PROCEEDINGS OF SCIENCE

Search in two-dimensional mass space for T'$\bar{\text{T}}$' $\rightarrow$ W'$^+$bW'$^-$ $\bar{\text{b}}$ in the dilepton final state with the CMS detector

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A search for $\text{T}'\bar{\text{T}}' \rightarrow \text{W}'^{+}\text{bW}'^{-}\bar{\text{b}}$ in the dilepton final state is presented using pp collision data at $\sqrt{s} = 8$ TeV recorded by the CMS detector and corresponding to 19.7 fb^{-1} of integrated luminosity. The analysis is based on a two-dimensional mass reconstruction of the $\text{T}'\bar{\text{T}}'$ system, where the two unknown particles T' and W' are reconstructed simultaneously by using the analytic solutions of the kinematical equation system together with constraints from the parton distribution functions. This analysis can search for the existence of any particle decaying with the same topology into the final states mentioned.

In the absence of a significant excess over the standard model predictions, 95% confidence level upper limits on a simplified littlest Higgs model are computed. The observed limit on $\text{M}_{\text{T}'}$ ranges between 800 - 920 GeV depending on $\text{M}_{\text{W}'}$.

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1. Motivation

The discovery of a new particle at LHC with a mass of 125 GeV consistent with the Standard Model (SM) Higgs Boson [1, 2] presages the existence of physics beyond the standard model (BSM) and therefore new particles at the TeV scale to keep radiative corrections to the Higgs boson mass confined to the electroweak scale. This analysis is searching simultaneously for both a new heavy top T' and a new heavy charged gauge boson W' ($T'\bar{T}' \to W'^+bW'^-\bar{b}$) [3], in which both W' bosons decay leptonically, $W' \to l\nu$. Missing transverse energy (MET) in the final state is predicted by many BSM theories, but discoveries with MET related observables are difficult to establish, since possible excesses typically manifest themselves in the tail of rapidly falling distributions.

Dalitz and Goldstein proposed already in [6] a method where the solvability of the system of kinematic equations was used in one dimension with a matrix element weight to reconstruct top decays. This and Kondo's earlier ideas [4, 5] lead to the matrix element weighting method (MWT) in Tevatron [7] and later the Analytical MWT (AMWT) in CMS [8]. The present analysis aims to remove the model dependence arising from the use of matrix elements in the procedure they proposed and more importantly searches for the unknown particles in two dimensions for decays involving two invisible particles. The method uses the solvability of the equation system to scan the two-dimensional mass space for the existence of a solution. The collision energy gives an upper limit to the allowed mass space, therefore probabilities from parton density functions (PDFs) are taken into account. In addition, the measured particle kinematics are smeared with the detector resolution.

A simplified littlest Higgs model [9, 10] is used to set 95% CL upper limits on the production cross section times branching ratio as a function of the T' and the W' mass. In little Higgs models spontaneously broken global symmetries are introduced, where the Higgs field appear as a pseudo-Nambu-Goldstone boson.

2. Event selection

The data used in this analysis were collected with the CMS Experiment [11] at the Large Hadron Collider at CERN at a center of mass energy of $\sqrt{s} = 8$ TeV and correspond to an integrated luminosity of 19.7 fb^{-1}. Events are selected with at least two isolated opposite sign leptons (either electrons or muons), at least two jets with a p_T greater than 50 GeV and with missing transverse energy greater than 50 GeV. The two most energetic leptons and jets are used together with the MET to reconstruct the masses. Additionally quality cuts are applied on all physics objects.

3. Mass reconstruction

The analysis is based on a two-dimensional mass reconstruction of the $T'\bar{T}'$ system performed for an assumed topology ($T'\bar{T}' \to W'^+bW'^-\bar{b}$), but without any assumptions on the underlying theory [12]. No constraints on the masses $M_{T'}$ and $M_{W'}$ are required.

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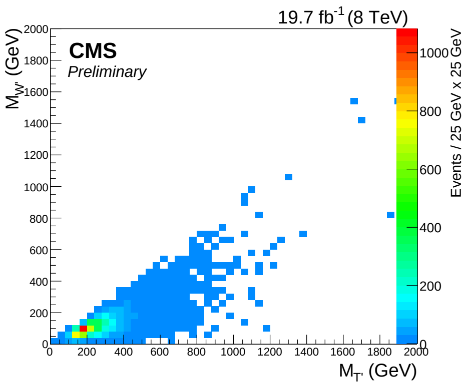

Figure 1: Two-dimensional mass reconstruction for $M_{T'}$ and $M_{W'}$ for the 2012 data set.

