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Exotica searches at 13 TeV by CMS

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Abstract. Results from searches for exotica signals in proton-proton collisions at $\sqrt{s}$ = 13 TeV in the CMS detector at the LHC are presented. The analysed data are collected during the first year of the LHC Run II in 2015 and correspond to integrated luminosities from 2.2 to 3.3 fb^{-1}.

1 Introduction

The Standard Model (SM) [1], [2] of particle physics has been very successful in explaining most of experimental data over the last half-century, and the recently discovered boson with a mass of 125 GeV [3], [4] could be the final particle required in this theory, the Higgs boson. However, the SM is not without its shortcomings, for instance one requires fine-tuned cancellations of large quantum corrections in order for the Higgs boson to have a mass at the electroweak symmetry breaking scale. This is otherwise known as the hierarchy problem. Other experimental data, such as neutrino masses (very small as compared to other particles) and oscillations, the large quantity of dark matter in the universe, look not quite natural or are difficult to fit into the SM. For this reason the searches for particles beyond the SM continue. In this paper the main searches for such particles in the CMS detector are described. Most of the searches for for particles that arise in various supersymmetric models are beyond the scope of this paper, although some overlap exists.

2 The CMS detector

A detailed description of the CMS detector can be found elsewhere [5]. The main features and those most pertinent to this analysis are described below. The central feature is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with particle detection systems. The steel return yoke outside the solenoid is instrumented with gas detectors used to identify muons. Charged particle trajectories are measured by the silicon pixel and strip tracker, with full azimuthal coverage within $|\eta|$ <2.5, where the pseudorapidity η is defined as $\eta = -ln[tan(\Theta/2)]$, with Θ being the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction. A lead-tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) surround the tracking volume and cover the region $|\eta|$ <3. The ECAL barrel extends to $|\eta|$ =1.48. A lead/silicon-strip preshower detector is located in front of the ECAL endcap. A steel/quartz-fibre Cherenkov forward calorimeter extends the

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calorimetric coverage to $|\eta|$ <5.0. In the region $|\eta|$ <1.74, the HCAL cells have widths of 0.087 in both pseudorapidity and azimuth (ϕ). In the (η, ϕ) plane, and for $|\eta|$ <1.48, the HCAL cells map on to 5x5 ECAL crystal arrays to form calorimeter towers projecting radially outwards from points slightly offset from the nominal interaction point. In the endcap, the ECAL arrays matching the HCAL cells contain fewer crystals. Calibration of the ECAL uses π^0s, $W \rightarrow e\nu$, and $Z \rightarrow ee$. Deterioration of transparency of the ECAL crystals due to irradiation during the LHC running periods and their subsequent recovery is monitored continuously and corrected for using light injected from a laser and LED system.

The sophisticated reconstruction algoriths are used to reconstruct various physical objects in CMS, such as charged particles, photons, muons, jets etc. The "Particle flow" algorithm is used to calculate the missing E_T of the event, i.e. the information from fifferent subdetectors is analysed and combined to create "particles" before summing them up. Particle - based isolation is used in the reconstruction of leptons and photons. Multivariate algoriths are used to identify τ and to reconstruct momentum of leptons and photons.

3 Run II in 2015

Run II of the LHC with the collision energy of 13 TeV started in 2015. The start of the run for CMS was not without problems. Because of them different analyses had to use data samples corresponding to rather different integrated luminosity. The data sample "good for all" corresponds to 2.2 fb^{-1}, the data sample for the analyses that don't use missing transverse energy (MET) corresponds to 2.6 fb^{-1}.

As a rule, exotic particles that are searched for are rather heavy because for smaller masses they are already excluded. In general, the reach of experiment to such particles is expressed in terms of effective luminosity, i.e. the luminosity of quarks and gluons that can produce an object with a certain mass. The comparison of Run I and Run II in this sense is shown in Figure 1. According to this figure, it is expected that the sensitivity of the first part of Run II should exceed the sensitivity of Run II for particles heavyer than 2.5 TeV.

4 Searches for resonances

The largest class of searches for exotic particles is the searches for resonances. They are summarized in Table 1.

Most interesting results are obtained in the search for diphoton resonances: the excess of events at about 750 GeV. This excess slightly increases when combined with Run I data. In Run I the excess at this mass was not very significant, but this is expected because of smaller collision energy. To increase statistics the analysis of data taken with solenoid off (0.6 fb^{-1}) was performed. The $M_{\gamma\gamma}$ distribution in Run II data is shown in Figure 2. The p-values of the combination of all available data are shown in Figure 3.

5 Dark matter searches

The interest to searches of Dark Matter iscreased significantly during the last few years. In CMS Dark Matter can manifest itself as monojets with large MET. Dark matter particle pairs could be produced through a vector mediator and escape from the detector. The results of the corresponding analysis using the first part of Run II are published in EXO-16-013 [15]. Some results can be seen as limits on a two-dimensional plot ($M_{DM} vs M_{mediator}$ in Figure 4.

