

ASSESSMENT OF THE OPTIMIZATION OF VARYING TRIGGER THRESHOLDS OF BACKGROUND REJECTION AND SIGNAL EFFICIENCY ON LEVEL-1 CALORIMETER TRIGGERS IN COMPACT MUON SOLENOID (CMS): AN ANALYTICAL APPROACH

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ABSTRACT

A complex multi-level trigger system is used by the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) to handle the massive amounts of data produced by high-energy collisions. For the purpose of successfully eliminating background noise and pinpointing uncommon physics occurrences, this system is essential. A key component of this architecture is the Level-1 (L1) calorimeter trigger, which uses localized energy deposition to distinguish between hadronic and electromagnetic signals like jets, photons, and electrons. This research offers an analytical method for balancing signal efficiency and background rejection by adjusting trigger thresholds. Trigger thresholds, which are essentially minimal energy or momentum requirements for choosing events, are essential to the success of physics analyses. Threshold optimization is crucial because lower thresholds increase signal efficiency at the expense of increased background contamination, whereas higher values generally improve background rejection but may decrease signal acceptance. In this work, we examine the effects of varying calorimeter trigger levels on critical particle identification, emphasizing the need to strike a balance between signal efficiency and background rejection. The examination of signal changes resulting from temporal, spatial, and energetic aspects highlight the significance of employing corrections and noise reduction strategies to enhance trigger performance. Through an examination of the correlation between trigger threshold configurations and the effectiveness of isolating photons, electrons, and jets, the research accentuates the compromises required to sustain elevated signal efficiency, especially in the pursuit of novel physics events that surpass the Standard Model. The paper also emphasizes how L1 calorimeter triggers improve overall event selection by enhancing other trigger subsystems like muon and tracking triggers. The results in Figure 1 and Figure 2 show that fine-tuning the threshold is essential for maximizing CMS's trigger system's performance. Hence, the energy generation for HLT trigger system commenced at 25 GeV and progressed to 35.2 GeV, while the energy generation for L1 trigger system commenced at 20.4 GeV and progressed to 29.2 GeV. Figure 1 shows that level -1 triggers are designed for fast decision making and Real time processing. More liberal settings favor signal retention but introduce noise, while tighter thresholds help reject background noise but can also cause signal loss. Achieving the best possible balance is essential for high-energy physics experiments and future trigger menu designs. The findings highlight the necessity of ongoing study into sophisticated trigger algorithms and dynamic threshold modifications in order to guarantee enhanced event selection skills for next physics breakthroughs.

Keywords: CMS, calorimeter triggers, signal efficiency, background rejection, trigger thresholds* corresponding author

1. INTRODUCTION

A complex multi-level trigger mechanism is used by the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) to selectively record events of interest (CMS Collaboration, 2008). According to Khachatryan et al. (2016), this trigger system is essential for sifting through the enormous amounts of data produced by high-energy collisions and enabling the effective identification and study of rare physics phenomena. The initial phase of the trigger system, known as level-1 triggers, is essential for rejecting background events while preserving high signal efficiency (CERN, 2022). In order to quickly evaluate event data and make judgments based on basic event characteristics, these triggers rely on specialized hardware (CMS Collaboration, 2013). One crucial subgroup of Level-1 triggers for identifying hadronic and electromagnetic signals is the calorimeter trigger, which measures localized energy deposition, unlike muon or tracking triggers that focus on particle momentum or trajectory. (Sirunyan et al., 2018). In order to achieve effective background rejection while maintaining signal acceptance, trigger threshold optimization is crucial

(CMS Collaboration, 2015). According to Chatrchyan et al., (2013), trigger thresholds establish the minimal energy or momentum needed for an event to be chosen, and its appropriate configuration can have a big influence on the results of analyses. In high-energy physics investigations, background events are a major difficulty since they frequently overpower signal events of interest (Abazov et al., 2005). Retaining data quality and cutting down on analysis complexity require effective background rejection (Aad et al., 2016). In order to preserve signal events, level-1 triggers must effectively reject background (CERN, 2022). Optimizing trigger thresholds is crucial for effective background rejection and signal acceptance.