The analytical solution of the decay is derived by solving a system of eight equations [13, 14] :

$$\not{E}_{x,y} = \mathrm{p}_{\nu_{x,y}} + \mathrm{p}_{\bar{\nu}_{x,y}} \tag{3.1}$$

$$\mathrm{E}^2_{\nu,\bar{\nu}} = \mathrm{m}^2_{\nu,\bar{\nu}} + \mathrm{p}^2_{\nu_x,\bar{\nu}_x} + \mathrm{p}^2_{\nu_y,\bar{\nu}_y} + \mathrm{p}^2_{\nu_z,\bar{\nu}_z} \tag{3.2}$$

$$\mathrm{M}^2_{W'^{\pm}} = (\mathrm{E}_{l^{\pm}} + \mathrm{E}_{\nu,\bar{\nu}})^2 - (\vec{\mathrm{p}}_{l^{\pm}} + \vec{\mathrm{p}}_{\nu,\bar{\nu}})^2 \tag{3.3}$$

$$\mathrm{M}^2_{(T',\bar{T}')} = (\mathrm{E}_{b,\bar{b}} + \mathrm{E}_{l^{\pm}} + \mathrm{E}_{\nu,\bar{\nu}})^2 - (\vec{\mathrm{p}}_{b,\bar{b}} + \vec{\mathrm{p}}_{l^{\pm}} + \vec{\mathrm{p}}_{\nu,\bar{\nu}})^2 \tag{3.4}$$

Every mass point ($\mathrm{M}_{T'}$, $\mathrm{M}_{W'}$) in the two-dimensional mass space is tested and we end up with zero, two or four solutions for the neutrino momenta per point. In CMS it is hard to distinguish between jets originating from b and $\bar{\mathrm{b}}$ quarks, therefore the equation system is solved again with the two jets inter-changed. This leads to more possible solutions of the equation system. Each solution gives the momentum $\mathrm{p}_{\nu_{x,y,z}}$ and $\mathrm{p}_{\bar{\nu}_{x,y,z}}$ of the neutrino and antineutrino. The solvability $S \in \{0,1\}$ is defined as the existence of a specific solution for a specific mass point.
Although detector effects can change a solvable event in a non-solvable one, the solvability can be recovered by smearing the measured particle kinematics N times according to the detector resolution. S_{iter} can be defined as the fraction for which a specific solution exists: $\frac{1}{N}\sum_{i=1}^{N} S^i(\mathrm{M}_{T'},\mathrm{M}_{W'})$.

The full reconstruction of the $\mathrm{T}'\bar{\mathrm{T}}'$ system per solution, mass point and event is then performed. The probability for a parton A (B) in a pp collison to carry a fraction $x_A(x_B)$ of the proton momentum is given by the PDF $F(x_{A(B)},Q)$. A final event PDF weight per solution and mass point is defined as $\sum_{a,b} F_a(x_A,Q)F_b(x_B,Q)$ by summing over all possible parton combinations (a,b). Among all solutions the one with the highest PDF weight is chosen for each mass point. Due to the finite collision energy there is an upper limit on the allowed masses produced. The final $\mathrm{M}_{T'}$ and $\mathrm{M}_{W'}$ estimation is the point where $P(\mathrm{M}_{T'},\mathrm{M}_{W'})$ is maximized, i.e. it is most probable to originate from a p-p collision. This procedure gives a single mass point per event.

$$P(\mathrm{M}_{T'},\mathrm{M}_{W'}) = \frac{1}{\mathrm{V}} \cdot \frac{1}{N} \sum_{i=1}^{N} \sum_{a,b}^{flavour} F^i_a(x_A,Q) \cdot F^i_b(x_B,Q) \cdot S^i(\mathrm{M}_{T'},\mathrm{M}_{W'}) \tag{3.5}$$

with $S \in \{0,1\}$ and $V = \int P \, \mathrm{dM}_{T'}\mathrm{dM}_{W'}$.

