Triggers, Efficiencies and Scale Factors

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Abstract

This report presents the work done on the trigger efficiencies and finding the scale factor in the CMS experiment at CERN from July 3 to August 25, 2023. The trigger system is responsible for selecting the most interesting events from the trillions of collisions that occur every second at the LHC. The trigger efficiencies are the probability that an event that passes the trigger selection criteria is actually a signal event. The scale factor is a correction factor that is applied to the trigger efficiencies to account for the fact that not all signal events are selected by the trigger.The research was dependent on the CMS framework to run the data coming from the LHC through jets and graph them using ROOT fitting and Monte-Carlo methods to get the graphs of the variation of the efficiency as a function of the momentum.Finding the scale factor is very helpful and essential in the performance of the triggers by covering more and more desired data through correcting the efficiency.

1 Introduction

The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator. It is located at CERN, the European Organization for Nuclear Research, in Switzerland. The CMS experiment is one of the four major experiments at the LHC. It is designed to study the fundamental particles and forces of nature.

I was involved in the CMS experiment from July 3 to August 25, 2023. My work focused on developing and implementing new methods for calculating the trigger efficiencies and scale factor. The goal of this work was to improve the performance of the CMS trigger system.

I arrived at the CERN site on July 2, 2023. I spent the first few days familiarizing myself with the site,getting to know new people, and read more on the CMS experiment and the trigger system using articles and pdfs that my supervisor, Mohammad Mohammad Abdalla gave it to me as a first step.

As we delve into the subsequent sections of this report, we will detail the methodologies, analyses, and outcomes that shaped our investigation into trigger efficiencies and scale factors.

2 Initial Steps

At the beginning I started attending lectures that where scheduled everyday morning concerning theoratical and experimental physics, Hadron Colliders, astrophysics and more interesting topics about particle physics and what CERN is involved in. Not to forget also the lectures that were made by the OpenLab team concerning programming, GPUs, quantum computing and many other interesting topics.

On the other hand, I setted the linux up on my laptop and started familiarizing myself with the terminal bash codes and how to deal with the desktop using the command line, and that was very essential for me to get into the usage of the lxplus, the supercomputer of CERN in order to work with the events and the data I need for my project.

Also, not to forget mentioning the extraordinary visits for the CERN sites that where scheduled and prepared by the HR team, thanks to their efforts,that helped me explore more the insightful work of different experiments and labs inside CERN, and explore the fantastic tools that are used.

3 Exploring CMS Experiment: More Into Triggers.

In the realm of particle physics, trigger efficiencies stand as a critical aspect of the data acquisition process, wielding the power to determine the selection of events of interest of particle collisions. In experiments like the CMS, where the rate of collisions far exceeds the capacity to record them all, trigger systems play a pivotal role in capturing events with the highest scientific potential. Trigger efficiencies quantify the probability that a given physics event, characterized by specific criteria or kinematic properties, will be successfully identified and recorded by the trigger system.

A visit to the CMS site, the heaviest experiment in CERN,was conducted exploring the site and learn more about the experiment, how things work there and going 100 meters underground to reach a place very close to the LHC.

Besides, one of the tools that is very essential for the fitting and graphing the data is the ROOT graphic software, something very commonly used in CERN data analysis, so I had the previlage to attain a workshop on ROOT conducted by the OpenLab team that was very rich and helped me dig more into the beauty of this software and how to benefit from it in stuff concerning my project.

4 CMS Framework Setup

At this stage of the project, I should setup the CMS Framework for the further analysis. First it started by using my CERN account that was issued to me at my first days to access space on the CERN lxplus computer.

Then, inside my lxplus, I started setting up my framework by first installing the CMS release needed for the data run, which it was the CMSSW11-1-8. Inside this release I setted up the CMS environment and made the appropriate analyzer directory needed for the analysis.

Now, that the environment is ready, I imported all the data needed from my supervisor's computer and prepared them on my computer for the analysis and the results.

