Evaluation of Trigger Efficiency of the ALICE FIT Detector using PYTHIA

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Abstract

The Fast Interaction Trigger detector is a trigger detector that informs which events are recorded by A Large Ion collider Experiment at the Large Hadron Collider. In the present study, we evaluate the geometric trigger efficiency of FIT. We do so via simulations of collision events, using PYTHIA 8.2 along with a filtering algorithm, which determines which products of collisions are within the regions covered by FIT. We control different acceptance conditions and calculate the efficiency accordingly. We find that the efficiency decreases at low multiplicity, high particle threshold, and conditions where both sides of FIT are hit by particles.

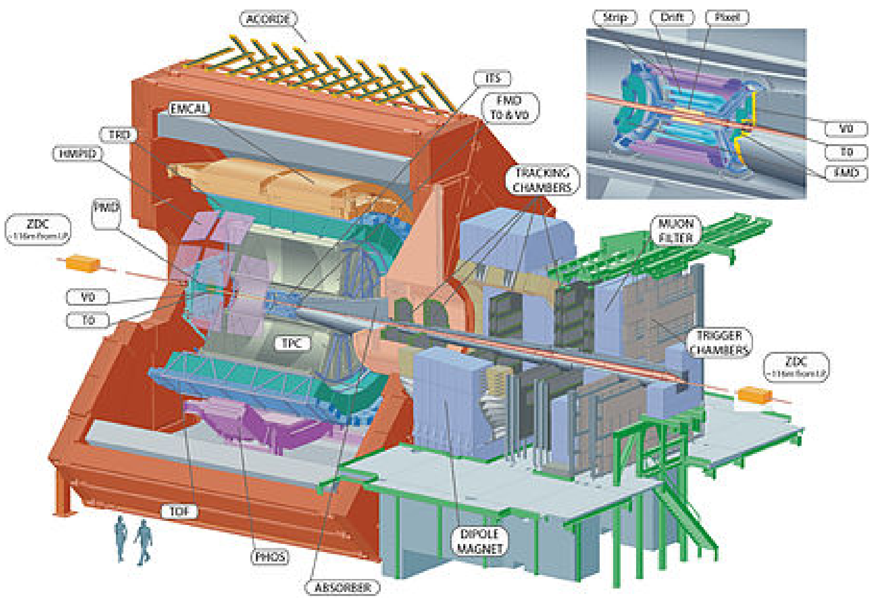


Figure 1: Schematic of the LHC Run I ALICE detector, including T0.[1]

1 Introduction

1.1 Experimental Setup

A Large Ion Collider Experiment (ALICE) at CERN's Large Hadron Collider is a composite of detector systems whose aim is to study strong nuclear interactions governed by Quantum Chromodynamics (QCD) (See Figure 1. The detector is designed for very high energy particle collisions, as well as the resultant interactions and byproducts. Such collisions include proton-proton or Pb-Pb beams. The collisions produce a quark-gluon plasma (QGP), a state of matter of very high energy and density, which ALICE probes by measuring multiplicities, energies, and trajectories of particles exiting the quark-gluon plasma. [1]

The latest upgrade to the LHC will allow for the collision of beams with rates as high as 2 MHz. This will require a trigger detector with very good time resolution to inform when ALICE should be detecting collision