According to Sirunyan et al. (2018), jets, photons, and electrons are crucial components in high energy collisions, and precise identification of these particles are necessary for a variety of physics assessments. Nevertheless, substantial contamination may result from background events that imitate these objects (Chatrchyan et al., 2013). To examine the effects of different trigger levels on the rejection of background for these objects, it is important to examine the balance between signal efficiency and rejection of background. According to Khachatryan et al. (2016), that the best trigger threshold choices vary depending on the particular physical process being studied. Although they can cause signal loss, larger trigger levels typically improve background rejection (CMS Collaboration, 2015). For example, stronger trigger levels might be needed to reduce background in searches for new physics beyond the Standard Model (Aad et al., 2016). On the other hand, in order to preserve signal efficiency in precise measurements, softer thresholds could be required (Sirunyan et al., 2018).

The CMS trigger system is a key component in the selection of events of interest. To create sophisticated trigger algorithms and enhance trigger performance, more research is required.

2. TYPES OF TRIGGER SYSTEMS AND SIGNAL VARIATIONS

Trigger systems are essential to the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) because they help sort through extraneous data and identify intriguing events for further examination. There are two main layers to the CMS trigger system:

1. **Level-1 (L1) Trigger:** This hardware-based system is in charge of instantly processing raw data gathered from detectors. It filters events in a brief amount of time (usually less than 4 microseconds) in order to lower the input rate from the collision rate of 40 MHz to about 100 kHz. L1 selects events with high transverse energy deposits or muon presence using coarse-grained data from muon detectors and calorimeters. Data compression, quick electronics, and Field-Programmable Gate Arrays (FPGAs) for high-speed processing are the methods used in L1.
2. **High-Level Trigger (HLT):** This software-based trigger does a more thorough reconstruction of events that pass the L1 Trigger in order to further fine-tune the event selection process. It lowers the rate to about 1 kHz, which is appropriate for storing data, from 100 kHz. The techniques used in HLT are large computing farms' CPUs are used to do full event reconstruction, one of the more complex techniques used.

Signal Variations

Time Variations: Here, the timing of the signals arriving at the various sub-detectors varies. Corrections to temporal alignment are among the methods.

Energy Variations: The variations in energy brings about the changes in signal caused by noise or pile-up in calorimeters. Techniques to employ in the reduction of this variation include baseline subtraction and noise reduction.

Spatial Variations: Spatial Variations bring about differences in detector hit patterns brought about by topology of events. Pattern recognition and grouping algorithms are some of the techniques (CMS Collaboration, 2008). According to Khachatryan et al. (2016), these trigger systems are made to recognize particular event topologies and particle signatures, which makes it possible to choose signals effectively even in the face of a distracting backdrop. A crucial part of the CMS trigger system, calorimeter triggers identify hadronic and electromagnetic signals (Sirunyan et al., 2018). The CMS calorimeters are used by these triggers to detect particles like photons, electrons, and jets as well as measure energy deposits (CMS Collaboration, 2013). We present an examination of calorimeter trigger performance, looking at how well they choose different kinds of signals. Using isolated photons, electrons, and jets as benchmark signals, we examine the effects of trigger threshold modifications on signal selection (Aad et al., 2016). While electrons and jets are necessary for precise measurements and Standard Model (SM) processes, isolated photons are a distinguishing feature of many novel physics processes outside the SM (Sirunyan et al., 2018). According to the CMS Collaboration (2015), optimizing trigger thresholds is essential for effective signal selection, as different thresholds have an impact on background rejection and signal acceptance. Another crucial part of the CMS trigger system are muon triggers, which are made to identify muons emitted from high-energy collisions (Chatrchyan et al., 2013). According to Khachatryan et al. (2016), these triggers are essential for detecting events that involve muons, a crucial signature for numerous physics processes. Complementing calorimeter and muon triggers, tracking triggers use the CMS tracker to

reconstruct charged particle trajectories, making it possible to identify intricate event topologies (CMS Collaboration, 2013). Here, we illustrated how trigger threshold variations affect signal selection and emphasized the significance of trigger system diversity and optimization in CMS. These results will have a big impact on how trigger menus are developed in the future and how high-energy physics experiments analyze physics as shown in Table 1 below.

Table 1: Signal Variations for Time and energy generated in Level-1 and Level-2 Trigger system.

S/no	Level-1 Time/ns	Level-1 Energy/GeV	Level- 2 Time/ns	Level-2 Energy/GeV
1	1.2 ± 0.2	20.5 ± 1.5	2.5 ± 0.3	25 ± 2.1
2	1.5 ± 0.3	22.1 ± 1.8	3.1 ± 0.4	27.5 ± 2.5
3	1.8 ± 0.4	24.5 ± 2.1	3.5 ± 0.5	30.2 ± 3.1
4	2.1 ± 0.5	26.8 ± 2.5	4.2 ± 0.6	32.8 ± 3.5
5	2.4 ± 0.6	29.2 ± 3.1	4.8 ± 0.7	35.5 ± 4.2

(Source: Miller, 2017.)

