Determination of ATLAS Trigger Efficiency for Di-Higgs Production in the $1\ell3\tau$ Channel – Summer Student Report

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Abstract

This project focuses on determining the ATLAS trigger efficiency for di-Higgs boson production in the $1\ell3\tau$ final state, which involves one light lepton (electron or muon) and three hadronically decaying tau leptons. The study is performed within the ATLAS Common Analysis Framework (CAF), a ROOT- based platform with C++ bindings for streamlined nTuple data analysis. Using simulated datasets, relevant trigger paths are selected, and efficiencies are evaluated by comparing the number of events passing specific trigger conditions to the total number of generated events. By combining multiple trigger paths, an overall efficiency of approximately 99.8% with a statistical uncertainty of 0.1% was achieved, ensuring nearly complete signal acceptance.

1 Introduction

Tau leptons play a central role in many Standard Model (SM) measurements and in searches for new physics at the LHC. In particular, decays involving tau pairs provide the strongest handle for probing the Higgs boson's coupling to fermions. Beyond the SM, final states with tau leptons are predicted in numerous scenarios, including heavier Higgs bosons and other exotic resonances. For these reasons, efficient triggering on hadronically decaying taus is crucial, given the bandwidth and computational constraints of the ATLAS trigger system. Since the Higgs boson's discovery in 2012, extensive progress has been made in studying its interactions. However, its self-coupling remains unmeasured and it is of fundamental importance. The production of Higgs boson pairs (di-Higgs, HH) directly probes this self-coupling and the structure of the Higgs potential (Fig. 1). Among the many possible decay signatures, the $1\ell 3\tau$ final state consisting of one light lepton (electron or muon) and three hadronically decaying taus offers unique sensitivity despite its complexity [1].

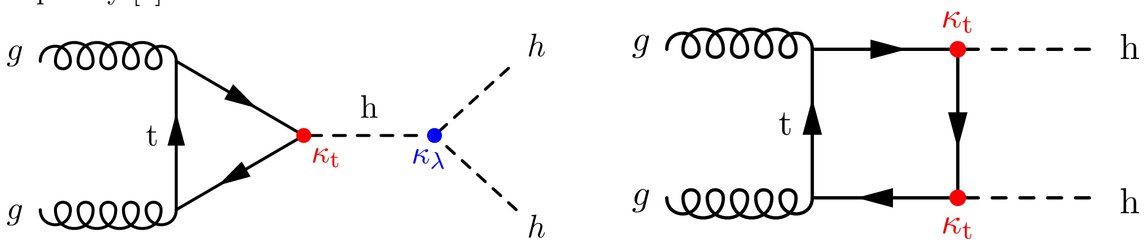

Figure 1: Feynman diagram for Higgs coupling

The ATLAS detector records up to 1.7 billion proton–proton collisions per second, producing over 60 million megabytes of data every second. Since only a small fraction of these events contain signatures relevant for new physics, the Trigger and Data Acquisition system [2] is responsible for selecting the most interesting events. The first stage, the Level-1 (L1) trigger, performs an initial event selection using coarse detector information to identify high-energy regions of interest (RoI). The L1 system reduces the event rate to a maximum of 100 kHz [3].

The second stage, the High-Level Trigger (HLT), is a software-based system that refines the event selection using full detector granularity and advanced reconstruction algorithms. Taking the RoIs from L1 as input, it performs detailed reconstruction of electrons, muons, taus, jets, and missing transverse energy, applying sophisticated selection criteria to suppress background. Ultimately, the HLT reduces the L1 output rate of 100 kHz down to about 1 kHz of events written to permanent storage, ensuring that the recorded data are both manageable in size and enriched with physics-relevant signatures for later analysis. Further details on this project are given in Ref. [4].

2 Data Description

The analysis was performed using simulated Monte Carlo (MC) datasets available within the Common Analysis Framework (CAF) directory. Specifically, three MC samples mcA, mcD, and mcE were employed, all corresponding to Release 22 of the ATLAS software. These datasets represent different simulation conditions or detector configurations but share the same physics process focus. The mcA dataset corresponds to ATLAS Monte Carlo simulations from the 2015 and 2016 data-taking periods. The mcD dataset corresponds to simulations matched to the 2017 ATLAS data-taking period, and mcE dataset is aligned with the 2018 ATLAS data-taking period. The primary signal studied is gluon-gluon Fusion (ggF) di-Higgs boson production in the $1\ell 3\tau$ final state.

