New Trigger Studies for Emerging Jets at CMS Experiment

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Work done during the University of Colorado Boulder Pathways Program

August 6, 2021

Abstract

The failure to find a dark matter particle is a significant outstanding issue with the Standard Model. A recent theory for the origin of dark matter involves a dark (or hidden) sector in which an analogue to the strong force exists, which results in the creation of dark baryons and dark mesons. In this model, the LHC could produce dark quarks that hadronize into dark mesons with a relatively long lifetime. The signature is called "emerging jets" as the particles in these jets come from the decays of dark mesons, which all decay at different times. The current analysis uses events that are selected by a trigger that requires a great deal of energy in the form of jets. This trigger does not take advantage of the unique features of the emergent jets analysis. In this study we evaluate the performance of the existing triggers and begin work towards developing a new trigger dedicated to Emerging Jets for the next round of data taking.

1 Introduction

The Large Hadron Collider (LHC) is an underground ring 27-km in circumference used as a research tool by physicists to accelerate bunches of protons within 99.999% of the speed of light and at high energies, making these collide head-on at around 600 million times per second. These collisions result in numerous subatomic particles shooting in all directions, a group of which consists of gluons and quarks that spur out in the shape of a cone out of the collision point (primary vertex). These subatomic constituents of protons interact through fundamental forces known as the Strong and Weak force, orchestrated through mediator particles (e.g. bosons and gluons). We use detectors like the Compact Muon Solenoid(CMS) to try and take a picture of these events. CMS is one of the biggest experiments in the world with over 5000 scientists, students and engineers worldwide. Located 100 m below ground, CMS is a multipurpose detector that acts as a giant high-speed camera taking “3D images” of proton-proton collisions up to 40MHz.[1]

Out of the massive amounts of collisions subatomic particles shoot out in all directions. A group of these particles (gluons and quarks) spur out in the shape of a cone out of the collision point (primary vertex), these are the jets that get captured by our sensors and make are the focus objects in the Emerging Jets Analysis.

1.1 Why search for new physics?

Granted that the Standard Model of Particle Physics (SM) has had incredible predictive prowess, it is still an incomplete theory. SM does not explain things like the asymmetry of Matter to Antimatter in the Universe, why the Higgs Boson is 125 GeV in mass? Are there other Higgs? What is Dark Matter made of? For this reason, we strive to find evidence for Physics "beyond the Standard Model" (BSM) to potentially extend the theory and find answers to these questions. To prove that Dark Matter makes up about 27% of the universe would require BSM physics. We have been able to see the gravitational effects of Dark Matter in our Universe but have not yet been able to produce these particles in the lab.[6]. Today we search for the possibility to produce and detect evidence of dark matter particles in the LHC collisions.

Figure 1: A visual representation of an event where an uncharged particle with long liftime decays and produces a displaced dijet via know processes (left). The parton shower of BSM matter decaying and producing multiple vertices that might be grouped into the same jet cone (right).

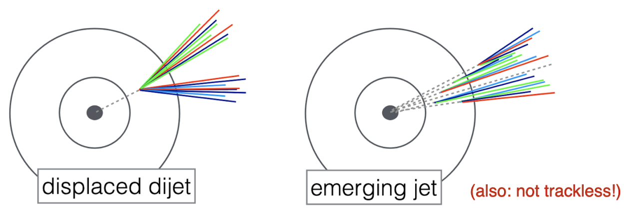
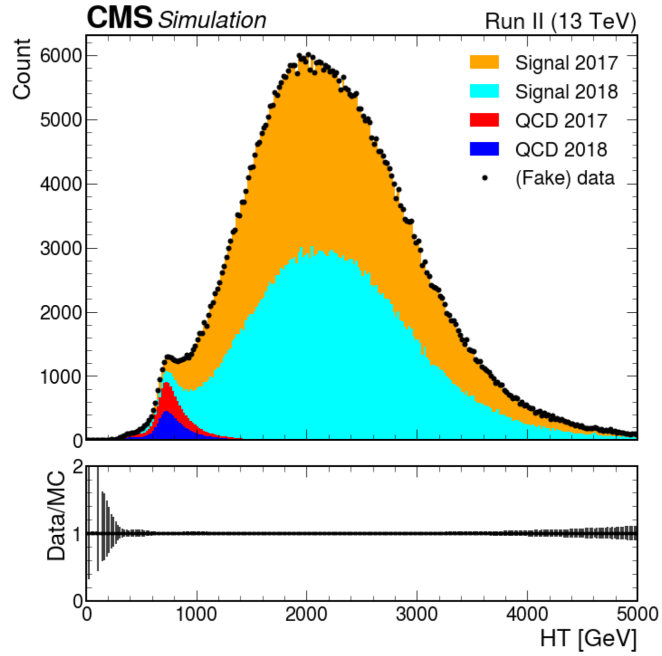