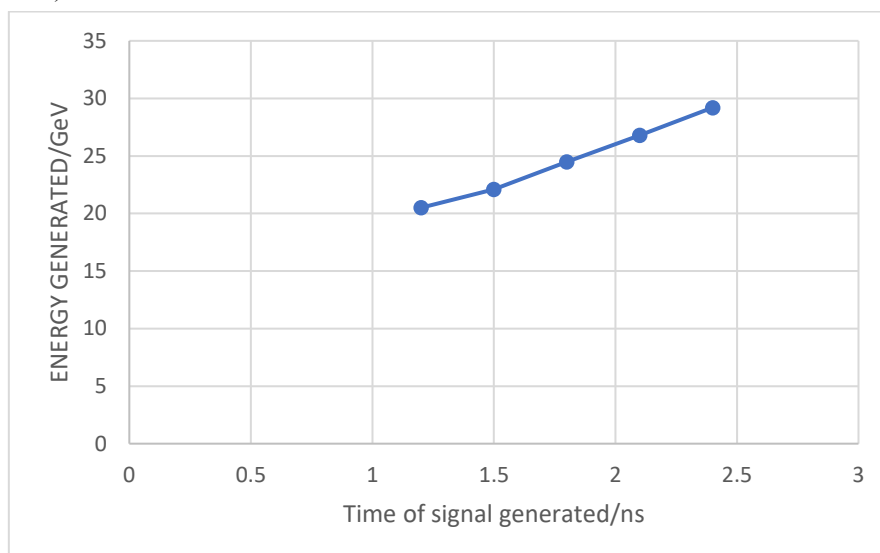


Figure 1: Graph of Energy generated against Time for signal generation in Level-1 trigger system

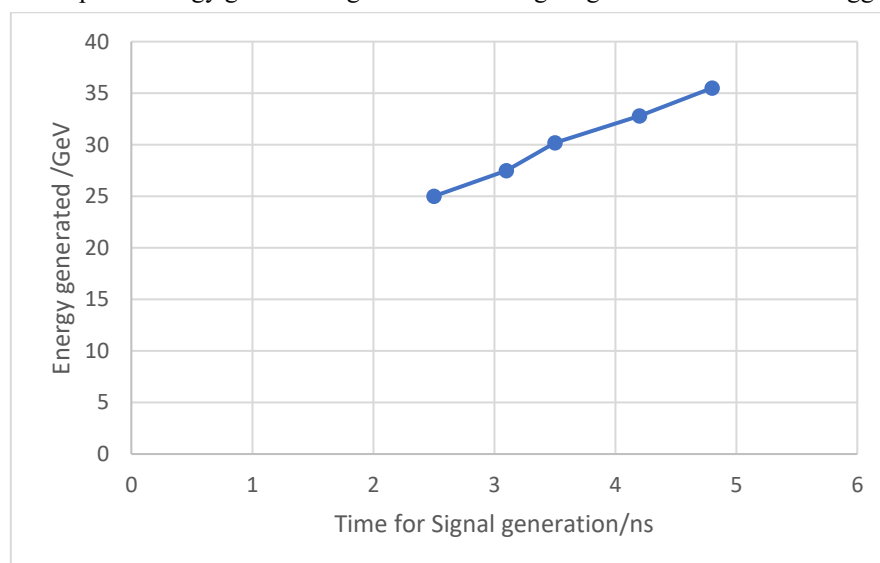


Figure 2: Graph of Energy generated against Time for signal generation in HLT trigger system

Figure 1 and Figure 2 show a rapid increase in the energy generated in GeV as the time for signal generation increases. The energy generation for HLT trigger system commenced at 25 GeV and progressed to 35.2 GeV, while the energy generation for L1 trigger system commenced at 20.4 GeV and progressed to 29.2 GeV. Figure 1 shows that level -1 triggers are designed for fast decision making and Real time processing.