5 Data Generation

Data generation for finding the scale factor is dependent on two specific data ranges, the probe and the reference triggers. A reference trigger is a trigger that is used to measure the efficiency of another trigger. The reference trigger is typically a more inclusive trigger, meaning that it selects a wider range of events than the trigger whose efficiency is being measured. To find the efficiency of a

¿X — c — c Dataset	# of raw events	$\mathcal{L}_{int}$ (pb^{-1})
/L1MinimumBias1/Run2016B--PromptReco-v2/MINIAOD	45,239,175	0.041855118

Table 1: Summary of analyzed data samples, along with their number of raw events, and the corresponding integrated luminosity.

trigger, we can use the following equation:

efficiency $= \frac{N(trig+trigfired)}{N(trigfired)}$

The data set that was used for this experiment is indicated in the table above.The probe trigger is the trigger whose efficiency is being measured.

The number of events passing the probe trigger is found by counting the number of events that have both the probe trigger and the reference trigger fired. The number of events passing the reference trigger is found by counting the number of events that have only the reference trigger fired.

The efficiency of a trigger can be affected by a number of factors, including the momentum of the particles, the collision energy, and the pileup. Pileup is the number of additional collisions that occur in the same bunch crossing as the primary collision.

Each efficiency curve has been fitted with the function given below:

$$\epsilon_{trigger} \; = \; \frac{1}{2} \; [1 \; + \; Erf(\frac{p_T - p_0}{\sqrt{2}.p_1})] \tag{1}$$

With the aid of the CMS framework and after collecting the data of the 2016 collisions used in the CMS AN-19-068 study (shown in the table above), we compile these data using the cmsRun command to get a histogram for each set of data. We had 40 sets between 20 reference trigger events and 20 effecient trigger events, divided in each to four main categories according to the momentum values Pt=30,50,80 and 100 Gev, each value having 5 event sets.

We faced at first a huge problem concerning running the data on my lxplus because it wasn't working, had some fatal errors. So my supervisor contacted the sevice desk center to check on this error and they told us that their is some maintenance, so we solved that, not to loose more time, by running the data on my supervisor's computer.

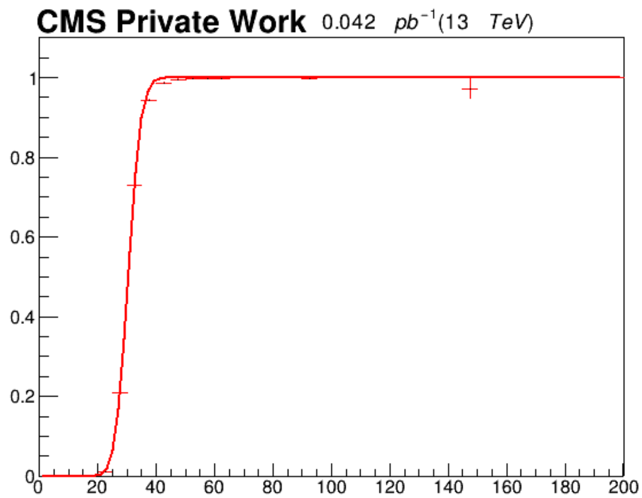

Figure 1: Efficiency as a function of momentum above 30Gev

6 Results and Analysis

Making a quick scan among the results above, we cannot but admit that it is very clear that first, for the smaller Gev,the 30 Gev in Figure 1 covers all the events above 40Gev in a very good accuracy (efficiency is equal to 1), and so on for the rest. Second, taking a lower Pt as a reference is very helpful to get the scale factor because it is already covering all the events of the probe trigger completely with efficiency=1. As an example, we can notice that for Figure 2, we can see that the efficiency between 40 and 60Gev is less than 1 till it reach the 1 at the 60Gev point. Here, this range is already covered by the less momentum trigger which is the 30, Figure 1, and so on. Using the following histograms, we can find the scale factor to correct the efficiency for each trigger for better future detection.
A trigger is considered to be fully effective when the efficiency becomes larger than 0.99.

For events where the leading jet p_T ranges from 35 to 43 GeV, trigger efficiency corrections need to be applied.

