An Analysis of Missing Transverse Momentum Triggers for Improving Efficiency at the ATLAS Experiment at CERN

by

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Abstract

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Chapter 1

Introduction

1.1 The Large Hadron Collider

The Large Hadron Collider is the most powerful particle accelerator in the world, located in CERN on the France-Swiss border. The circumference of the LHC is 27km, and is located 100m underground. The maximum energy possible to accelerate the particles to in the LHC is directly dependent on the size of the LHC and the strength of the magnets used to accelerate the particles. In order to achieve the design energy of 7 TeV per proton, it was necessary to have a circumference of 27km, and to use some of the most powerful dipoles and radiofrequency cavities in existence. Inside the pipes where the protons travel, a very strong vacuum is required, and so the pressure in some parts is over $10^{-9} Pa$. The beams are made up of cylinder-like bunches. Using these bunches, the expectde number of collisiosn is 10^{34} per cm^2 per second. The time between bunches is about $25ns$, so in the entire circumference of the LHC, there are about 3550 bunches.

1.2 ATLAS Experiment

ATLAS (A Toroidal LHC ApparatuS) is one of seven particle detector experiments constructed at the Large Hadron Collider, a particle accelerator at CERN. When the LHC runs at full energy and intensity, about 600 million proton-proton collisions take place every second inside the ATLAS detector. The amount of data collected for each event is around 1MB, which means that there is approximately:

$$10^9 Hz(1Mb) = 1Pb/s$$

of data produced. Because this is significantly larger than any practical system can handle, there are **triggers** that are designed to reject uninteresting events and keep the interesting ones. For ATLAS, the trigger system is deisgned to collect about 200 events epr second. This means that ATLAS collects about 4 petabytes of data per year. There are 10^{11} protons in a bunch. The proton-proton interaction cross section is approximately $100mB$.

1.3 Efficiency Curves

An efficiency curve illustrates the probability of a given test algorithm to classify an event as above or below a certain threshold as a function of some given true determination of the MET. So we can ask, what is the efficiency of L1 $>$ 30 as a function of CELL MET. What this is means is we are taking the MET as determined by CELL to be the true MET, and we want to know how well L1 does at classifying events as having MET above or below 30 at each value of the MET determine by CELL. The way one would read a plot of this efficiency is to pick a value of CELL MET (on the x-axis) and ask "when CELL determined events had this MET, how often did L1 determine the MET of those same events was greater than the threshold [30 GeV]". The fraction [of the total amount of events CELL determined was in that MET bin] that L1 determined was greater than the threshold would be the height of the efficiency curve at that value of CELL MET. A perfect efficiency curve would look like a step function centered at the threshold around which one is trying to classify the MET of events. The fact that efficiency curves in reality do not look like step functions can be understood in terms of Type I and Type II error. The step function for the efficiency curve would be centered on the threshold one is asking for the efficiency about. The fact that the efficiency curve immediately to the left of the threshold is not zero means that there were events that CELL said had an MET lower than the threshold, but L1 said those same events were higher than the threshold. The fact that the efficiency curve, immediately to the right of the threshold is not one means that there were events that CELL said had a higher MET than the threshold, but L1 said those same events were lower than the threshold. In this case, the fraction of events L1 determined had an MET higher than the threshold, given that CELL said the MET was higher than the threshold, is less than one.

1.4 Trigger System

In particle physics, a trigger is a system that uses simple criteria to rapidly decide which events in a particle detector to keep when only a small fraction of the total can be recorded. The trigger system is necessary because of limitations in terms of data storage capacity and rates. In general, the experiments typically search for "interesting" events (decays of rare particles) that occur at relatively low rates, so we need to have trigger systems that identify events that should be recorded for later analysis. The Large Hadron Collider has an event rate of approximately 1 GHz. The triggers are divided into levels so that each level selects the data that becomes an input for the next level, which has more time available and more information to make better decisions. There is the **Level-1 (L1)** system, which is based on custom eletronics, and the **High Level Trigger (HLT)** system, that relies on commercial processors. The L1 system uses only coarsely segmented data from the calorimeter and muon detectors, while holding all the high-resolution data in pipeline memories in the electronics.