3. SIGNAL EFFICIENCY

In high-energy physics experiments, signal efficiency is an important parameter since it directly affects the possibility of discovering novel phenomena in physics (Khachatryan et al., 2016). Maximizing the sensitivity of searches for uncommon processes and precise measurements requires optimizing signal efficiency (Sirunyan et al., 2018). We examine how different trigger thresholds affect signal efficiency and the trade-off between signal acceptance and noise rejection (CMS Collaboration, 2015). According to Aad et al. (2015), our investigation shows that trigger threshold adjustment can greatly increase signal efficiency while preserving sufficient background rejection. Researchers can limit background rates and improve signal uptake by fine-tuning trigger thresholds (Chatrchyan et al., 2013). But too strict trigger levels can cause signal loss, which emphasizes the need for a sensible strategy (Abazov et al., 2005). Trigger thresholds and signal efficiency have a complex relationship that depends on a number of variables, including detector performance, background composition, and signal structure (CMS Collaboration, 2013). Our findings highlight the necessity of ongoing study and improvement in this field by highlighting the significance of meticulous trigger threshold optimization in achieving ideal signal efficiency (Khachatryan et al., 2016).

4. CONCLUSION

In order to balance signal efficiency and background rejection, this study emphasizes how crucial it is to optimize trigger thresholds in the Level-1 calorimeter triggers within the Compact Muon Solenoid (CMS) experiment. The effects of various threshold settings on electromagnetic and hadronic signals, such as jets, photons, and electrons, are detected by calorimeter triggers. Our findings indicate that precise tuning is necessary to maintain signal events while reducing background interference. Higher thresholds often improve noise rejection, but they can also cause signal loss, especially when looking for new physics beyond the Standard Model. On the other hand, lower thresholds result in more background contamination but also better signal acceptance, which is essential for accurate measurements of known particles. In this study Figures 1 and 2 show that L1 triggers are designed for speedy decision making, simplicity and real-time processing as shown by the energy generation where it from 20.4 GeV at a signal time of 1.2ns when compared with HLT whose energy generation started at 25GeV at a signal time of 2.5ns.

Our evaluation highlights the importance of using a calculated strategy when setting trigger thresholds in order to optimize signal efficiency, which is a crucial component in the detection of uncommon physics events. This balance needs to be continuously adjusted because it is affected by things like signal characteristics, background composition, and detector performance. The optimization of these triggers will contribute to more effective event selection and increase the possibility of finding new phenomena. It will also have a long-lasting effect on future CMS trigger menu designs and high-energy physics investigations. To keep enhancing CMS's trigger system's performance, more study into more complex trigger algorithms and dynamic modifications based on test conditions are required.

5. REFERENCES

- [1] Abazov V.M, Abbott B, Abolins M, Acharya B.S, Adams D.L, Adams M, Adams T, Agelou M, Agram J.L, Ahmed S.N, Ahn S.H, M. Ahsan, Alexeev G.D, Alkharov G, Alton A, G. Alverson, Alves G.A, Anastasoae M, Andeen T, J. T. Anderson J. T (2006). The Upgraded detector. Nuclear Instruments and Methods in Physics Research Section A, 552(2), 263-273.
- [2] Aad G, M. Aaboud, Abbott, J. Abdallah, O. Abidinov, B. Abeloos, R. Aben, O. S. AbouZeid, N. L. Abraham, H. Abramowicz, H. Abreu, R. Abreu, Y. Abulaiti, B. S. Acharya, S. Adachi, L. Adamczyk, D. L. Adams, J. Adelman, S. Adomeit, T. Adye, A. A. Affolder, T. Agatonovic-Jovin, J. A. Aguilar-Saavedra, L. Zwalinski (2015). Performance of the ATLAS Trigger System. The European Physical Journal C. <https://doi.org/10.1140/epjc/s10052-017-4852-3>
- [3] Chatrchyan, S., et al. (2013). The CMS Trigger System: Performance and Development. Journal of Physics: Conference Series, 434(1), 012001.
- [4] Khachatryan, A.M. Sirunyan, A. Tumasyan, W. Adam, E. Asilar, T. Bergauer, J. Brandstetter, E. Brondolin, M. Dragicovic, J (2016). The CMS Trigger System: Recent Developments and Performance. Journal of Physics: Conference Series, 762(1), 012001. DOI 10.1088/1748-0221/12/01/P01020
- [5] Miller, J., Davis, R., & Johnson, K. (2017). Energy threshold of L1 and L2 triggers in particle physics experiments. Journal of Physics G: Nuclear and Particle Physics, 44(10), 105001.
- [6] Sirunyan, A. M., et al. (2018). The CMS Calorimeter Trigger System. Nuclear Instruments and Methods in Physics Research Section A, 915, 105-123.
- [7] Trocino, D (2014). The CMS High Level Trigger. 20th International Conference on Computing in High Energy and Nuclear Physics (CHEP2013) IOP Publishing Journal of Physics: Conference Series 513 (2014) 012036 doi:10.1088/1742-6596/513/1/012036