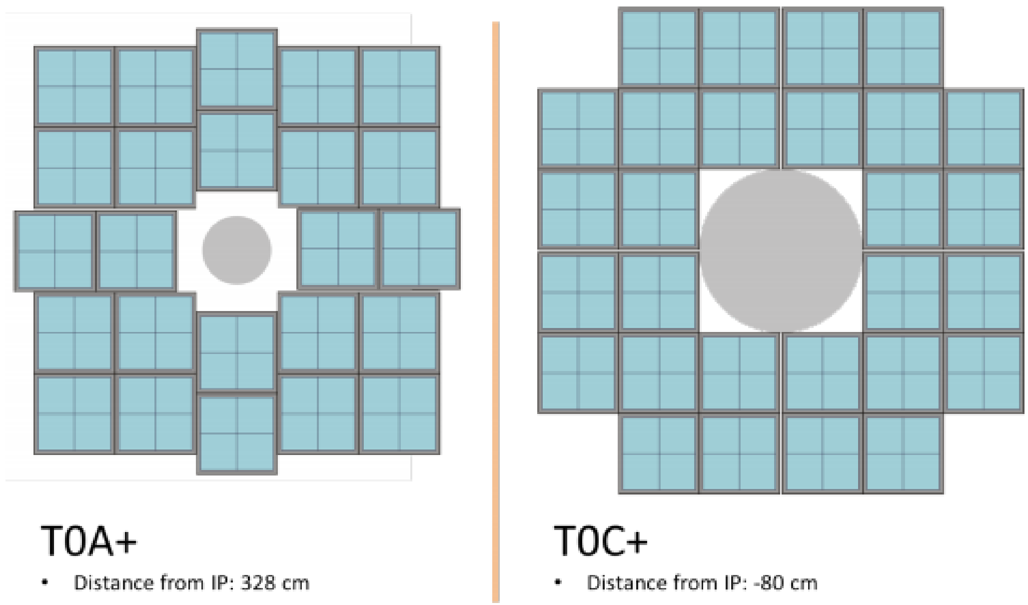


Figure 2: Composition of A-side and C-side detectors

products. The detector must also be able to reject background events and noise. The Fast Interaction Trigger detector (FIT) is the one responsible for these tasks. [2]

FIT comprises a set of fast detectors situated on either side of the collision location, called A-side and C-side detectors, respectively. One of the components of FIT is the T0+ detector, whose role is to determine the start time ("T0") of a collision for measuring times of flight for products of collisions. The A-side detector (T0A+) is located 328cm away from the collision location, while C-side (T0C+) is 80cm away. The detectors are composed of 24 modules (A-side) and 28 modules (C-side), each 6cm in length and width, and 4cm in depth. These modules are Cherenkov arrays of quartz scintillators connected to photomultiplier tubes. See Figure 2 for the geometric build of the FIT detectors. [2]

1.2 Background

Quantum Chromodynamics (QCD) is the study of the strong nuclear force, and which governs the interactions involving quarks and gluons. The strong nuclear force is the force that binds quarks to form baryons and mesons. QCD states that the strong nuclear force becomes weaker as the distance between quarks and gluons decreases—contrary to gravitation and electromagnetism. This means that at sufficiently high energy and density, the strong force becomes weak enough for quarks and gluons to dissociate, and form a state of matter called the quark-gluon plasma (QGP). [3]

The QGP, in the early stages of its formation, produces photons and leptons that can be detected, and which carry information about the QGP. In the later stages, when the high temperature has subsided, the distances between the quarks and the gluons increases, and the force between them becomes strong again such that they recombine to form hadrons. Those hadrons have momenta that range from a few hundred MeV/c to hundreds of GeV/c, with the bulk of particles having energy on the order of 1 GeV, and are what FIT detects. [3]

1.3 Motivation and Expectations

The aim of the present study is to simulate the production of particles produced by collision events, and examine the multiplicities of generated particles compared to those detected by FIT. We use the PYTHIA software package [4] to generate collision events and the resultant particles, supplemented by code that filters the particles that are within the regions of the detectors. This allows us to evaluate the efficiency of FIT at varying multiplicities and for different thresholds of particles accepted by the detector. Additionally, results of this study may be used in later work to determine a cutoff threshold for accepted event detection. They may also be used to estimate a correction factor for low-multiplicity events to allow for reliable statistical analysis.

The variables in our simulations are two. One is the number of particles detected for an event to be accepted. The other condition is whether accepting an event occurs when a subset of collision products hits one detector (A-side OR C-side), or both detectors (A-side AND C-side). We expect the efficiency of FIT to increase with event multiplicity because, as the number of particles in an event increases, the probability of one of them being detected increases as well. We also expect the efficiency to be higher for lower particle thresholds, meaning the probability of, say, at least one particle hitting the detector is larger than the probability of at least two particles hitting the detector. Lastly we expect the OR configuration to accept more events, and show higher efficiency, compared to the AND configuration.

2 Methods

The main piece of software we use is PYTHIA 8.2, which is a commonly used program that simulates the production and evolution of jets of particles that are byproducts of hadron collisions[4]. It does so using a set of physical laws derived from both theoretical and experimental models. The outputs of PYTHIA include the final product particles that do not interact further, as well as their energies and trajectories. The trajectories are given by polar angle, pseudorapidity, and transverse momentum (ϕ, η, p_T).