3 Methodology

For each dataset in this analysis (mcA, mcD, mcE), trigger efficiencies were evaluated for three categories: Single Tau Triggers (STT), Di-Tau Triggers (DTT), and Single Lepton + Tau Triggers (SLTT). Efficiencies were studied as a function of the transverse momentum (p_T) of taus and leptons.

Subsequently, results from mcA, mcD, and mcE were combined to provide an overall efficiency. This was examined against the leading, sub-leading, sub-sub-leading tau and leading lepton's transverse momentum, thus yielding to a complete picture of trigger performance in the $1\ell\,3\tau$ channel. By consolidating the datasets, a more robust and statistically significant measure of the overall trigger efficiency in the $1\ell 3\tau$ channel was achieved. A logical OR have been made of STT, DTT and SLTT to see the conbined efficiency of all types of triggers and this combined view provides a clearer understanding of the effectiveness of these triggers in capturing potential di-Higgs production events.

4 Analysis

The performances of all the combined triggers are analyzed below: From figure 2, it is clear that STT and DTT triggers perform very well for leading taus with p_T above 50 GeV. The Single Tau Triggers are our primary triggers for events with a single high-momentum tau. Its efficiency rises quickly reaching efficiency above 95% for taus with a transverse momentum higher than 150 GeV. Di-Tau Trigger, or DTT is designed to select events with at least two taus. Its efficiency also rises with momentum, reaches plateau after 100 GeV, which is expected given its different selection criteria. The Single Lepton Trigger, or SLT (the yellow triangles), also shows higher efficiency at low momentum. This confirms that our trigger selection is efficient in capturing the most energetic tau.

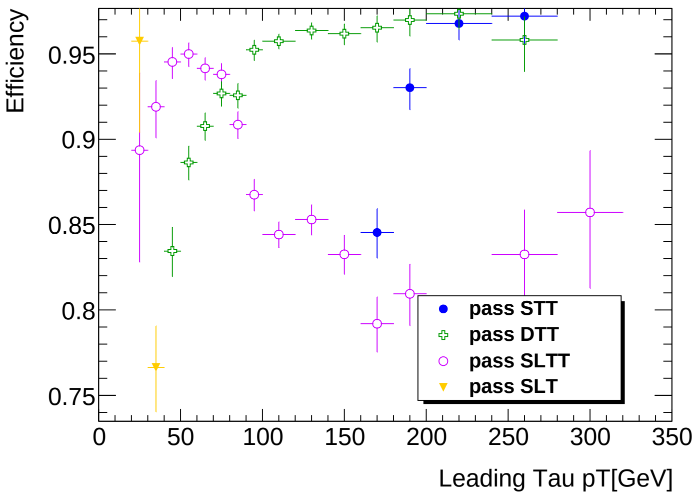

Figure 2: Combined efficiencies for all triggers as a function of the transverse momentum of the leading tau

For figure 3, almost similar efficiencies can be observed. Also the DTT triggers still show good performance, especially in the mid-range of p_T. The Single Tau Trigger, or STT, is also shown, but its efficiency is notably lower at all p_T values compared to the DTT. This is because the STT is designed for events with only one high-momentum tau.

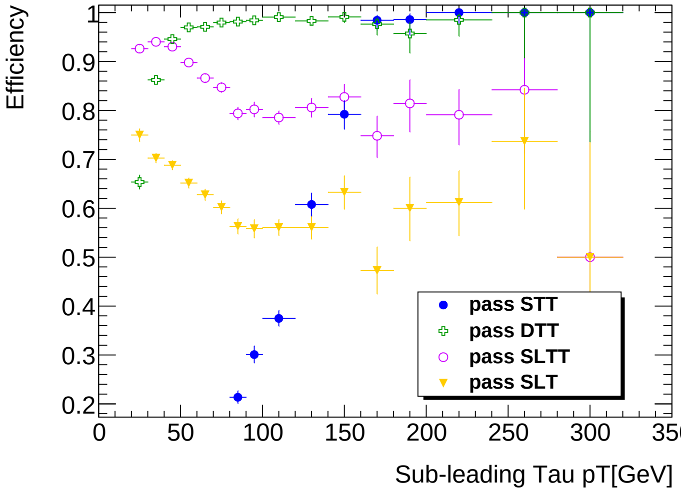

Figure 3: Combined efficiencies for all triggers as a function of the transverse momentum of the sub-leading tau

