2nd Semester Report
Search for new physics beyond the Standard Model with the CERN LHC CMS detector

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Introduction

The MTA-ELTE Lendület CMS group in collaboration with HEPHY in Vienna continues the previously introduced search for the production of scalar top (stop) quarks in a supersymmetric extension of the Standard Model with a compressed mass spectra. The current research is focused on electron reconstruction development in the presence of large impact parameters, and related detector performance studies for the extension of the 4-body stop searches to long lifetimes.

Research

Electron reconstruction studies

In the second semester of my PhD studies, I have continued my research on new techniques to help improve the standard method of soft electron reconstruction.

Two additional collections are being considered. Firstly, the LowPt collection from the newer v9 version of the centrally reconstructed dataset, optimised by the B-physics working group [1], with regards to the low pt region dominated by electrons originating from B-hadron decays. Due to the similarly soft electron objects in the final state, it is expected to yield a more robust performance in the low-pt regime than the standard collection.

Secondly, an alternate method for reconstruction is matching the electron to closely paired isotracks and photons (isotrack-photon pair, IPP objects), exploiting that tracks reconstructed with the Kalman Filter tracking algorithm (called isotracks) have looser requirements than the electron-specific GSF (Gaussian Sum Filter) method for reconstructing electron tracks. This method is expected to be a good supplementary method for displaced electron reconstruction, because it is expected to find electrons that would otherwise be lost in the standard collection due to track limitations.

These reconstruction methods (Standard, LowPt, IPP) can be used together in various combinations, and different identification methods (IDs) can be used to create working points on ROC curves[1]. The Standard collection has cut-based and multivariate (boosted

[1] Receiver Operating Characteristic curve, displaying the background rejection as a function of the signal efficiency

decision-tree based model) identifications, the LowPt collection has a boosted decision-tree based score, and IPP also has cut-based and multivariate methods for the contained photon. After studying the different options, the best results are shown in this report.

The methods were examined on four different signal samples: a displaced sample (mass of stop: 350 GeV, mass of LSP: 335 GeV, $c\tau$ = 157.85 mm), a prompt signal (mass of stop: 500 GeV, mass of LSP: 420 GeV), a $t\bar{t}$ decay sample, and a sample with leptonic W decay and jets. The background sample is a pt-binned QCD sample. The pt-integrated results are shown on figure 1.

