The top decays are identified first removing low energy stuff, mainly due to pile-up using the so-called *pruning* algorithm. Then, jets originating from boosted electroweak bosons and top quarks are distinguished from those originating from light quarks or gluons using the $N - subjettiness$ variables. They exploit the fact that the internal structure of W and top jets present subjets while the QCD jets are more standard. In the case the top decays semileptonically the resulting lepton and jets are not separated and modified isolation criteria need to be used. The fact that part of the jet energy may overlap with the lepton is taken into account by an isolation cone that depends on the energy of the lepton and become smaller for larger energies.

### VLQ in Z-top final state

The first analysis is based on the Z-top final state [3]. It searches for 2/3 charge vector-like T quarks, which are heavy partners of the top quark. The models involving these new quarks are appealing because they solve the hierarchy problem since there are new particles running in loops. The Z boson is reconstructed leptonically and the top fully hadronically with the requirement of the presence of a b jet. The events are divided in 10 categories based on the topology of the hadronic top decay, which is determined with the $N - subjettiness$ variables, and the possible presence of an extra forward jet. The main discriminating variable is represented by the invariant mass of the reconstructed top and Z system. An example is shown in Fig.2 left. The main background is due to Z+jet events. It is extracted from control regions on data, determined inverting the b tag requirement and it is properly taken into account when deriving the signal yields. The limits on the mass of the top partner are within the range 0.85 - 1.45 TeV, depending on the production mechanism and the width of the particle.

### $X_{5/3}$ in Same-Sign Dilepton

The analysis searches for the production of 5/3 charge vector-like quarks ($X_{5/3}$) in pairs [4]. Each $X_{5/3}$ further decays into a W boson and a t quark. W and t are required to decay in modes with leptons and the final state is represented by two same-sign leptons and jets. The leptons are selected with modified isolation to take care of the boost and the overlapping jets. The background (mainly diboson and $t\bar{t}$ events determined using simulation) is separated using the scalar sum of the transverse momentum of all leptons and jets in the event. No significant excess is observed and upper limits on the production cross section are set. The 95% CL limit on the $X_{5/3}$ mass corresponds to 1.16 (1.10) TeV on right- (left-) handed top partner.

### W′ in tb final state

Many theories predict the existence of new heavy vector bosons (W′), which are connected to new symmetries in the theories which solve the hierarchy problem. If the new resonance is heavy enough, it can decay into W′→tb. The search in this final state complements other W′ searches: in some models the tb decay is enhanced and it allows for a full reconstruction of the W′ mass. In this analysis [5] the top quark decays semileptonically and the b quark is identified with b tagging. The mass of the W′ is reconstructed after imposing the W mass constraint and the presence of the neutrino introduces a quadratic ambiguity. The events are divided into 8 categories depending of the jet tranverse momentum, lepton flavor, and number of b-tagged jets. No relevant excess is observed in any of the categories, thus allowing to put strong constraints on the mass of the W′. The results are interpreted in different scenarios. In the right-handed case mass limits are in the range 3.4-3.6 TeV. The left- and right-handed coupling strengths to fermions ($a_R$ and $a_L$) can be also varied. The resulting mass limits in the $a_R$ vs $a_L$ plane are shown in Fig. 2 right.

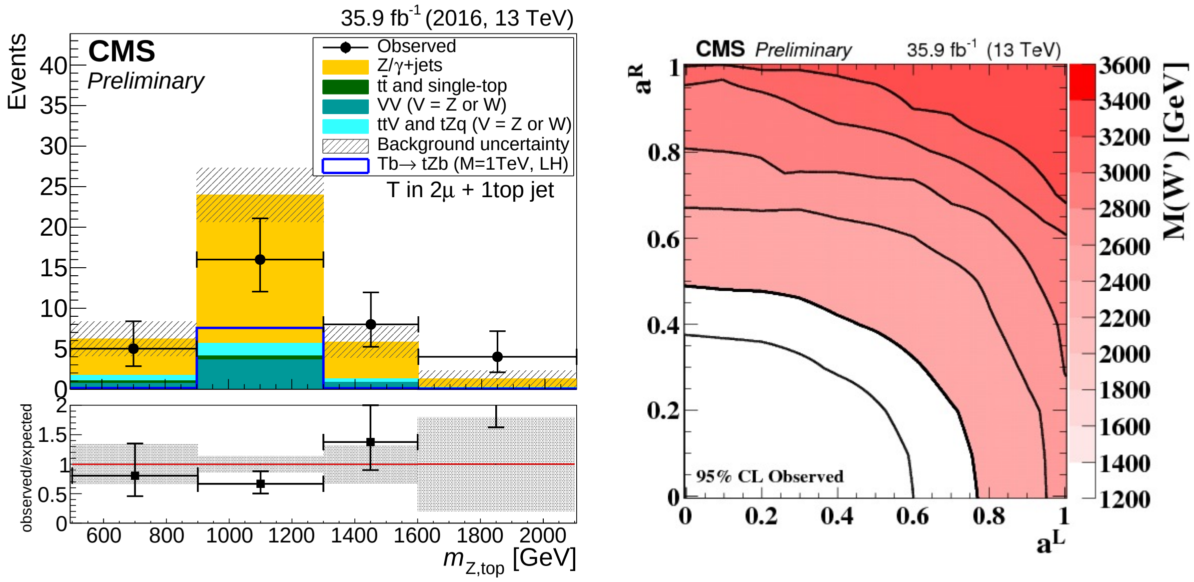


Figure 2 – Left: Z-top invariant mass for events with the Z boson decaying into muons compared with the background estimates as derived from control regions. Right: observed limit on the W′ signal mass as function of the left-handed and right-handed couplings. Black lines represent contours of equal mass.