For figure 4, the efficiency drops noticeably, especially at lower p_T, due to the fact that most triggers are optimized for one or two tau signatures, not three. But as before, the DTT is still showing good efficiency from the beginning.

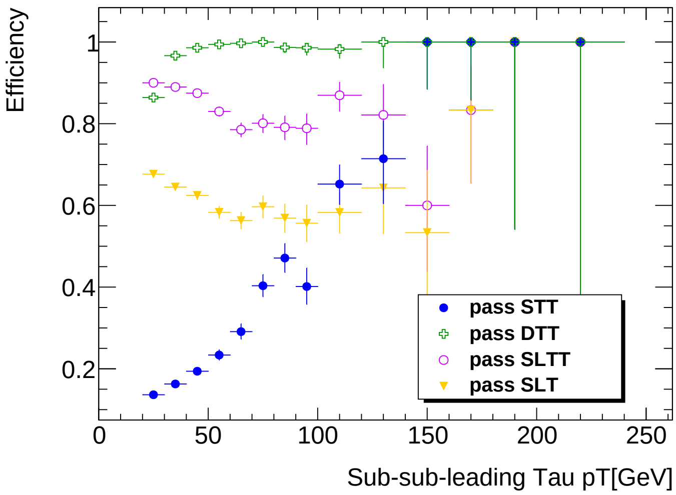

Figure 4: Combined efficiencies for all triggers as a function of the transverse momentum of the sub-sub leading tau

For figure 5, it is noticeable that the efficiency curves are quite different from what we saw for the taus, which is to be expected since we are looking at a different particle type. Here, we see that SLT and SLTT triggers provide good coverage for electrons and muons in the 20–60 GeV range. These triggers are essential in identifying the light lepton (electron or muon) component in our final state and are especially useful in cases where the tau triggers alone may not fire.

For figure 6, the efficiency of the combined trigger path is exceptionally high, consistently staying at or near 100% across all the taus and lepton transverse momenta. This is a very powerful result. It demonstrates that our analysis is not sensitive to a single trigger alone, but rather benefits from the combined acceptance of several different trigger paths. The small error bars up to 150–160 GeV and consistent performance across a wide range of transverse momentum values give us high confidence in this result.

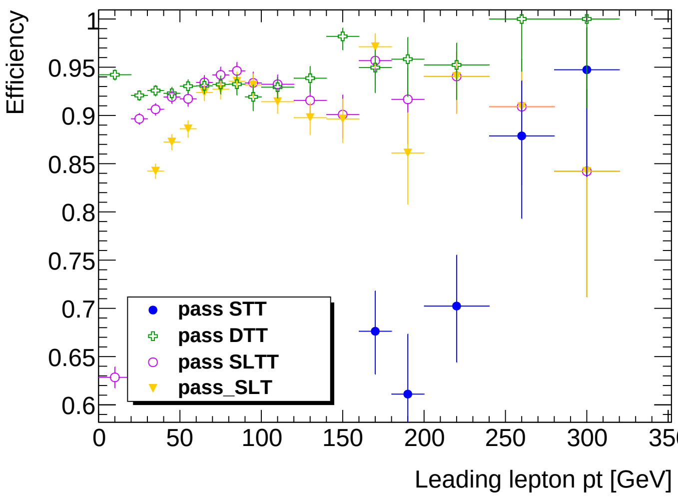

Figure 5: Combined efficiencies for all triggers as a function of the transverse momentum of the leading lepton

