4th 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 studies the production of scalar top (stop) quarks in a supersymmetric extension of the Standard Model with a compressed mass spectra. My research is focused on reconstruction development in the case of soft, large impact parameter electrons, and on related detector performance studies for the extension of the 4-body stop searches to long stop lifetimes.

Research

Electron reconstruction studies

My research aims to test existing and develop new techniques – the low transverse momentum (LowPt) electron collection developed for b-physics studies and a new custom collection of closely matched isotrack-photon pairs (IPP)– to improve the efficiency (while also keeping high purity) over the standard method of electron reconstruction in case of large impact parameters and a soft momentum spectrum as expected in SUSY models with a small mass difference between the produced sparticle and the lightest SUSY particle (LSP) to which it decays.

In this semester the work was aimed at two aspects: finalizing the setup of the combination of the standard and LowPt collections to be used in the analysis, and calculating the scale factors for the LowPt collection and the combined collection. (IPP studies are postponed for the moment due to the added complexity that its inclusion brings.)

The efficiency study was repeated in the barrel ($|\eta| < 1.4$) and endcap ($1.44 < |\eta| < 2.5$) regions, separated by pseudorapidity (η). After a detailed study of all the p_T bins ($[1-3, 3-5, 5-12, 12-20, 25-50, 50<]$ GeV) in both η regions, **the conclusions are:** (1) **Go down in p_T to 3 GeV**, and (2) **use the standard and LowPt electron reconstructions combined.** (3) Since the efficiency of the **standard electron collection** is negligible-to-none below 5 GeV, it **is not to be used below the $p_T = 5$ GeV threshold**. This is shown for two p_T bins on figure 1. In the top row (below 5 GeV) it is shown that the combination (red) performs worse than just LowPt (blue) on its own, meaning that the inclusion of standard in this bin does not improve efficiency but may instead reduce background rejection. This behavior is true for both barrel and endcap but is more prevalent in the latter. Above 5 GeV (bottom row), the combination (red) starts to outperform LowPt on its own, and provides flexibility towards larger efficiencies than standard on its own. (4) **The exact working point will be defined after the electron efficiency and fake rate are measured in data, and the physics reach of the measurement is estimated for the SUSY model under consideration.**