Figure 2: The image shows a stacked histogram showing the area covered by the different data looked at. Signal refers to the simulated EMJ events and QCD is the Background for the analysis.



2 Emerging Jets

While it is possible that DM has only gravitational interactions, many compelling models of new physics contain a dark matter candidate that interacts with SM quarks. One such way is to look for the pair production of a new heavy particle that acts as a mediator between dark sector matter (BSM) and normal matter (SM) that decays to a light quark and a new fermion called a dark quark. The dark quark is charged under "Dark QCD" and forms an "emerging jet" via a parton shower, containing long-lived dark hadrons that give rise to displaced vertices when decaying to standard model hadrons. A novel strategy is to look for events with jets that are predominantly composed of displaced vertices and many different vertices within the same jet cone like portrayed in the Figure 1. The mechanism proposed and regular QCD processes both produce displaced jets in the final state. This denotes QCD as a background to our analysis search where the "emerging jets" (EMJ) come from the decay product of the dark sector particles. Thus there is a necessity for a trigger that identifies the candidates for these rare events by looking for multiple displaced vertices and thus multiple tracks with large impact parameters. The analysis looks to identify jets that come from a new process called "Dark QCD" via models that can naturally explain the mass densities of matter and dark matter observed in astrophysical studies[2]. Currently, the Triggers available are not sensitive to the exotic physics proposed in the energy regime that we are looking in.

Figure 2 shows the amount of space that our signal (EMJ events) and our background (QCD jets) cover with respect to varying HT. Naturally, the previous iteration of the EMJ analysis studied the higher energy range $\mathcal{O}$(TeV) where the distribution of signal is cleaner. Despite this, the effort was not fruitful in detecting these events. The current analysis effort is pushing to study the lower energies $\mathcal{O}$(100 GeV) where the space is dominated in large part by the background. This makes the study require more sophisticated methods to ensure optimal ratio of signal to background. One of the methods to achieve better event selection is a new Trigger for identifying EMJ events in our data.

3 Triggers

Most of the data gathered from these events does not contain new information and we are limited by the capacity of our electronics to make quick decisions and the bandwidth for which they are rated for. Naturally, we must find a balance in order to store enough data that we can make statistically significant measurements and have conclusions from them but not so much that we overflow our limited storage capacity quickly. Thus, the Trigger takes the role of making these decisions by having hardware level and software level thresholds that "trigger" the buffering and recording of the events during the data taking process as well as deciding to write the events to storage.

CMS has a 2-level Trigger system. The L1 Trigger is the hardware based trigger that reduces the event rate from 40MHz down to 100KHz using basic low level information from the detector from only the calorimeters and the muon detector. The L1 Trigger has a fixed running time of approximately 4μs to accept or reject an event. Then comes the High Level Trigger (HLT) which is the type of trigger this work focuses on. It's a software based trigger with full event information and reduces the event rate down to 1.3 kHz, has the flexibility to do whatever it can within the range of running times it has with an average of 350ms. These running times depend on the complexity of the trigger [4].