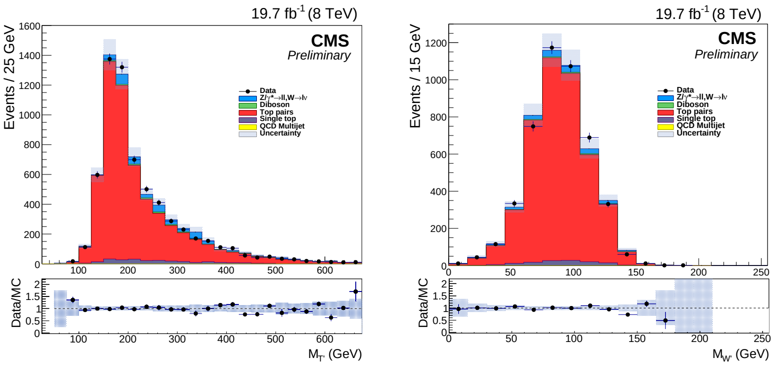

Figure 2: Projection on the $M_{T'}$ and $M_{W'}$ axis around the observed mass peak in data.

4. Results

This analysis was performed by scanning the range of 0 - 2 TeV of the two-dimensional mass plane in steps of 5 GeV for both the $M_{T'}$ and $M_{W'}$ axes, with 100 iterations used to smear each event. In Fig. 1 the two-dimensional mass reconstruction for data events is presented. As a proof of principle a projection on each axis around the observed peak in the data leads to an observation of both the top quark and the W boson without any prior mass assumption, as shown in Fig. 2. The reconstructed data distributions agree with the Monte Carlo (MC) prediction.

The shape of a possible signal in simplified littlest Higgs MC samples is shown in Fig. 3 (left and middle). $M_{T'}$ and $M_{W'}$ are successfully reconstructed for different mass assumptions. In the right plot of Fig. 3 the MC background distribution composed of top pairs (+W/Z/H), dibosons, single tops and Z+jets samples, is plotted together with an injected signal sample of $M_{T'}$ = 1000 GeV and $M_{W'}$ = 600 GeV. The method leads to a good separation of signal and background in the two-dimensional plane.

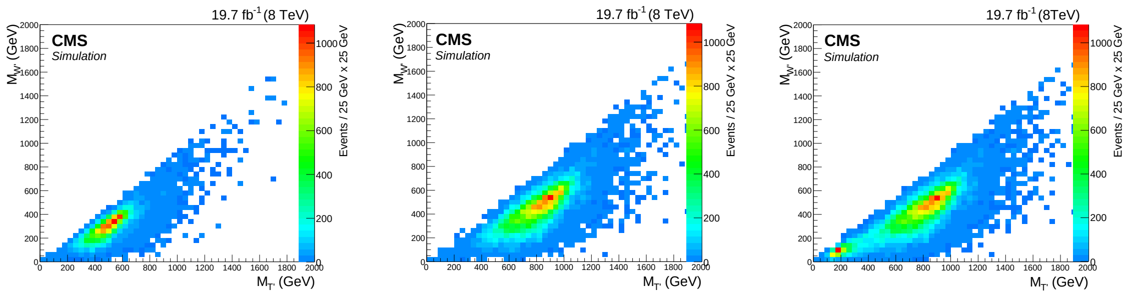

Figure 3: Simplified littlest Higgs Signals: $M_{T'}$ 600 GeV, $M_{W'}$ 400 GeV (left), $M_{T'}$ 1000 GeV $M_{W'}$ 600 GeV (middle) and the latter sample on top of the SM background MC.

The observed and expected 95% CL upper limits for a simplified littlest Higgs model is presented in Fig. 4. The observed limit on $M_{T'}$ ranges between 800 - 920 GeV depending on $M_{W'}$. This is the first dedicated simultaneous search for a new heavy top and a new heavy charged gauge boson as predicted by littlest Higgs models at LHC.

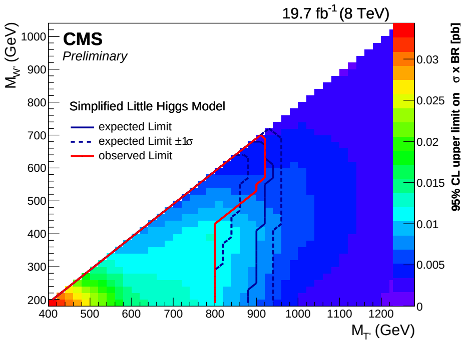

Figure 4: The expected and observed 95% CL upper limits on the production cross section times branching ratio as a function of the T′ and the W′ mass for a simplified littlest Higgs model.

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