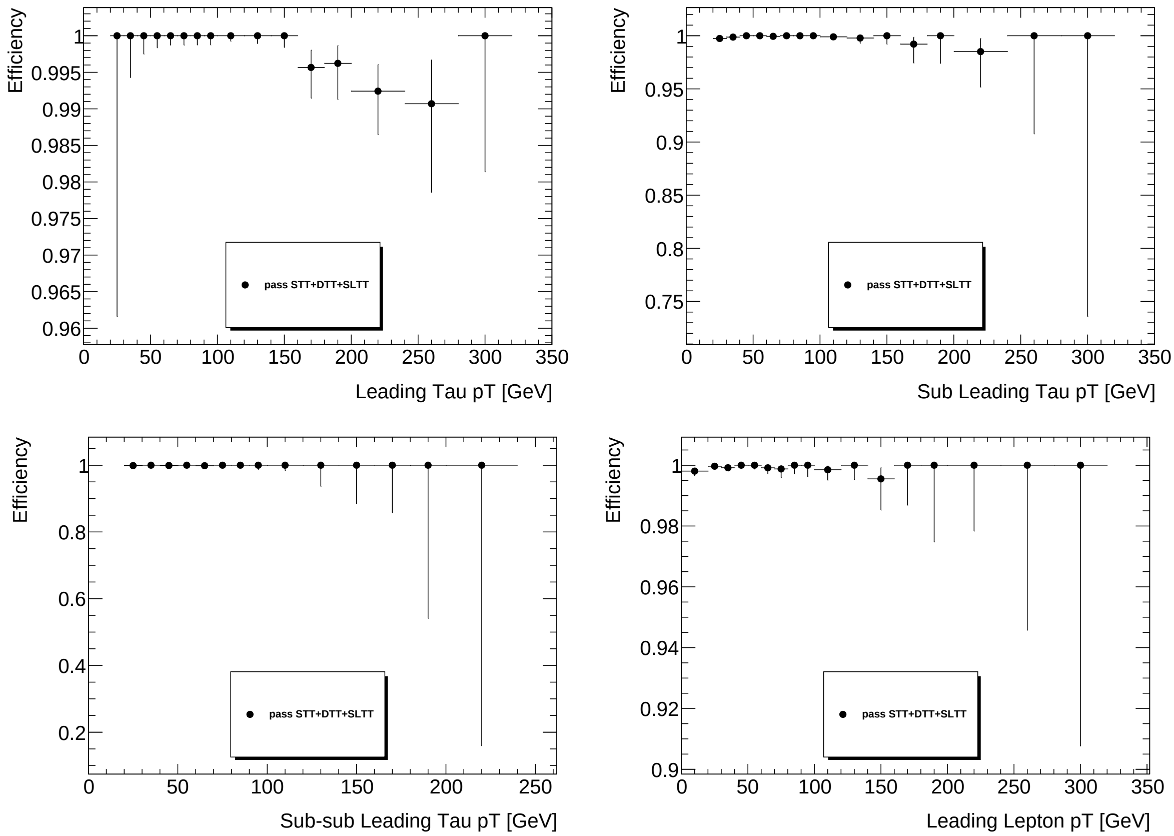

Figure 6: Overall combined efficiencies of all triggers as a function of the transverse momenta of the taus and of the leading lepton

5 Conclusion

This study provided a detailed evaluation of trigger efficiencies in the challenging $1\ell 3\tau$ channel, a key final state for probing di-Higgs production. We examined the performance of the Single Tau Trigger (STT), Di-Tau Trigger (DTT), Single Lepton Trigger (SLT), and Single Lepton + Tau Trigger (SLTT) across datasets mcA, mcD, and mcE. Our results show that the DTT and STT triggers deliver the strongest performance, consistently reaching plateau efficiencies above 90–95% for sufficiently high transverse momentum. The SLT and SLTT triggers complement this coverage by efficiently capturing the lepton component of the final state, especially at lower p_T. When combined, these triggers yield an overall efficiency of 99.8% with only 0.1% statistical uncertainty, ensuring nearly complete signal retention. This exceptionally high efficiency is critical for maximizing sensitivity to di-Higgs production in the $1\ell 3\tau$ channel. Looking ahead, these efficiency measurements will be integrated into the full $1\ell 3\tau$ analysis to quantify the channel's contribution to constraining the Higgs self-coupling and improving the overall di-Higgs search sensitivity.

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