1.5 Missing Transverse Momentum

1.6 Bisection

In this assignment, we wanted to see if we could obtain an increase in efficiency by combined some uncorrelated algorithms together, subject to the constraint of the trigger rate. The way I did this was to try all combinations of algorithms, impose the constraint that the algorithms keep the same fraction individually, and then I performed bisection along that line in parameter space to find the value closest to the trigger rate. There are two level curves of interest in this project. The first one is what I call the production possibility frontier, to borrow a term from economics. This curve represents the solution space to the set of pairs of thresholds one could use for the pair of algorithms that satisfies the constraint of the trigger rate. The second curve that is illustrating to look at is the curve showing the pairs of points on the curve where we constrain the two algorithms to individually keep the same fraction (the line $y = x$ in the parameter space). We want to find the pair of thresholds for the algorithms that when we use both of the algorithms, such that they individually keep the same fraction of events, keep the trigger rate [fraction of events]. The level curve describing the set of pairs of thresholds such that the trigger rate constraint is satisfied is given by the constraint:

$$f(\tau_\alpha, \tau_\beta) = C$$

for some C. Here, f is the function representing the fraction of events kept when the algorithms are used together at the same time. We expect f to be a monotonic decreasing function in the thresholds, as increasing the threshold would cause fewer events to be kept by the algorithm. In order to compute C, we used the fraction of passnoalg data that passed an L1 MET cut of 50 GeV and a CELL MET cut of 100 GeV. For our analysis, C turned out to be 0.0059. So we needed to solve the equation $f(\tau_\alpha, \tau_\beta) = 0.0059$. However, because the parameter space is two-dimensional, and the evaluation of f takes a long time (fraction of events kept by both algorithms, and by each one individually), we introduced the constraint that the two individual fractions kept needed to be the same. This turned our problem into a one dimensional one, as we were solving for the intersection of the production possibilities frontier curve and the constraint curve on the individual fractions. Then, we were able to solve this one dimensional problem by using the root-finding bisection algorithm on each of the pairs of high level trigger algorithms.

1.6.1 Transverse Mass Cut

In addition to the cuts on the various algorithms, we also needed to introduce a cut on the transverse mass that is detected to ensure we only keep events with a transverse mass close to that of the W boson ($80.379 \pm 0.012 GeV/c^2$). We compute the transverse mass using:

$$m_T = \sqrt{2P_\mu P_\nu(1 + \cos(\phi))}$$

In addition to the aforementioned cuts, we also added a cut on this quantity for the range $40 \leq m_T \leq 100$.

1.7 Results

We found that we were able to achieve an increase in the overall efficiency for some of the pairs of algorithms considered.

1.8 Reconstructing the MET Distribution

Our goal is to empirically reconstruct the unbiased MET distribution using ZeroBias HLT noalg L1XE30 and HLT noalg L1XE50 data. We want to use this data to determine the CELL MET distribution as a function of μ. Because the zerobias events only allow us to go up to about 80 GeV, we use the `HLTnoalg_L1XExx` triggered events in order to extend to higher MET. We correct the `HLTnoalg_L1XExx` data using the efficiency curves determined from lower threshold triggers. In addition to performing this correction, we needed to propagate the errors properly on the corrected distribution because it depends on the fit functions to the efficiency in which the fitting parameters have some uncertainty. In order to do the reconstruction, we needed to perform several steps:

1. compute the efficiency of $L1 > 30$GeV for `HLT_ZB_L1ZB` data as a function of CELL MET

2. correct the `HLT_ZB_L1XE30` data back to the `HLT_ZB_L1ZB` distribution by multiplying by the prescale and dividing by the efficiency.

3. compute the efficiency of $L1 > 50GeV$ for `HLT_ZB_L1XE30` data as a function of CELL MET

4. correct the `HLT_ZB_L1XE50` data back to the `HLT_ZB_L1ZB` distribution by multiplying by the corresponding prescale, and dividing by both of the previously computed efficiencies.

For this project, we used the 2015, 2016 and 2017 combined `HLTnoalg_L1Z` , `HLTnoalg_L1XE30` and `HLTnoalg_L1XE50` data produced by Jonathan Burr on 11/17/2017 from the zerobias and JETM10 trees. In addition, we removed the events from runs 330203, 331975 and 334487 because these events had large MET events without jets and the logbook says there were calorimeter noise problems in these runs.

Appendix A

Code