1st Semester Report
Search for new physics beyond the Standard Model with the CERN LHC CMS detector

Ármin Kadlecsik (kadlec@student.elte.hu)
Supervisor: Gabriella Pásztor (Dept. of Atomic Physics, ELTE TTK)

Introduction

The MTA-ELTE Lendület CMS group in collaboration with HEPHY in Vienna searches for the production of scalar top (stop) quarks in a supersymmetric extension of the Standard Model with a compressed mass spectra. Such spectra where the scalar top is nearly degenerate in mass with the lightest supersymmetric particle, a neutralino, can arise in natural supersymmetry. For a potential discovery, two decay processes of the stop are considered, a 4-body decay with direct neutralino production ($\tilde{t}_1 \to b + f + \bar{f}' + \tilde{\chi}_1^0$), and a prompt 2-body decay to a b quark and a chargino (the fermionic partner of the SM charged bosonic states) leading to a similar final state ($\tilde{t}_1 \to b + \tilde{\chi}_1^{\pm} \to b + f + \bar{f}' + \tilde{\chi}_1^0$) [1].

Recent studies have been aimed at a compressed SUSY scenario, in which case the lifetime of the stop is expected to be longer, thus it travels a significant distance before decaying in the detector. This gives an additional challenge in particle reconstruction, especially with soft (low momentum) final state leptons. 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 first semester of my PhD studies, I have continued my research where my MSc studies ended. As a new technique to help improve the standard method of soft electron reconstruction, an extended reconstruction was developed: in this method, reconstructed photons are paired with close isolated tracks. These photon-track pairs are then also considered as possible electron candidates. The isolated tracks (isotracks) are created with the KF (Kalman Filter) algorithm, which has looser requirements than the electron-specific GSF (Gaussian Sum Filter) method. Therefore considering these photon-isotrack pairs could help in recovering electrons that would otherwise be lost. The finalization of this technique took place in the early parts of the semester, where track extrapolation was studied: we examined, how much the pairing of the photon and the isolated track can be improved, if the track was first extrapolated onto the surface of the calorimeter, thus calculating the matching more precisely. An important limiting factor for this improvement is the centrally pre-applied cut on low momentum photons in the central data samples, which hinders the potential of the extended reconstruction between 5 and 10 GeV in transverse momentum (pt).

Secondly, another technique was also investigated. In a newer version of the centrally reconstructed dataset (using the v9 version of the nanoAOD format), a new alternative algorithm is available to reconstruct electrons, optimised by the B-physics working group [2], 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, our research group has also started studying the new low-pt electron collection.

The performance studies were carried out on a signal sample for stop pair production, and background studies were performed on a $t\bar{t}$ decay sample with semi-leptonic and leptonic final states. The results are shown on a Receiver Operating Characteristics (ROC) curve on figure 1 that shows the efficiency for a signal sample and the background rejection for a background sample for various electron reconstruction methods. For the extended reconstruction, an increase in signal efficiency, and a decrease in background rejection is observed. Further study is needed to determine whether the improvements in efficiency are larger than the decrease in background rejection. However, the new low pt electron reconstruction gives very promising results by outperforming the standard reconstruction method in the studied samples.

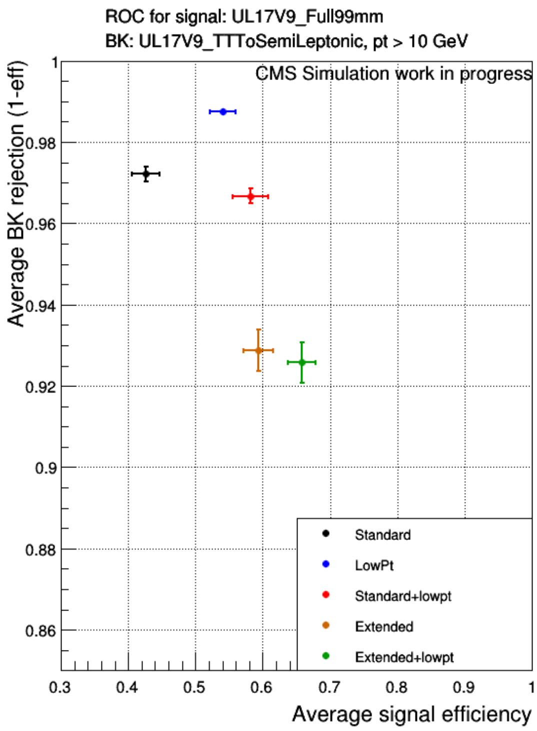

Figure 1: ROC curve with points for the examined reconstruction methods for electrons with $p_T > 10$ GeV. The new low-pt electron reconstruction (blue) outperforms the standard reconstruction (black) by having both better signal efficiency and better background rejection in the studied samples. A combination of using both the standard and the low-pt reconstruction is shown in red. The extended reconstruction (brown) has even better signal efficiency at the cost of worse background rejection.

The next steps of the analysis is to examine the details of the low-pt technique, such as particle identification (ID) options by optimising the boosted decision tree (BDT) settings or introducing additional isolation requirements. It is important to study the correlation with isolation variables, the definition of a suitable high-pt control region, and switching to a pt-binned QCD sample for background studies.

High Level Trigger studies

As the second part my PhD project, I have also joined a technical working group in CMS contributing to a central experimental physics task regarding the High Level Trigger (HLT) for electrons and photons. The work I took part in is aimed at improving the trigger - fast online event selection - by using the MIP (Minimum Ionising Particle) Timing Detector (MTD) of the CMS.

A brief initial study was conducted to find out which timing variables are suitable to work with: the time difference of the electron tracks with regards to the primary vertex (dt), and its significance (dt divided by the square root of the squared sum of the uncertainties of the measured time values). Based on the initial shape of the distributions, the dt significance optimization was tried first. In the analysis, the ROC curve (signal efficiency vs. background rejection) is studied for different isolation cuts. The ROC curve is expected to be affected by the newly introduced criteria on dt significance of the tracks that are included in the isolation sum. The technical information of the configurations and used samples are detailed in [3].

It has been found that a cut on the dt significance does not help the discrimination power of track isolation even though a priori it was expected to improve its performance. The results of this analysis were presented on the 5th HLT Upgrade Workshop [3]. Further studies will include cuts on dt instead of the dt significance, cuts with regards to the electron GSF track time instead of the primary vertex time, and a more sophisticated background estimation.

Conferences

I have presented my results for the HLT studies as a part of the E/gamma research group's results on the 5th HLT Upgrade Workshop [3].

Publications

No complete publication has been finished in my first semester. The results of the analysis by the MTA-ELTE Lendület CMS group and HEPHY in Vienna are planned to be published in 2022.

Education and teaching

In this first semester I have attended 3 ELTE courses: Experimental Methods in Particle Physics II (FIZ/2/004E), Phase Diagram of the Strongly Interacting Matter (FIZ/2/024E), and Conformal Field Theories (FIZ/2/018E). As a part of my PhD obligations, I taught the Classical Physics Laboratory practical course for BSc students, which represents 4 hours per week student contact hours.

References

[1] CMS Collaboration, A.M. Sirunyan et al., Search for stop quarks decaying via four-body or chargino-mediated modes in the single-lepton final state at $\sqrt{s} = 13$ TeV, JHEP09 (2018) 065.

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

[3] Ármin Kadlecsik, MTD Timing Studies for Electron Reconstruction 5th CMS HLT Upgrade Workshop, CERN (online), 2021, December, https://indico.cern.ch/event/1087907/