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Searches for resonant and non–resonant new phenomena in CMS

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Searches for resonant and non–resonant phenomena from the CMS experiment are presented. In the first part of this proceeding, the CMS legacy Run1 results are detailed. It includes searches for new physics in the following final states: dijets and multijets, dileptons (ee, $\mu\mu$,$\tau\tau$), diphotons, as well as leptons + missing transverse energy (MET) topologies. In the second part, preliminary results of the analysis of the CMS Run2 dataset at 13 TeV are reported.

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1. Introduction

The search for new physics beyond the Standard Model (SM) is one of the main goals of the LHC at CERN. The LHC delivered proton-proton collisions at an energy of 7 and 8 TeV in the center of mass in years 2010-2012, the so-called Run1 period of data taking. After a shutdown period to upgrade the machine and the detectors, the LHC restarted in June 2015 with proton-proton collisions at 13 TeV. This new energy regime enlarges considerably the discovery potential for new heavy particles. In this proceeding, legacy Run1 results from the CMS Collaboration on the search for resonant and non–resonant phenomena are presented, in various final states: dijets and multijets, dileptons (ee, $\mu\mu$,$\tau\tau$), diphotons, as well as leptons + missing transverse energy (MET) topologies. Preliminary results of the analysis of the CMS Run2 dataset at 13 TeV are also reported. The CMS detector is described in detail in [1].

2. Legacy CMS results from the LHC Run1

2.1 Dijet and multijet final states

Searches for new physics at the LHC in the dijet mass spectra has been performed in CMS and published in a Run1 legacy paper in [2]. The particle flow candidates are clustered into jets using the anti-k_t algorithm with $\Delta R = 0.5$. Geometrically closed jets with $\Delta R < 1.1$ are combined into wide jets, which are used to measured the invariant mass of the two jets. The following selections are required on both jets: the transverse momentum $p_t > 30$ GeV and the jet pseudorapidity $|\eta| < 2.5$, the dijet invariant mass M(jj) > 890 GeV and the pseudorapidity difference of the two jets $|\Delta\eta| < 1.3$. After applying the selection on the 2012 CMS data (8 TeV, luminosity of 19.7 fb^{-1}), the dijet mass spectrum is presented in Fig. 1 (left). The highest dijet mass event in Run1 is observed at 5.15 TeV. Model independent limits have been extracted on the cross section production for gg, gq and qq resonances, and compared to predictions from various models, see Fig. 1 (right). Examples of mass limits (at 95% CL) for narrow resonance models are: string resonance > 5 TeV, excited

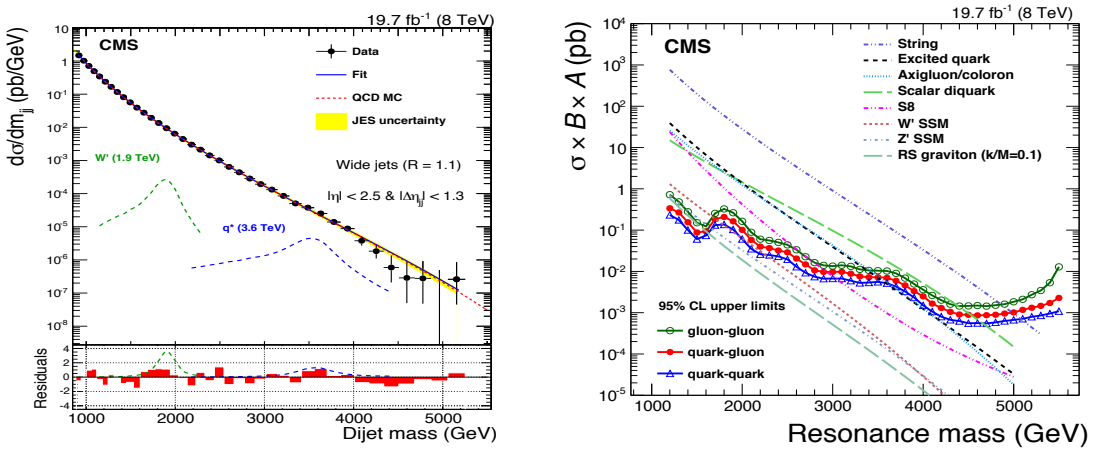

Figure 1: Dijet mass spectrum (left) and upper limit on the production cross section times branching fraction as a function of the resonance mass (right).