## 4 Search in dijet final state

The dijet search represents the most sensitive search at the LHC to explore the high mass phase space, thanks to the large cross section involving final states with jets[6]. The search is sensitive to several scenarios of new physics, like excited quarks, strings, new heavy bosons, gravitons, and dark matter. The analysis is simple and robust. Jets are reconstructed in wide cones ($\Delta$R=1.1) to recover the final state radiation effects. A loose selection on kinematics is applied, basically only a requirement on the difference in the pseudorapidity of the jets is used ($\Delta\eta$ <1.3) to reduce the overwhelming QCD contribution. To deal with the huge rate of selected events at low masses ($m_{jj}$ <1.6 TeV), the events are reconstructed, selected, and recorded in a compact form by the high-level trigger in a technique called data scouting.

The background contribution is extracted directly from a fit to the dijet invariant mass distribution. The fit for the low masses is shown in Fig.3 left. No significant deviations from the standard model are observed. The results are finally interpreted in different models, using the proper mass lineshape for qq, gq, and gg resonances. The upper limits on the mass of the resonance cover a wide range, as it can be seen from Fig.3 right. String resonances with masses below 7.7 TeV, scalar diquarks below 7.2 TeV, axigluons and colorons below 6.1 TeV, excited quarks below 6.0 TeV, color-octet scalars below 3.4 TeV, W′ bosons below 3.3 TeV, Z′ bosons below 2.7 TeV, RS gravitons below 1.7 TeV and between 2.1 and 2.5 TeV, and dark matter mediators below 2.6 TeV are excluded.

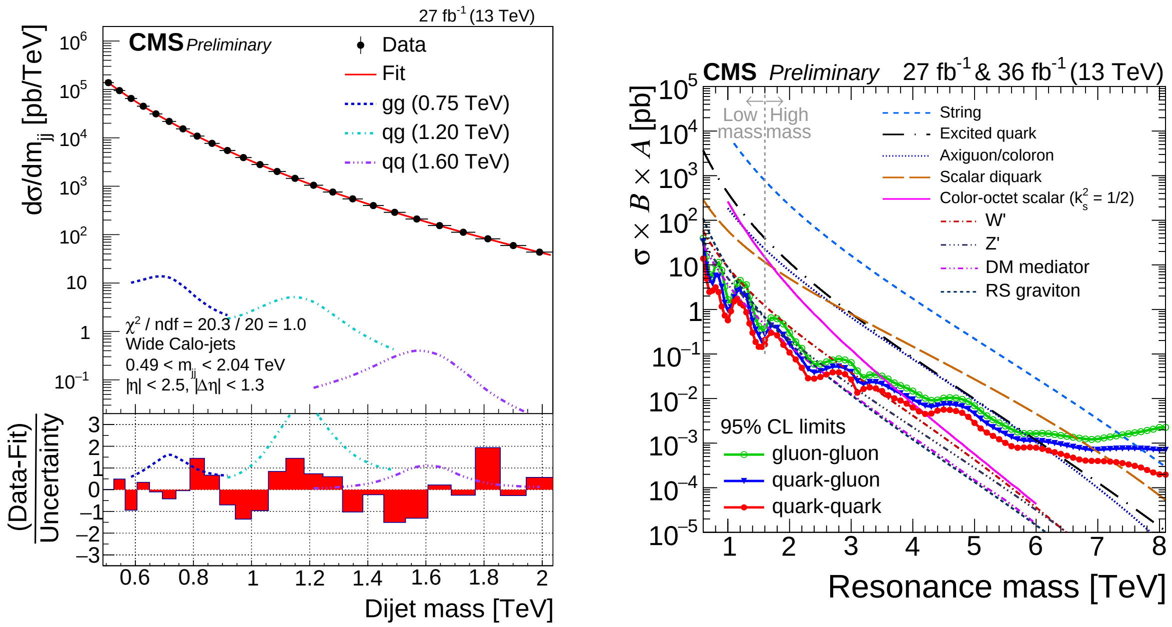


Figure 3 – Left: Dijet mass spectra (points) compared to a fitted parameterization of the background (solid curve) for the low-mass search. The lower panel shows the difference between the data and the fitted parametrization, divided by the statistical uncertainty of the data. Examples of predicted signals from narrow gluon-gluon, quark-gluon, and quark-quark resonances are shown with cross sections equal to the observed upper limits at 95% CL. Right: the observed 95% CL upper limits on the product of the cross section, branching fraction, and acceptance for quark-quark, quark-gluon, and gluon-gluon type dijet resonances. Limits are compared to predicted cross sections for different models.

## References

1. CMS Collaboration, 'The CMS experiment at the CERN LHC', JINST 3:S08004,2008.
2. CMS Collaboration, CMS-PAS-EXO-17-006, https://cds.cern.ch/record/2256657 .
3. CMS Collaboration, CMS-PAS-B2G-17-007, https://cds.cern.ch/record/2256762 .
4. CMS Collaboration, CMS-PAS-B2G-16-019, https://cds.cern.ch/record/2256747 .
5. CMS Collaboration, CMS-PAS-B2G-17-010, https://cds.cern.ch/record/2256800 .
6. CMS Collaboration, CMS-PAS-EXO-16-056, https://cds.cern.ch/record/2256873 .