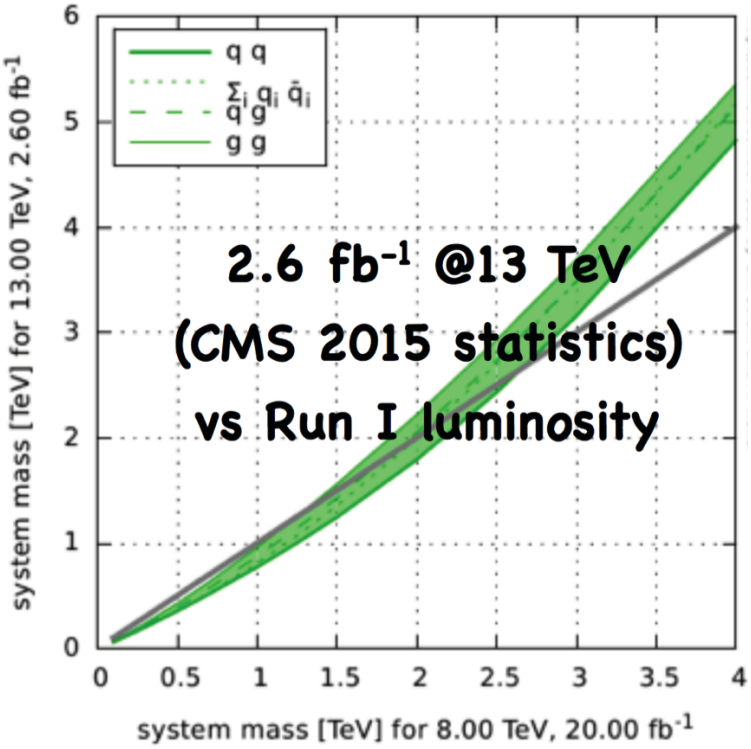

Figure 1. The Run I - Run II comparison of the effective luminosity for high mass objects production.

6 Searches for new long-lived particles

In CMS there is an extensive program of searches for long-lived particles. The following manifestations of their existence are searched for:

- Heavy, long-lived, charged particles, can produce high ionization due to slow speed. Time of flight can be measured.
- Displaced vertices of electrons, muons or jets
- Delayed decays
- Visible decays in flight

Heavy stable charged particles search is presented in EXO-15-010 [16]. The mass limits are set from 800 to 1600 GeV depending on the nature of such particles (most stringent limits are for gluino production).

7 Searches for Black Holes

The search for microscopic Black Holes is performed using the variable S_T, the scalar sum of E_T of all particles in the event. To reduce background, it is also required that the event MET exceeds 50 GeV.

Table 1. Summary of Higgs analyses and documentation

Analysis	Data used, fb^{-1}	Mass limit, TeV	References
Z', neutral spin 1 particle to ee, $\mu\mu$	2.6 - 2.8	2.6 - 3.15	EXO-15-005 [6]
High mass $e\mu$ resonances e.g. QBH production	2.7	2.5 - 4.5	EXO-16-001 [7]
$W' \to e, \mu + MET$ (SSM)	2.2	4.4	EXO-15-006 [8]
$W' \to tb \to bl\nu$	2.2	2.38	B2G-15-004 [9]
$W' \to \tau\nu$	2.3	3.3	EXO-16-006 [10]
Dijet narrow resonances	2.3	2 - 7	PRL [11]
Diphotons, scalar and spin 2 e.g. for spin 2 graviton	3.3	Limit on σB up to 3 TeV	EXO-16-016 EXO-16-018 [12]
$Z\gamma$	2.7	Limit on σ B up to 2 TeV	EXO-16-019 [13]
Diboson $WW \to l\nu qq$ e.g graviton	2.3	Limit on σ B up to 1 TeV	B2G-16-004
tt (boosted tops)	2.6	3 - 3.5	B2G-15-002 [14]

The results are reported in EXO-15-007 [17]. In the existing models the Black Hole cross section production is rather large. For this reason the limits on the Black Hole mass are rather stringent, of the order of 8 - 9 TeV. For the same reason they are much more stringent than the Run I limits.

8 Searches for Type III SeeSaw fermions.

The seesaw mechanism could explain the existence and smallness of neutrino masses, one of the fenomena that do not neturally fit into the Standard Model. The type III seesaw mechanism assumes the existence of heavy fermions that can be produced at the LHC. The analysis EXO-16-002 [18] searches for pairs of such fermions that decay to ordinaly leptons, charged and neutrinos. The final state with at least three charged leptons (electrons or muons) and MET is the signature of this analysis. The main background is WZ production. Heavy fermions with masses up to 450 GeV are excluded. At these masses the effective luminosity for Run II 2015 data is significantly smaller than for Run I data, however, due to a number of improvements of the analysis, the sensitivity of EXO-16-002 is better than in the similar Run I analysis.