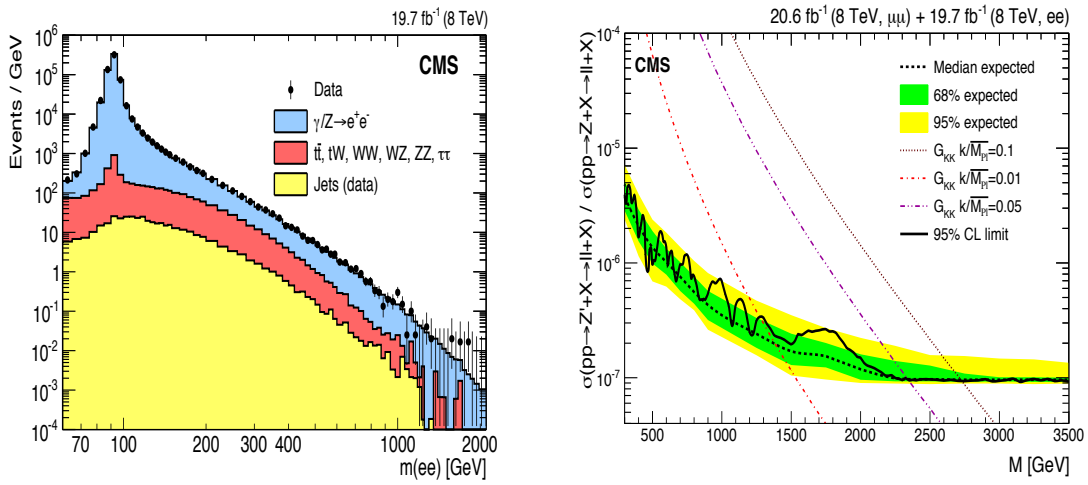

Figure 2: Dielectron invariant mass spectrum (left); Exclusion limits for the combined dielectron and dimuon channels (right).

quark $>$ 3.5 TeV, Sequential Standard Model (SSM) W' boson $>$ 2.2 TeV, Z'(SSM) boson $>$ 1.7 TeV, first excited state of the Randall-Sundrum (RS) graviton (with a coupling $c = 0.1$) G $>$ 1.6 TeV. Mass limits are also estimated for wide resonances, with a width to mass ratio up to 30%, as well as for quantum black hole models. Detailed studies of the dijet angular distributions have been performed [3]. The predictions of the SM (perturbative NLO QCD prediction + EWK NLO corrections), as well as expected signals from quark contact interaction models and models with large extra spatial dimensions, are compared to the data.

Multi-jet resonance searches have been investigated in two different channels: the pair produced resonances decaying into jets : X $\rightarrow$ YY, with Y $\rightarrow$ jj, leading to final states with 4 jets [4], and the pair produced resonances decaying into 3 jets : X $\rightarrow$ ZZ, with Z $\rightarrow$ jjj, leading to final states with 6 jets [5]. No new physics signal has been found and limits are placed in the context of SUSY models with R-parity violation.

2.2 Dilepton and diphotons final states

The dilepton final state is a very competitive channel to search for new resonances. It benefits from simple final state (two high p_t isolated leptons) with low backgrounds from Drell-Yan, top-antitop, WW and multijets processes. CMS has searched for new phenomena in dilepton mass spectra and reported their results in a Run1 legacy publication [6]. The ee and $\mu\mu$ mass spectrum are observed to be in agreement with SM predictions, see Fig. 2 (left) for the dielectron spectrum. The highest dilepton mass event observed in Run1 is at 1.79 and 1.87 TeV in the ee and $\mu\mu$ final states, respectively. Examples of mass limits (at 95% CL) for narrow resonance models are: Z'(SSM) boson $>$ 2.9 TeV, the GUT-inspired E_6 model Z'(ψ) boson $>$ 2.57 TeV, RS graviton (coupling $c = 0.1$) $>$ 2.73 TeV. Mass limits are also given in the up and down coupling plane (c_u, c_d). The results are in addition interpreted in non-resonant models as large extra-dimension models from Arkani-Hamed, Dimopolous, and Dvali (ADD) and compositness models (CI).