7 Conclusion

In conclusion, during my participation in the CMS experiment I have been focused on optimizing trigger efficiencies and scale factors. Through hands-on work, I've worked on the development of methods to enhance the CMS AK4

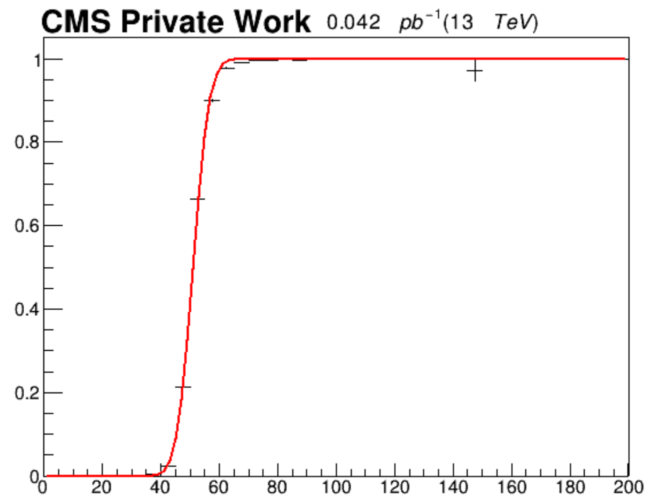

Figure 2: Efficiency as a function of momentum above 50Gev

trigger system's accuracy in selecting crucial physics events from collisions. This project's outcomes contribute to refining data acquisition, aiding the pursuit of fundamental particle research.

8 Acknowledgments

I would like to express my sincere gratitude to my supervisor, Dr Muhammad Muhammad Abdalla, for his guidance and support throughout this project. I would also like to thank the HR team, especially Ana Dordevic who guided me through the whole journey. I am grateful for the CERN organization who hosted me for this special experience. This work would not have been possible without the support of all of these individuals and organizations.

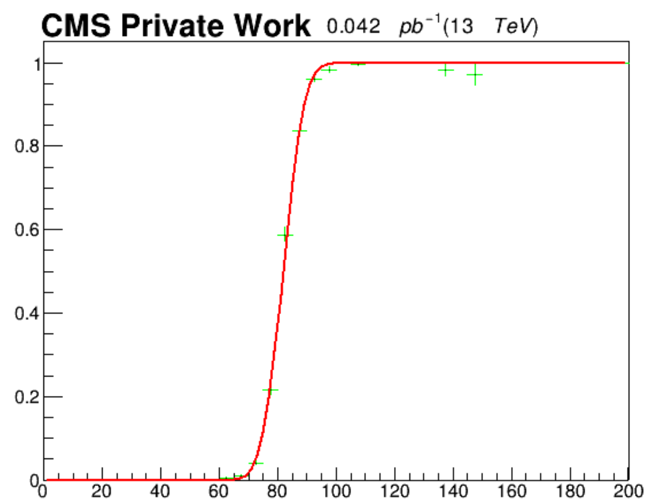

Figure 3: Efficiency as a function of momentum above 80Gev

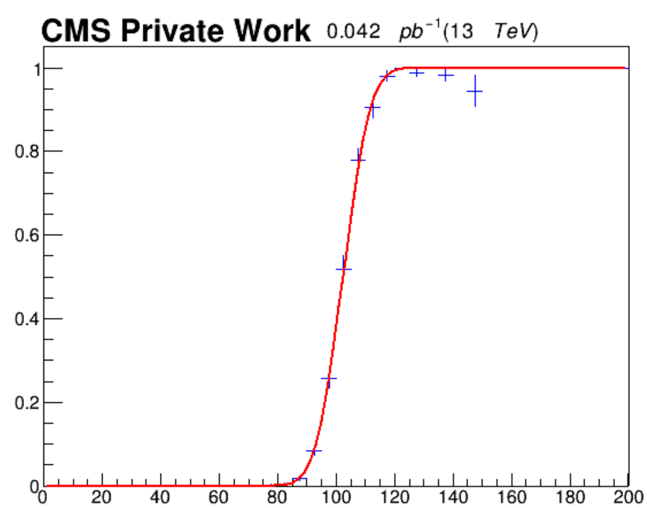

Figure 4: Efficiency as a function of momentum above 100Gev