3.1 Trigger Design

The HLT is comprised of all the different Triggers made available for each version of CMS Software (CMSSW) in one single python file called the HLT Menu configuration. A trigger menu is defined as the sum of all object definitions and algorithms that define a particular configuration of the CMS trigger system[3]. The HLT Menu consists of over 100k lines of python code that defines the produces, prescalers and filters for each trigger (a.k.a. the Trigger Paths). Figure 3 shows a snapshot of the ConfDB GUI. The ConfDB GUI is a tool to easily create, edit, and store trigger paths in ConfDB. In order to develop a new Trigger Path one must connect to a machine at CERN, execute the GUI and login to ConfDB. Afterwards navigate the GUI to find the latest CMSSW version and save a copy of the configuration to the user's folder in ConfDB. The stucture of a path is combination of producers and filters like seen in Figure 4. The starting point was to select a reasonably efficient trigger for our signal and begin tweaking parameters according to what is found to produce higher physics gain. Further work is needed to complete the production of the new EMJ Trigger as of the time of writing.

3.2 Measuring Trigger performance

After a trigger is developed it will be evaluated based on the resources it consumes vs the amount of physics data for CMS it can produce. One of the ways to verify this is measuring the Trigger's efficiency. Figure 5 shows an example of a trigger efficiency for simulated QCD events. This plot shows the ideal behaviour of a Trigger where near the region of a specified threshold the efficiency increases sharply to optimal efficiency. This is called a sharp "turn on" curve. A curve that takes a less sharp turn on indicates a less ideal trigger.

The next step is to measure the efficiency of all current triggers that are good candidates to be the base of our new EMJ trigger. Figure 6 shows an example of the HLT_PFHT650_DisplacedDijet trigger efficiencies for different model points. A model point is a combination of theoretical parameters that change the dynamics of the new physics proposed. These originate from the theory papers that predict our EMJ events to be produced (if they are true of course) withing certain range of parameter values. For example, a parameter for which we study it's effect on the efficiency of the trigger is the lifetime of the dark particle ($c\tau$). Another variable studied is the mass of the dark mediator particle (`mMed`). Mediator particles gives rise to forces between other particles. These particles are bundles of energy (quanta) of a particular kind of field, for example the photon is the mediator particle of the electromagnetic force. The top three plots in Figure 6 show the efficiency of this trigger when varying the dark mediator mass. The bottom three, show efficiency when varying the lifetime of the dark particle. We see that the overall behaviour of this trigger is not exactly ideal as it does not present a sharp turn on curve but it does hover over the 80% efficiency for the ranges of energy that interests us in at least one model point, making it a good base for our new EMJ trigger.