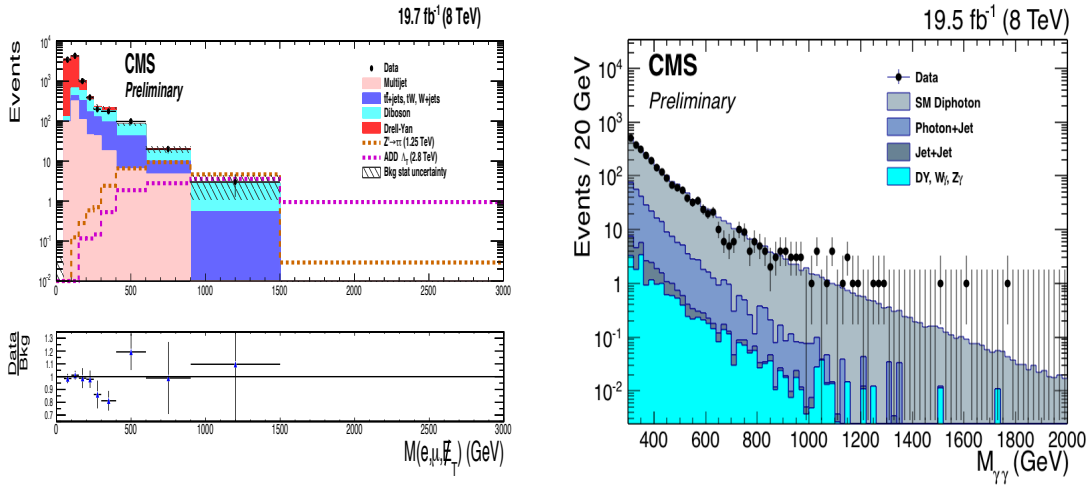

Figure 3: Distributions of the ditau mass $M(\mu, e, \not{E}_T)$ (left) and diphoton mass (right).

To test possible non-universal coupling to the first two- and the third generation of leptons, CMS recently presented a search for new physics in the high-mass ditau final state with one tau decaying in the electron channel and one tau decaying in the muon channel [7]. The electron and muon p_t are required to be higher than 20 GeV. The data are in good agreement with the SM prediction, see Fig. 3 (left). Narrow resonance models as the Z'(SSM) and Z'(ψ) are excluded for masses up to 1.3 and 0.81 TeV, respectively. The results are further interpreted in terms of the ADD model, setting an exclusion limit on the parameter Λ_T up to 2800 GeV.

Search for new signal in the diphoton spectrum is an important complementary search to the dilepton ones. In particular, diphoton resonance could be a signature of an excited state of the graviton in the RS scenario. The CMS analysis requires two high p_t photons ($p_t > 80$ GeV) with pseudorapidities $|\eta| < 1.444$ [8]. The background to this signal comes from SM diphoton production, and from photon+jet or dijet processes where one or two jets produce a fake photon signature in the detector. The observed diphoton mass distribution is compared to the background prediction in Fig. 3 (right). No signal of new physics is observed and limits are set in the parameter space of the RS model: masses below 1450 - 2780 GeV are excluded for the RS graviton, for values of the coupling parameter in the range $0.01 < c < 0.1$.

2.3 Lepton and missing transverse energy final states

CMS results on the search for new heavy W boson in the leptonic decay channel : W' $\rightarrow e\nu$ and W' $\rightarrow \mu\nu$ is detailed in the Run1 legacy publication [9]. No significant deviation of the transverse mass distribution of the charged lepton-neutrino system from the SM prediction is found, and mass exclusion limits are extracted for a W'(SSM) up to 3.28 TeV. In addition, a dedicated analysis was performed in the W' $\rightarrow \tau\nu$ decay channel to test possible non-universal coupling [10]. In this search, hadronic decay channels of the tau lepton are considered. CMS has investigated as well the W'$\rightarrow$ tb decay channel in the all hadronic final state, using dedicated algorithms for top-tagged jet as explained in [11].

3. New results from the LHC Run2

After the successful Run1 data-taking period (2010-2012), the LHC restarted taking data in June 2015 at an energy of 13 TeV in the proton-proton center of mass system and with 50 ns time spacing between bunch crossings. The total integrated luminosity delivered by the LHC and recorded by CMS up to July 20th 2015 are given in Fig. 4. At the conference, the LHC experiments presented their preliminary results of the analysis of the very fresh 13 TeV collision data for the first time.

