We present the results of the Model Unspecific Search in CMS (MUSiC), which systematically scans the data taken by the CMS detector for deviations from the Standard Model predictions. Due to the minimal theoretical bias this approach is sensitive to a variety of models for new physics. Events containing at least one electron or muon are classified according to their content of reconstructed objects (muons, electrons, photons, jets and missing transverse energy). A broad scan of three kinematic distributions in those classes is performed by identifying deviations from Standard Model expectations, accounting for systematic uncertainties.

In this particular search data taken by CMS in the year 2010, corresponding to an integrated luminosity of 36.1 pb$^{-1}$, have been analysed.

1. Introduction

The start-up of the LHC brings forth a new era of high energy particle physics. What we will find is yet unknown, however, there is a large number of theories predicting possible outcomes. Many of those theories are tested by dedicated analyses at CMS and the other LHC experiments. However, new physics could as well manifest itself in ways no-one has thought of yet. For this purpose a Model Unspecific Search in CMS: “MUSIC” has been implemented.

MUSIC automatically scans and compares the measured data to the simulated SM expectations without assuming any specific model of new physics. Thus, covering a large phase space, it is sensitive to a lot of potential signals.

Any uncovered significant deviation needs additional interpretation, such that its origin can be determined. Possible causes could be insufficient understanding of the collision, event generation or detector simulation, or indeed genuine new physics in real data. Thus, the output of MUSiC must be seen as only the first, but important step in the potential discovery of new physics.

More details on this and following topics can be found in the Physics Analysis Summary [CMS Collaboration 2011].

2. Implementation

New physics usually shows up in distinctive final states and so the first task is to sort the events. We consider the following physics objects: muons ($\mu$), electrons ($e$), photons ($\gamma$), particle flow jets (anti-$k_T$), and missing transverse energy ($E_T^{\text{miss}}$).

Each event is sorted into precisely one event class, which represent a single final state, depending on its content of reconstructed objects. Together with the requirement of at least one charged electron or muon in any analysed event, this leads to about 250 event classes containing at least one event in data or simulation.

Three kinematic distributions are examined, which are promising to spot new physics:

- Scalar sum of the transverse momentum of all participating objects: $\sum p_T$.
- Combined (transverse) invariant mass $M_{(T)}$ of the objects in the event class.
- $E_T^{\text{miss}}$ in classes containing $E_T^{\text{miss}}$ above our predefined threshold.

Out of these distributions $\sum p_T$ is the most general observable, sensitive to many new physics models involving heavy new particles or modified high-energy behaviour. The invariant mass allows the discovery of new resonances. New physics with heavy or highly boosted “invisible” particles will show up in the $E_T^{\text{miss}}$ distribution. The kinematic variables are calculated from the objects passing the selection criteria listed below. Objects not fulfilling those criteria are not considered.

2.1. Event and Object Selection

Events are selected by single lepton triggers (muon or electron). The triggers require a minimal $p_T$ and additional quality criteria. Due to the rapidly changing instantaneous luminosity, the thresholds have been increased over time, the highest being 15 GeV for muons and 22 GeV for electrons. In order to remain well above the trigger thresholds, at least one muon with 25 GeV or one electron with 30 GeV is required. The trigger efficiency on selected leptons is above 95%.

A summary of the selection criteria applied on physics objects in each event is given in tab. [I]
Table I: Selection criteria applied to the physics objects in each event.

| Object | $p_T^{\text{min}}$ | $|\eta|$ | Other Cuts |
|--------|------------------|--------|-----------|
| $\mu$  | 18 GeV < 2.1     |        | isolation/track |
| $e$    | 25 GeV < 2.5     |        | shape/tracking/shape/isolation |
| $\gamma$ | 25 GeV < 1.4   |        | shape/isolation |
| jet    | 50 GeV < 2.5     |        | energy fraction |
| $E_T^{\text{miss}}$ | 30 GeV |        |          |

To avoid using the same energy entry more than once, objects are removed if they are too close to each other ($\Delta R < 0.2$). Jets are removed if there are photons or electrons nearby, and photons are removed if an electron is close.

### 3. Search Algorithm

All kinematic distributions are fed through a scanning algorithm that systematically scans for deviations, comparing the simulated SM prediction with the measured data. Since all distributions are analysed as binned histograms, the bin width is adjusted to the resolution of the considered variable.