9 Conclusion.

The exploration of initial 13 TeV data of Run II has given some interesting sesulta and allowed to improve the sensitivity of meny searches for exotic particles. Mor data is a key to understanding if the diphoton excess is real or just a fluctuation. In the nearest future at least ten times more 13 TeV data are expected.

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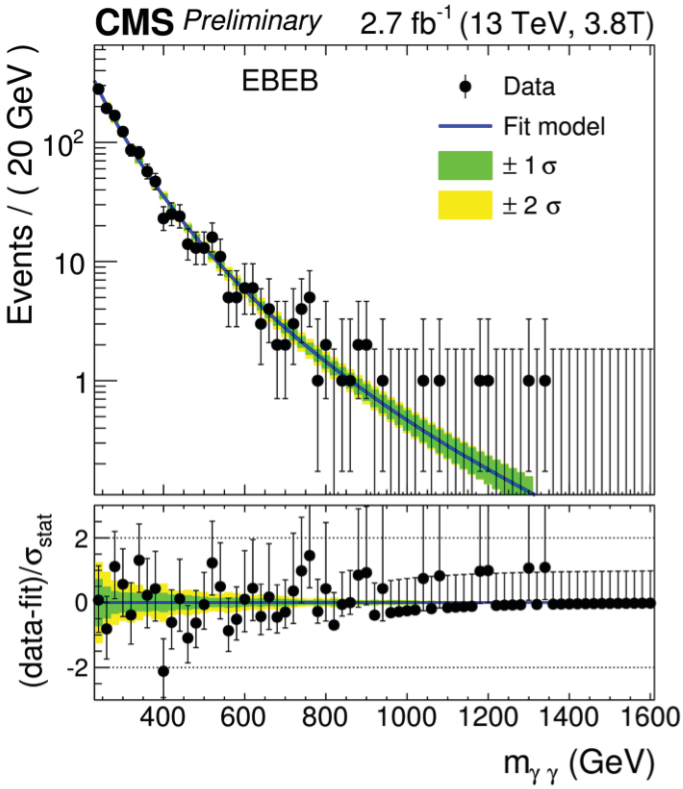

Figure 2. $M_{\gamma\gamma}$ distribution for the category EBEB (both gammas in the barrel)

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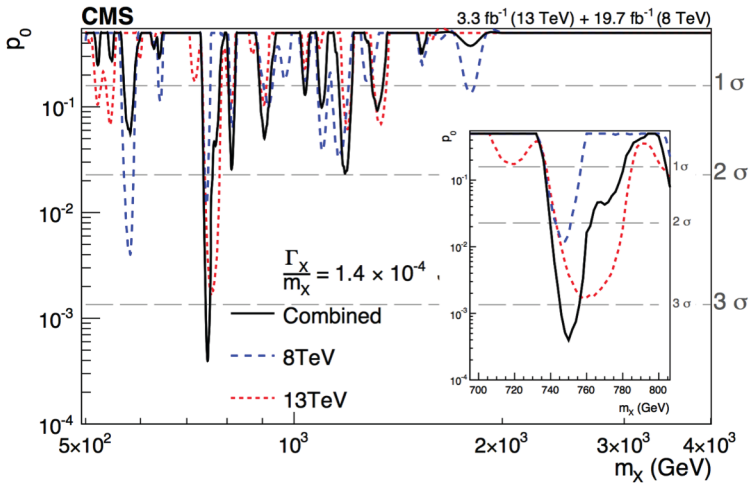

Figure 3. p-values of the combination of all available diphoton data, for the hypothesis of narrow scalar resonance

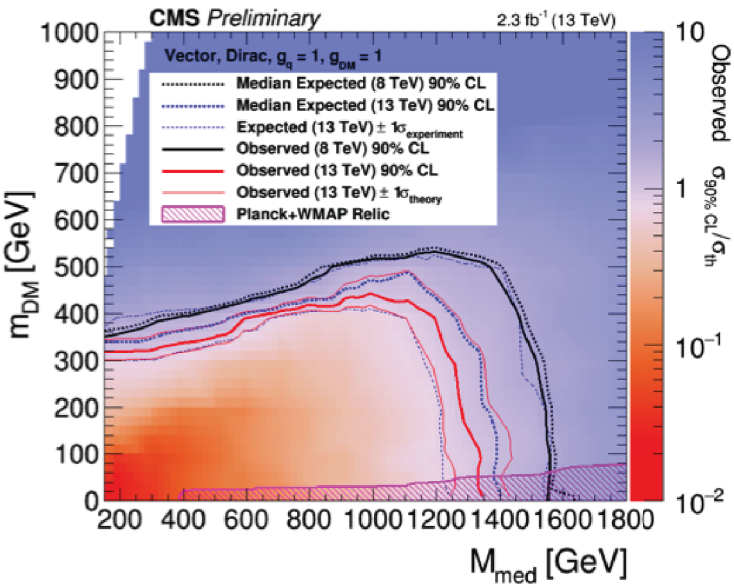

Figure 4. Limits on the Dark Matter particle masses

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