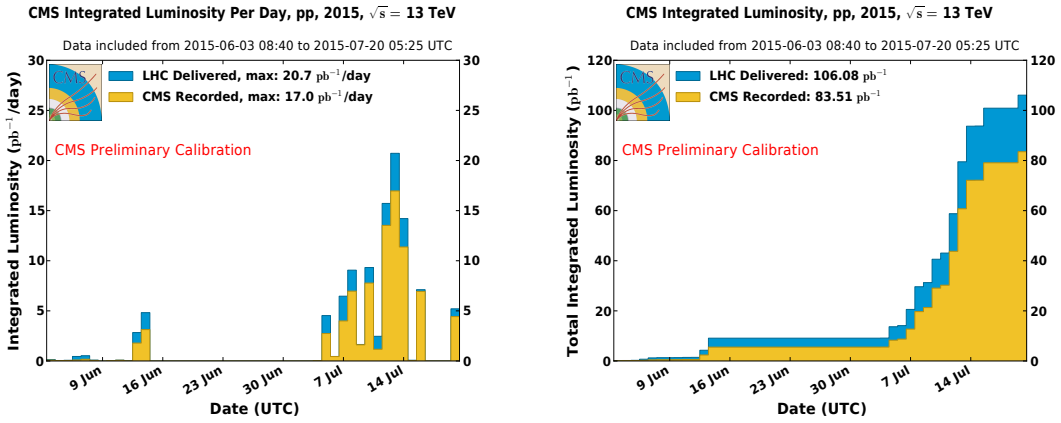

Figure 4: Distributions of the CMS integrated luminosity per day (left) and the total (cumulated) integrated luminosity (right) as a function of time, from 2015-06-03 up to 2015-07-20.

3.1 Analysis of the dijet final state events

A dijet event selection, similar to the one performed on the 2012 data using wide jet reconstruction, has been applied to the 13 TeV sample: the p_t of the 2 jets should be above 60 and 30 GeV, with pseudorapidity $|\eta| < 2.5$ for both jets, the dijet invariant mass M(jj) > 1.1 TeV and the pseudorapidity difference of the two jets $|\Delta\eta| < 1.3$. After selection, the distributions of $\Delta\eta$ and of the azimuthal angle difference $\Delta\phi$ of the two jets in the events are shown in Figs. 5 (top left) and (top right), respectively [12]. The 2015 data sample analysed for this analysis corresponds to an integrated luminosity of 37 pb^{-1}.

The dijet mass spectrum is presented in Fig. 5 (bottom left); a fit to the data is shown as the (red) dotted line. The (blue) dash-dotted line shows, for illustration purpose, an excited quark $q^* \to qg$ resonance signal at mass of 4.5 TeV. The highest dijet mass candidate event is observed at 5 TeV and a 3D display view of this event is shown in Fig. 5 (bottom right). The p_t of the jets are measured at 2.41 and 2.36 TeV. Soon after the EPS conference, CMS updated the analysis and reported upper limits on various new physics models as detailed in [13].

3.2 Spectacular dilepton CMS event displays

The highest dilepton mass event observed in the CMS Run2 dataset is a dielectron event at a mass of 1 TeV [14]. The transverse energies of the electrons are measured at 377 and 371 GeV.