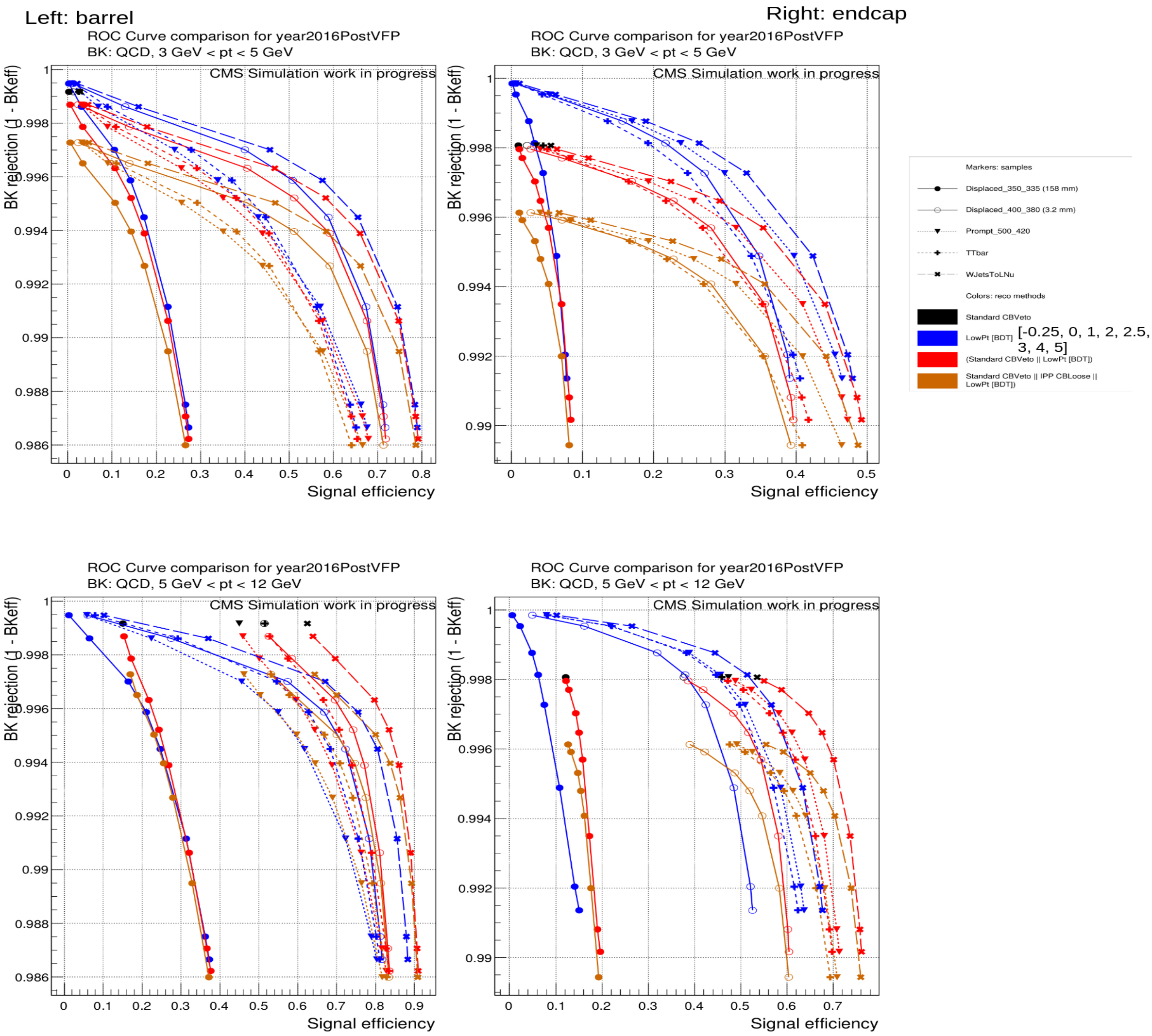

Figure 1: Receiver Operating Characteristic (ROC) curves for electron reconstruction in (top row) the 3 GeV $< p_T <$ 5 GeV transverse momentum bin (bottom row) and the 5 GeV $< p_T <$ 12 GeV bin, separately for the CMS (left column) barrel (right column) and endcap region. The different marker styles denote different signal samples, and different colors show the reconstruction methods. The points of the lines corresponds to increasing cuts on the BDT score of the LowPt collection. For the standard collection, the loosest "cut based veto" identification working point is used. The background rejection is calculated from the same p_T-binned QCD sample for each line.

In the combination, there are electrons that pass both the LowPt and standard reconstruction requirements. In case of ambiguity, it needs to be decided which collection to prefer with priority, based on the energy resolution of the reconstruction methods. We define $\Delta p_T = p_T^{\text{gen}} - p_T^{\text{reco}}$, i.e. the p_T difference of the true and reconstructed electron, and we plot $\Delta p_T / p_T^{\text{gen}}$ as a function of p_T^{gen}. This is shown on figure 2 for the dM = 80 GeV prompt signal sample, separately for barrel and endcap.