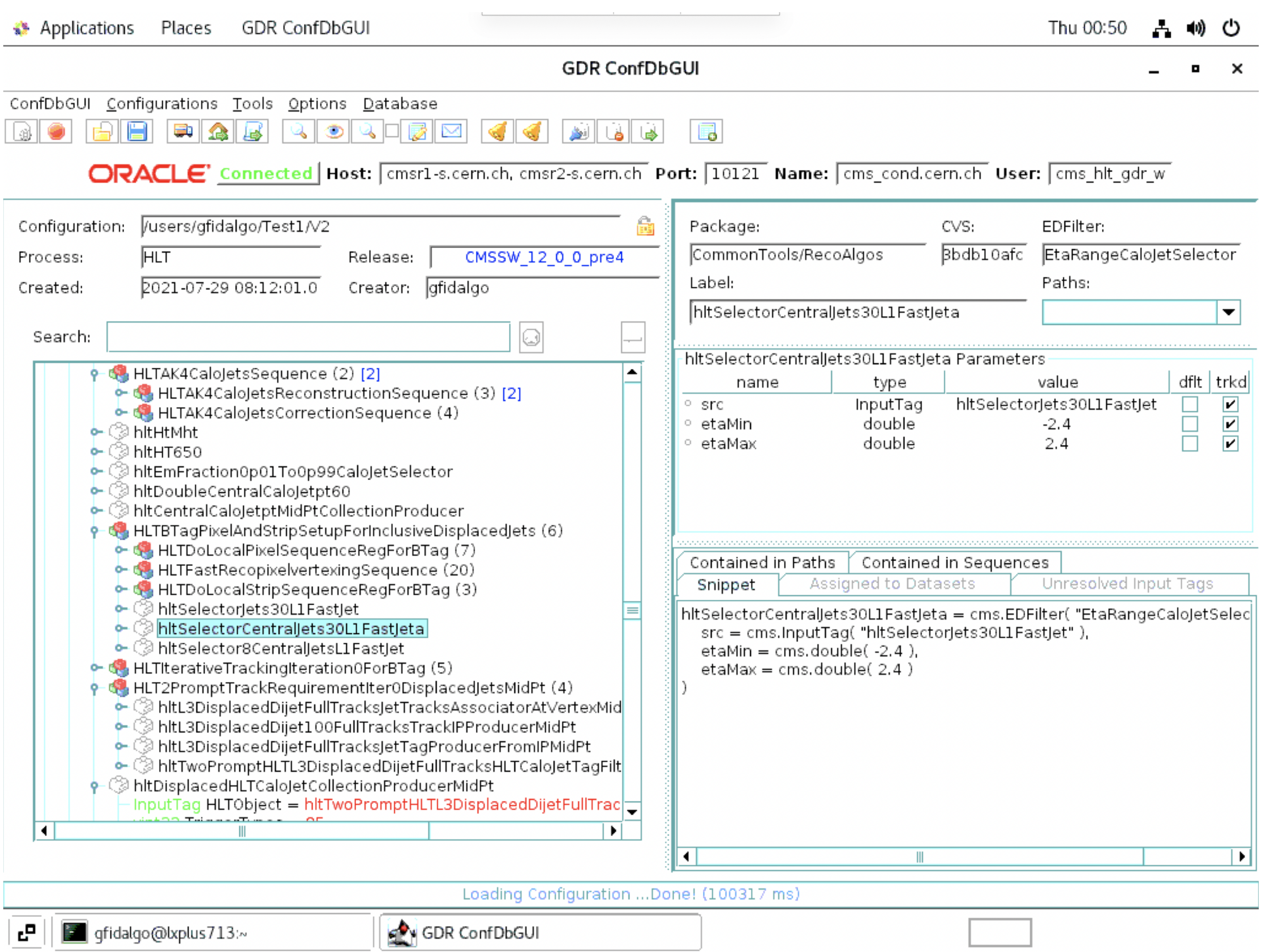


Figure 3: ConfDB Gui showing an example of a selector and it's parameters. This filters the output of a previous selector in the path.