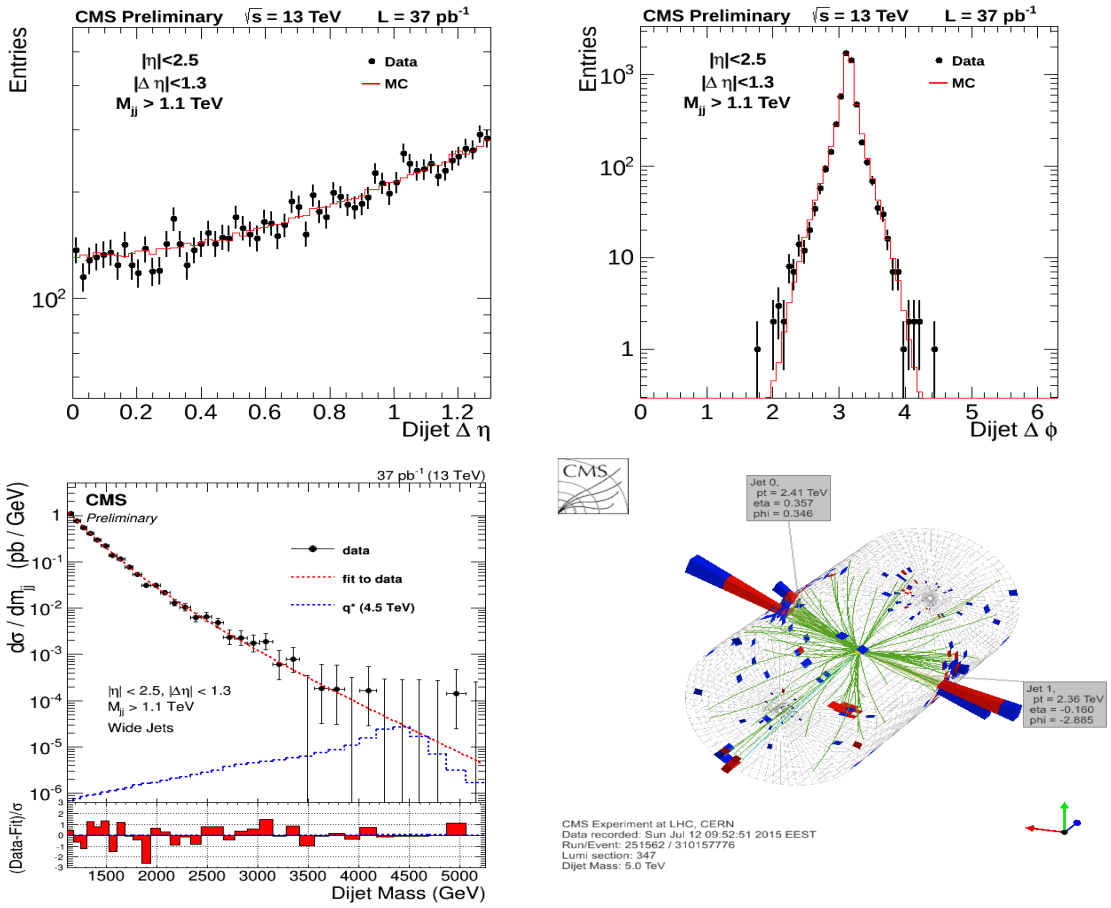

Figure 5: Distributions of the pseudorapidity difference $|\Delta\eta(jj)|$ (top left) and of the azimuthal angle difference $\Delta\Phi$ (top right), between the two jets in the event. Dijet invariant mass spectrum (bottom left) and event display of the highest dijet mass candidate (bottom right).

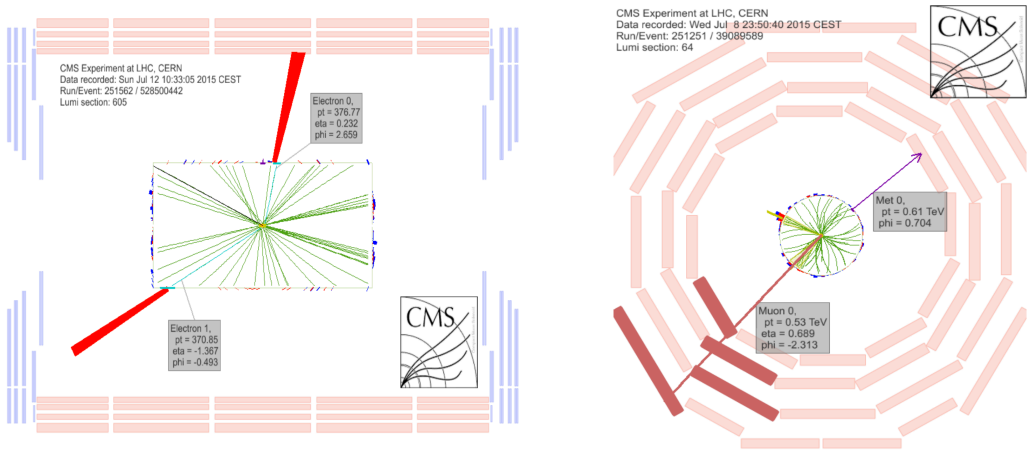

Figure 6: Displays of the highest dielectron mass event (longitudinal view) (left) and of the highest (muon+MET) transverse mass event (transversal view) (right) observed in the CMS Run2 data sample.

The highest (lepton+MET) transverse mass event observed is a muon+MET event at a transverse mass of 1.1 TeV [15]. The p_t of the muon is measured at 0.53 TeV, the MET = 0.61 TeV and the azimuthal angle difference between the muon and the MET direction is 3.0. Event displays of both events are presented in Fig. 6 (left) and (right), respectively.

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