For each region of adjacent bins the algorithm calculates the number of expected events ($B$), its uncertainty ($\sigma$), and the number of observed events ($N$). The uncertainty calculation takes into account possible correlations between bins and individual uncertainties (see section 5 for more details). A Poisson tail probability $p$ can be computed which denotes the probability of a random fluctuation to be at least as extreme as the observed value. To incorporate the systematic uncertainties on this probability, the Poisson distribution is convoluted with a normal distribution:

$$p = \begin{cases} 
A \cdot \sum_{i=0}^{\infty} e^{-\mu} \frac{\mu^i}{i!} \cdot \int_{0}^{\infty} \frac{1}{\sigma^2} e^{-\frac{\mu^2}{\sigma^2}} \cdot e^{-\frac{\mu^2}{\sigma^2}} \cdot \frac{\mu^i}{i!} \cdot d\mu & \text{if } N < B \\
A \cdot \sum_{i=N}^{\infty} e^{-\mu} \frac{\mu^i}{i!} \cdot \int_{0}^{\infty} \frac{1}{\sigma^2} e^{-\frac{\mu^2}{\sigma^2}} \cdot e^{-\frac{\mu^2}{\sigma^2}} \cdot \frac{\mu^i}{i!} \cdot d\mu & \text{if } N \geq B 
\end{cases} \tag{1}$$

The factor $A$ ensures normalisation, since the normal distribution is truncated at 0. In each distribution, the region with the smallest value of $p = p_{\text{data}}$ is chosen as the Region of Interest (RoI).

### 4. Look-Elsewhere-Effect

While $p_{\text{data}}$ denotes the probability of each RoI seen individually, it cannot be used as a statistical estimator for the global significance for such a deviation in any region. A penalty factor needs to be included to account for the number of investigated regions. Using $O(10^5)$ pseudo-experiments, we can compute a new probability $\tilde{p}$ of measuring at least one deviation in any region in a given distribution with a lower $p$-value than the one seen in the RoI of the data. Each pseudo-experiment consists of one pseudo-data histogram for each distribution, thus representing one possible outcome of a measurement. The pseudo-data distribution for each class is fed into the same scanning algorithm as described above, resulting in a collection of $p$-values $p_{\text{pseudo}}$. The value $\tilde{p}$ for a given distribution is then simply the number of pseudo-experiments with $p_{\text{pseudo}} < p_{\text{data}}$, divided by the total number of pseudo-experiments:

$$\tilde{p} = \frac{N_{\text{pseudo}}(p_{\text{pseudo}} < p_{\text{data}})}{N_{\text{pseudo}}} \tag{2}$$

### 5. Systematic Uncertainties

This kind of search is highly affected by systematic uncertainties. An overview of the uncertainties used in this analysis is shown in table II. Some of the included uncertainties can be correlated between bins of one distribution or across classes.

Table II: Overview of the systematic uncertainties used in this analysis.

| Contribution                  | Value | Remarks   |
|-------------------------------|-------|-----------|
| MC statistics                 | various| sample dependent |
| Luminosity                    | 4 %   |           |
| parton density flt.           | various| PDF reweighting method |
| jet energy corr.              | 3 to 5 % | $p_T$ and $\eta$ dependent |
| reconstruction eff.           | 1 to 4 % | object dependent |
| misreconstruction prob.       | 30 to 100 % | object dependent |
| W-boson cross sec.            | 5 %   | NLO       |
| Drell-Yan cross sec.          | 5 %   | NNLO      |
| di-boson cross sec.           | 10 %  | NNLL      |
| $T$ cross sec.                | 30 %  | measured cross sections |
| QCD-multiprofile cross sec.   | 50 %  | LO        |
| photon+jet cross sec.         | 50 %  | LO        |

The reconstruction efficiencies and the misidentification probability are determined from simulation and uncertainties are applied to cover possible differences to data.

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$1\Delta R = \sqrt{\Delta \phi^2 + \Delta \eta^2}$
6. Results

As a demonstration two typical distribution are shown. The first one shows a Drell-Yan dominated class with two muons in the final state (fig. 1), the second one shows a \( t \bar{t} \) dominated class with one electron, one muon, two jets and missing transverse energy in the final state (fig. 2).

Overall 287 distribution in 118 event classes have been analysed in 2010 data.

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The \( \hat{p}_T \) distributions of the analysed event classes are determined separately for the three different kinematic variables.

As can be seen in fig. 3, 4, 5, the predictions for the \( \hat{p}_T \) distributions are very accurate. The used SM samples describe the data very well.

In the scope of this analysis no deviations from the SM have been found in LHC 2010 data.

References

CMS Collaboration, CMS PAS EXO-10-021 \[1360173\] (2011).