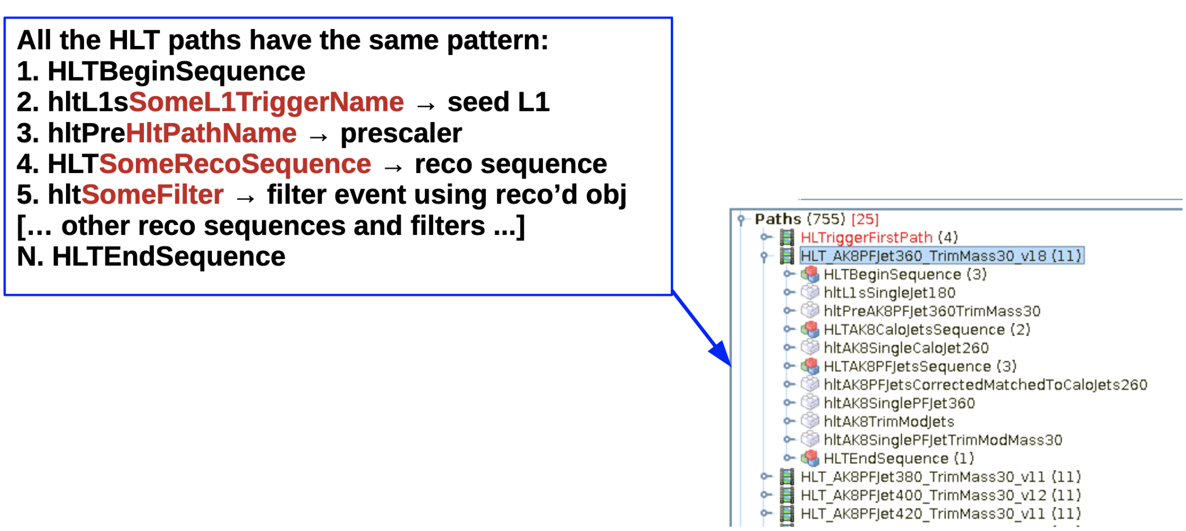
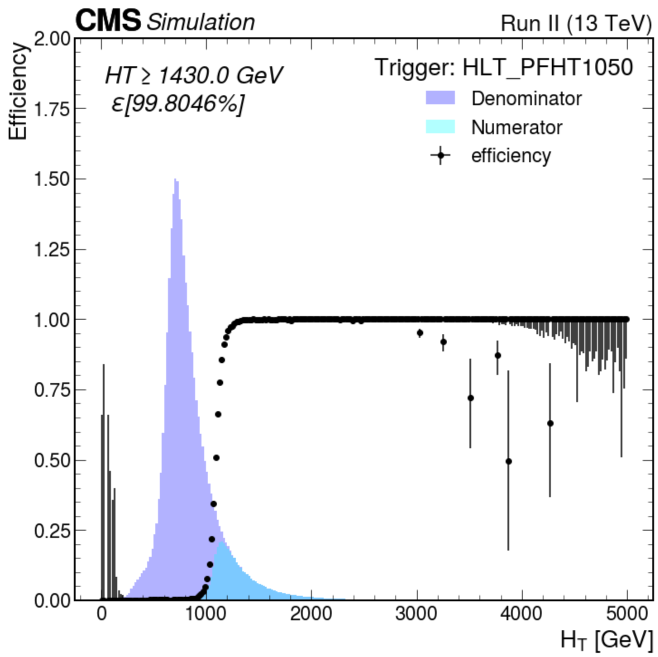


Figure 4: Basic stucture of an HLT Path Credit: Silvio Donato

Figure 5: The plot is composed of 2 histograms and an efficiency curve. The histogram labeled as Denominator represents the entirety of simulated QCD events for 2017 and 2018. The Numerator is the amount of events remaining after applying the HLT_PFHT1050 trigger. The efficiency is the ratio of Numerator and Denominator histograms.



4 Conclusions

We have observed the gravitational influence of dark matter in the Universe. It is hoped that LHC collisions can produce DM particles and that CMS can detect evidence of their decay modes. This analysis would identify and use the decay modes of these dark particles into SM particles to identify Emerging Jets. The previous search for Emerging Jets has been unsuccessful in identifying candidate events in high energy regimes. In this work we have shown efficiency measurements of the current triggers available. The particular triggers studied show signs of having good starting points for the new EMJ trigger and will be further inspected for future development. The design of a new EMJ trigger is a work in progress as of the time of writing.

5 Acknowledgements

A special thanks to my local advisor Prof. Sudhir Malik for his guidance, Prof. Keith Ulmer and Prof. Kevin Stenson for accepting me into their lab and providing me the opportunity to work in the Colorado University Pathways program. Thanks to Prof. Bill Ford. Postdocs - Scarlet Norberg and Alexx Perloff as they were critical in this work. Christine Morrow for the planning and execution of the CU Pathways program activities and providing the inclusivity factor so that I could attend remotely this summer. Thanks to the Mitchel foundation for the funding of this work.