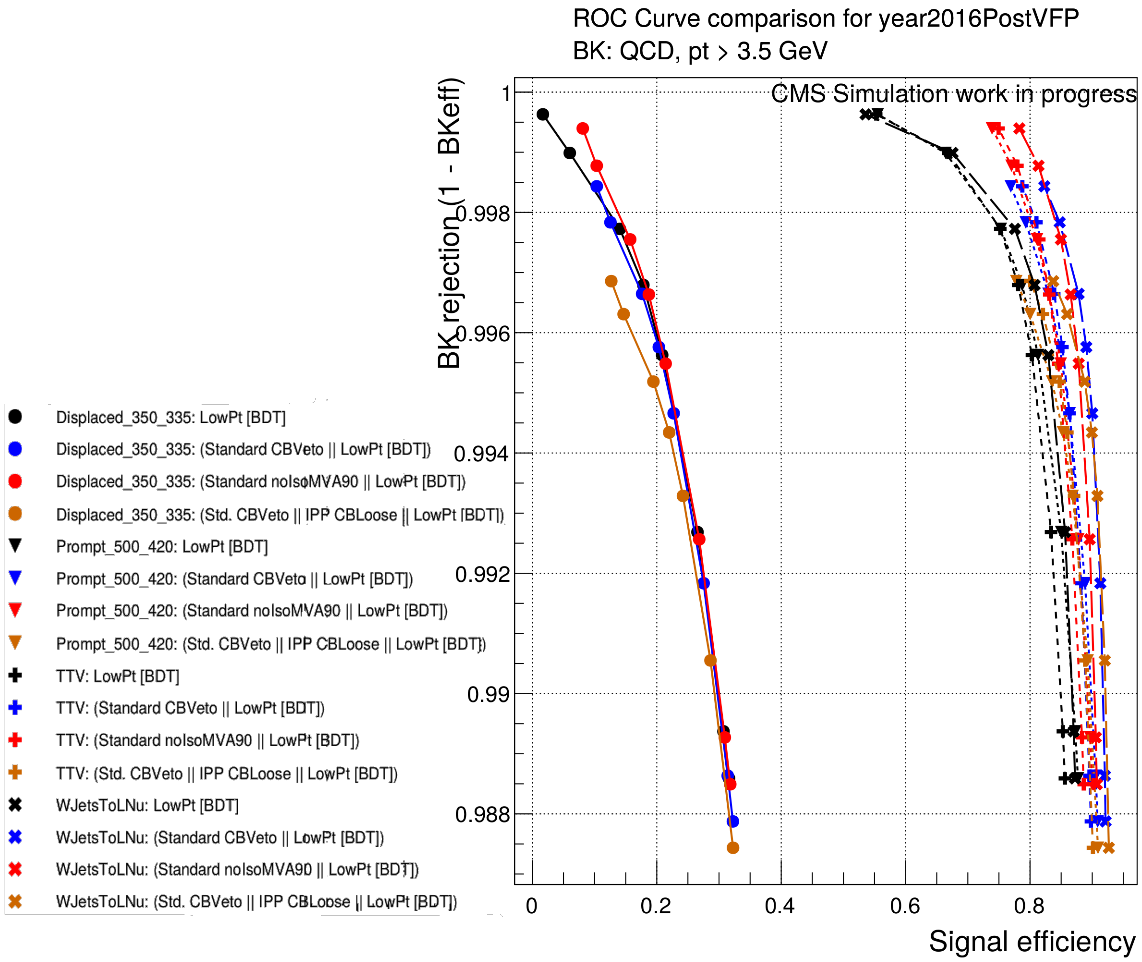

Figure 1: ROC curves for electron p_T above 3.5 GeV. The marker styles correspond to the different signal samples, and the colors denote the used combination of reconstruction methods. These combinations avoid double-counting by using an „or" (denoted as ||) logical operator to combine the collections. The selected ID workingpoint is shown on the legend for each sample and the points on the curves are given by sequential cuts on the LowPt collection's BDT score. The PostVFP era means that the HIP problem detailed in [2] is not present.

The first important aspect to decide was whether to switch from Standard to LowPt completely, or to use their combination. In the prompt signal, there is an apparent gain by retaining the Standard collection alongside the LowPt. This suggests that these collections can be well used together and studying their overlapping regions also shows that they complement each other well. These considerations opt for using the combination of the two electron collections.

However, from this result we see no advantage to also including IPP to the reconstruction, and in the displaced signal we even see a decrease in performance. This is due to the fact that figure 1 is dominated by electrons below 10 GeV, but there are centrally imposed strict cuts on photons below 10 GeV, which makes IPP unusable to detect them. The same ROC curves are shown therefore on figure 2, but in a limited pt range. Here the inclusion of IPP can bring a very good performance increase in the displaced signal. This is further confirmed by plotting the efficiency as a function of the impact parameter, where we can see that efficiency drops to zero with the standard collection, but it is retained when including LowPt electrons, and there is a further gain to be had when also including IPP.