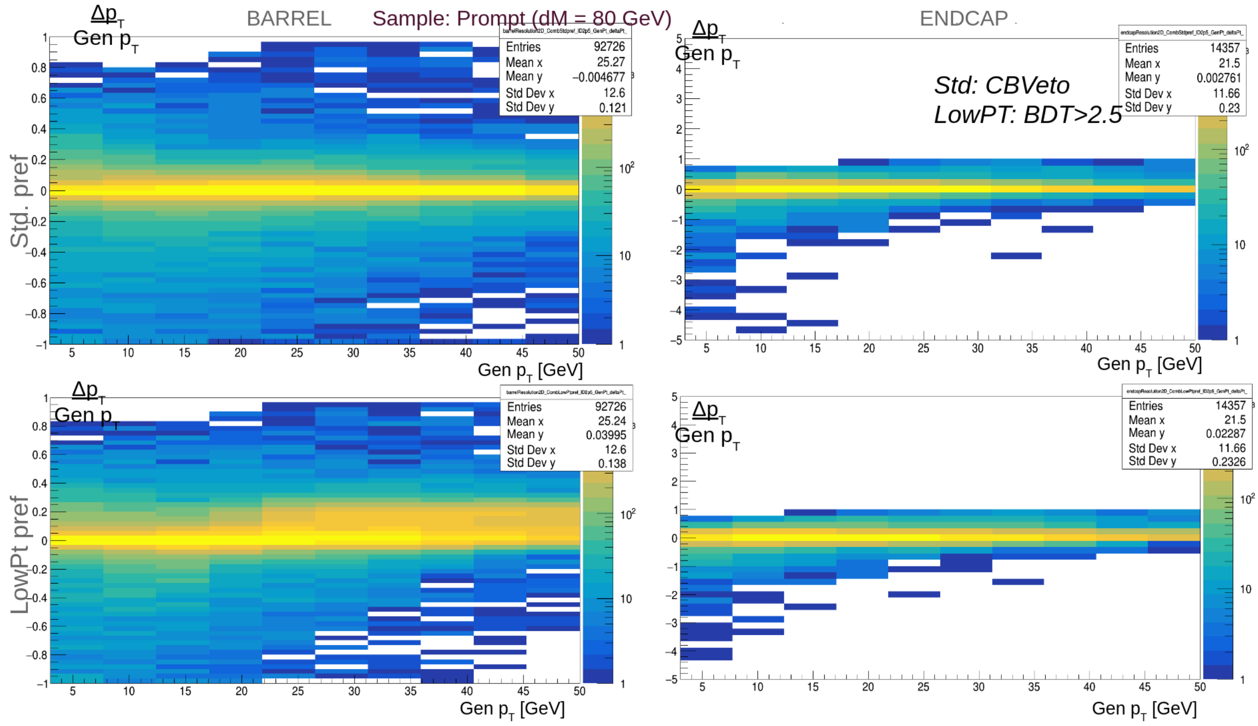

Figure 2: $\Delta p_T/p_T^{\text{gen}}$ resolution plotted against p_T^{gen} for the dM = 80 GeV prompt signal sample. Top row shows the combination where standard is preferred in case of ambiguity, bottom row shows where LowPt is preferred. The identification on the standard collection is the cut based veto working point, and the requirement on LowPt collection is a BDT score above 2.5 (which corresponds to the 4th point from above on the ROC curves).

In the barrel region, a widening smearing is visible in case of favouring LowPt reconstruction in the combination above 20 GeV. A similar smearing is observable in other samples, but it gets slightly less pronounced with larger displacement of the decying stop. The effect is not present in case of favouring standard electron reconstruction. This shows that (5) **the energy calibration of the standard electron reconstruction is more precise, making it the recommended choice of preference when an object is found by both methods**.

The closing figures of this study are comparing the RMS of the $\Delta p_T/p_T^{\text{gen}}$ distributions of the collections separately (shown in [4]), which also support the decision to favour standard reconstruction.

The conclusion of my study based on MC simulations for the analysis is thus to use only LowPt electrons below 5 GeV, and above that to use the combination of standard and LowPt, preferring standard when both are available. The final decision - especially at higher p_T where the lowPt reconstruction brings smaller improvement – may be altered based on the expected sensitivity (exclusion limits), the efficiency uncertainty and the fake rate measured in data, and also the effect of the isolation requirement in conjuction with the identification method on the efficiency and background rate.

Selection efficiency for the SUSY signal can only be estimated from Monte Carlo simulation. However, the modelling of electron reconstruction might not be perfect in simulation. The quality of modelling thus need to be verified in data. The scale factors[1] (a correction factor for the efficiency) need to be measured for the LowPt electron reconstruction and for the combined reconstruction. This is done by a tag and probe method using Z(ee) events. This was not done previously for the new collections, as the central tools[2] are provided only for the standard electron collection. Thus a new CMSSW analyzer plugin is being developed to process the variables of the lowPt and the combined collections. This is the first step to measure the efficiency and the scale factor for the MC simulation for these non-standard electron collections.

Central responsibilities

I continue to fulfill the role of HLT Monte Carlo validator for the Egamma POG (Electron and Photon Physics Object Group organisation). When a new version of the CMS Software (CMSSW) is released, comparisons and checks must be made to ascertain that the performance of the HLT algorithms are unchanged (or improved as expected). In case of a discrepancy, the change must be investigated and understood (often involving various experts). In 2023 I have been nominated as data validator of the offline reconstruction for the Egamma POG. These two experimental physics responsibility (EPR) tasks (estimated to be 4 months full time equivalent work per year) fulfill the official requirements to retain my CMS authorship.

I also plan to participate in the experimental data taking, similarly to 2022, by doing central trigger related shifts at the CMS control room at CERN, in the summer of 2023.

Conferences and presentations

- ”CMS Phase-2 Electron/Photon High-Level Trigger Upgrade Using MTD Precision Timing Informaiton” poster, 6–8 February 2023, CMS Upgrade Days [3]
- ”Studies with LowPt electrons in the context of displaced SUSY search” presentation to Egamma POG, 2 June 2023, EGM General Meeting [4]

Publications

The results of the displaced stop analysis by the MTA-ELTE Lendület CMS group and HEPHY in Vienna are planned to be completed and then the publication procedure to be started in 2023. The run 3 electron and photon reconstruction performance will be published by the Egamma POG, to which paper I will also contribute.

Education, teaching and outreach

In my fourth semester I have attended the Beyond the Standard Model (FIZ/2/003E) course.

I continued to teach in the Classical Physics Laboratory practical course for BSc students, taking 4 student contact hours per week. I have further contributed to the laboratory by developing new measurement and evaluation software for some workstations related to thermodynamics, and I have been tasked with maintaining other software used by these measurements.

I have participated as an organiser at the "ELTE - CERN International Masterclass 2023"[5] event held at Eötvös University on 16 March 2023.

References

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

[2] Egamma tag and probe module:
https://github.com/cms-egamma/egm_tnp_analysis
Egamma ntuple producer:
https://github.com/cms-egamma/EgammaAnalysis-TnPTreeProducer

[3] CMS Upgrade Days https://indico.cern.ch/event/1225033/

[4] https://indico.cern.ch/event/1289325/

[5] http://higgs.elte.hu/masterclass2023/