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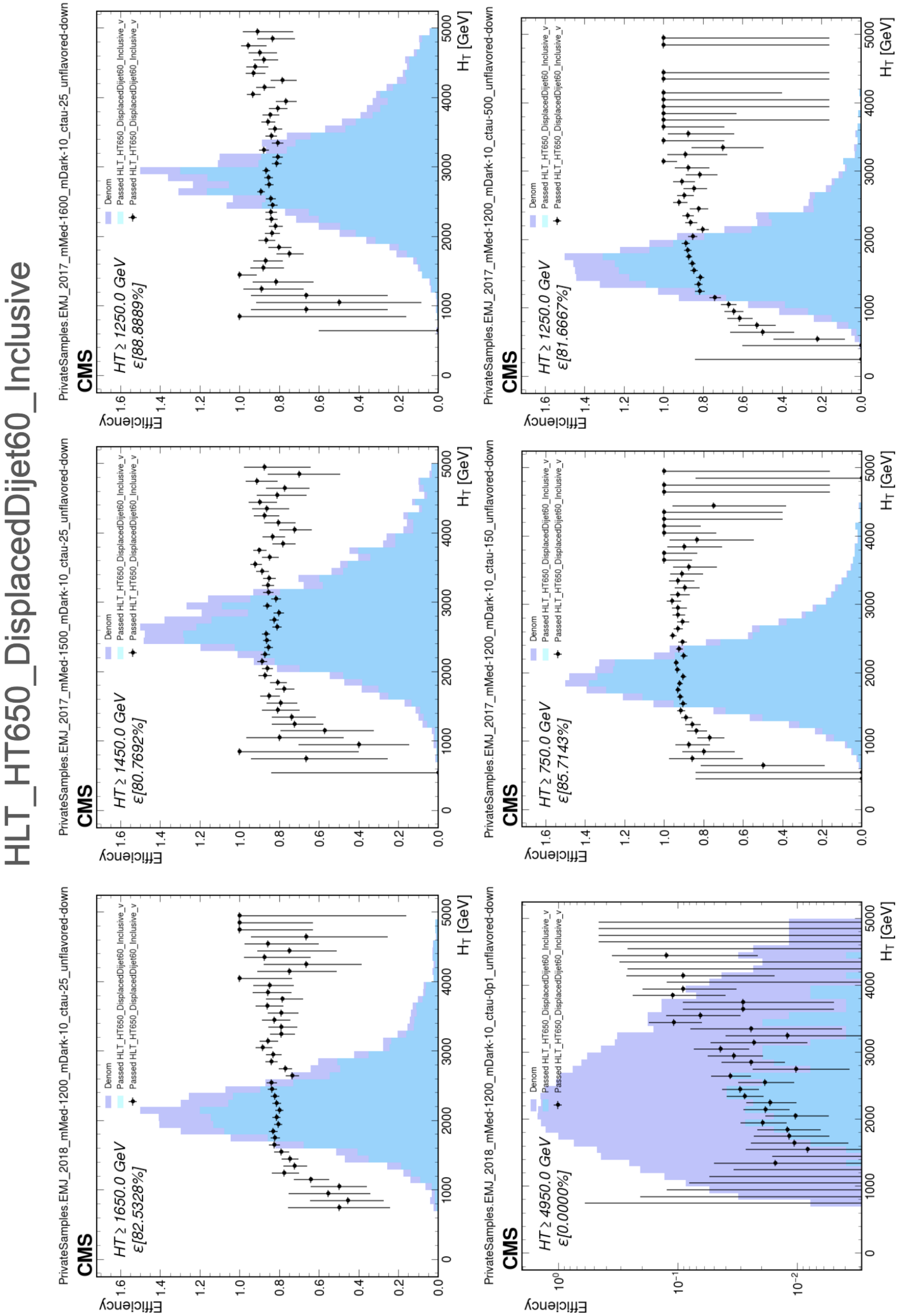

Figure 6: Efficiencies of the HLT_PFHT650_DisplacedDijet trigger