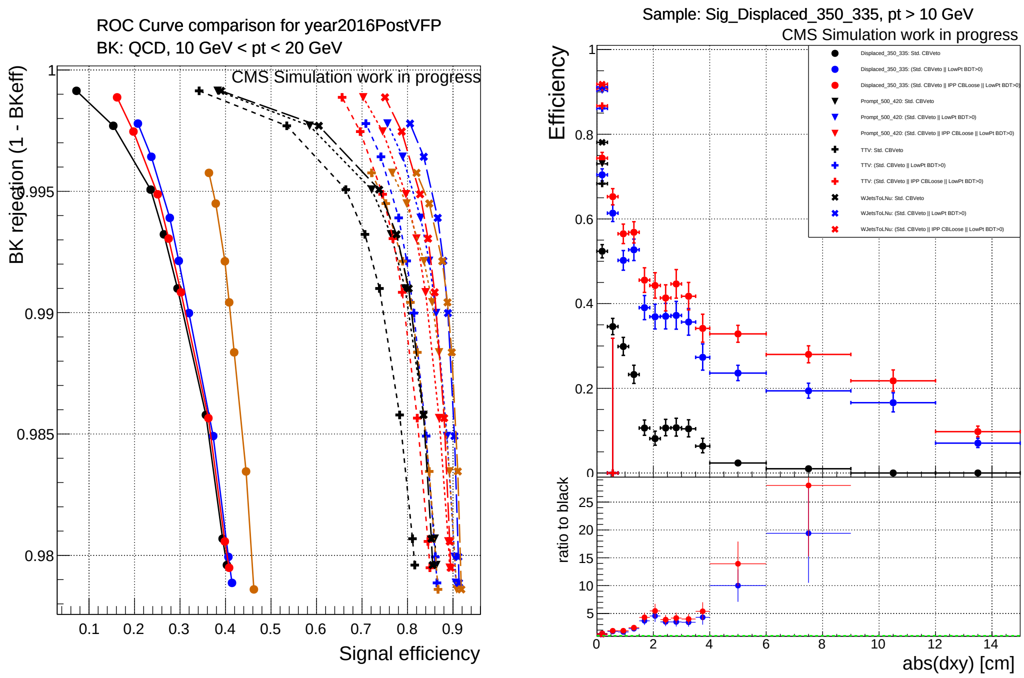

Figure 2: Left: The ROC curves shown for electrons with p_T between 10 and 20 GeV. In the displaced signal, a considerable improvement is shown for the yellow curve that corresponds to the combination of all methods, including IPP. The improvement is also present in the prompt samples, though not so prevalent.
Right: The efficiency as a function of the impact parameter. It is shown here that the efficiency converges to zero with high impact parameter values for the standard collection (black), but it is retained when adding the LowPt collection (blue), and an even further gain is to be had by also adding IPP to the combination (red).

Based on these results it is appears that using the LowPt collection can definitely bring improvements to the reconstruction. However, it is likely not enough on its own to take over completely, and it has to be supplemented with the Standard collection. The results also show that further adding IPP to the combination can incidentally improve the performance, however it is not yet decided whether this region-specific gain is worth the extra complexity that the implementation of this method would bring. The research is therefore currently focused on implementing every required step for the inclusion of the LowPt collection and combining it with the Standard collection. One such step is measuring the quality of the modelling in the CMS simulation of the various electron reconstruction methods such that differences with regards to the performance in the data can be corrected using scale factors [3] for the LowPt collection, and this is the next chapter of my studies.

High Level Trigger studies

I have continued to work with the technical group in CMS contributing to a central experimental physics task regarding the High Level Trigger (HLT) for electrons and photons. Previously only the dt significance (time difference over error on time) with respect to the primary vertex was studied. In the new studies, the bare time difference itself was also studied, and the time variables were also computed with respect to the electron GSF track, thus adding up to 4 possible variables. As determined in the previous studies, the ROC curves strongly depend on the dz cut of the tracks, therefore the performance of all combinations of a cut on dz and a cut on one of the time variables were measured in preliminary samples, and an algorithm was developed to determine the best combination.

Recent results indicate that for the barrel region a time cut doesn't seem to be able to complement a moderate dz cut ($dz > 0.15$ cm). However, in the endcap region it seems that there is performance to be gained by significantly loosening up the dz cut and complementing it with a time cut. The optimisation to find the best combination is being worked on, and it is also planned to examine the effect of taking further variables into the combination.

Publications

The results of the displaced stop analysis by the MTA-ELTE Lendület CMS group and HEPHY in Vienna are planned to be published in the end of 2022.

Education and teaching

In this second semester I have attended 3 ELTE courses: Standard Model (FIZ/2/002E), Advanced Quantum Field Theory (FIZ/2/001E) and Deep learning and machine learning in science (FIZ/3/089). As a part of my PhD obligations, I continued to teach in the Classical Physics Laboratory practical course for BSc students, which represents 4 hours per week student contact hours.

Additionally I have given two educational presentations to secondary school students about particle physics and detector systems.

References

[1] CMS B-Physics Analysis Group (BPH PAG)
`https://twiki.cern.ch/twiki/bin/viewauth/CMS/B-Physics#Low_pt_electrons`

[2] Ram Krishna Sharma's GitHub page on the HIP-problem:
https://ram1123.github.io/tools/2020/03/19/CMS-Analysis.html

[3] Electron Scale Factor summary:
https://twiki.cern.ch/twiki/bin/view/CMS/ElectronScaleFactorsRun2