For our purposes, we use PYTHIA 8.2 to generate 1000 p-p collision events along with their final products. The energy of these protons is set to 7 TeV per beam or 14 TeV in the center of mass. We also configure PYTHIA to allow for both hard and soft QCD interactions to occur. We then use the straight-line trajectory information to calculate the (x, y) coordinates of each particle as they arrive at the location of the T0+ detectors on the C and A side, $z = 0.8$m or $z = 3.20$m, respectively. This is done using the values of ϕ and η, the latter being given by

$$\eta \equiv -\ln\left(\tan\left(\frac{\theta}{2}\right)\right).$$

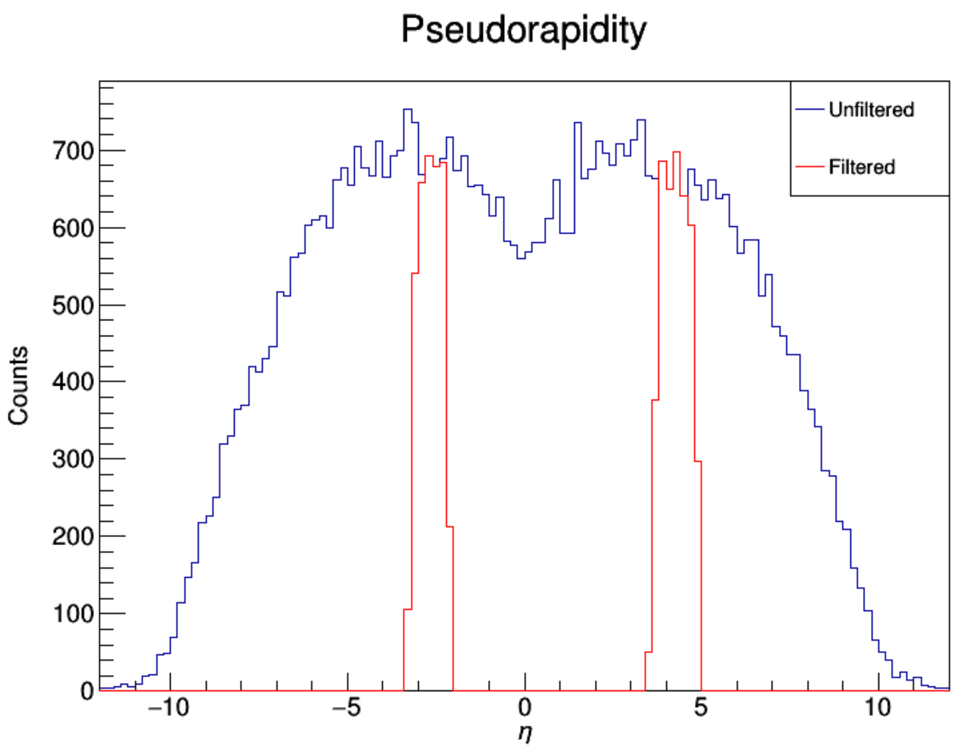


Figure 3: Pseudorapidity of filtered and unfiltered particles.

This means the coordinates for each particle can be found using

$$x_i = z_i \cos(\phi)\,\text{csch}(\eta), \text{ and}$$
$$y_i = z_i \sin(\phi)\,\text{csch}(\eta),$$

where i is A or C for the detectors on each side. After calculating the (x, y) coordinates at the desired z, we can filter the particles that hit the detector from those that don't. This filtering is what we use to determine the efficiency of FIT.

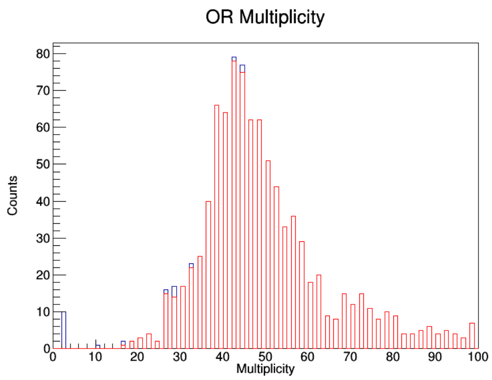
3 Results and Discussion

One of the observables in these simulations is the pseudorapidity defined above. Figure 3 is a histogram of the pseudorapidity for all particles generated in every event in blue. In red, are the particles accepted by the filtering function. The figure shows that the accepted particles fall within two narrow regions, which correspond to the locations of the A-side and C-side detectors, whose pseudorapidity regions are $2.2 < \eta < 5.0$ and $-3.4 < \eta < -2.3$ respectively. This verifies that the filtering of our code works as desired, and is indicative of the reliability of our results.

The counts of these particles allow us to evaluate the effect of filtering as a function of multiplicity for each event. We also compare how detection changes based on the detection condition used, namely whether we require that particles hit one detector or the other, or that they hit both detectors. Another condition we consider is how many particles are required to consider an event as detected. Figure 4 shows a side-by-side comparison for the OR and AND conditions for six thresholds. Each plot shows the total events generated by PYTHIA (in blue) along with those that we considered detected (in red). One expects fewer events to be detected with the AND condition than with the OR condition. We also expect the detection rate to fall with higher particle detection thresholds. Figure 4 shows that indeed fewer events are detected for the AND condition, and for higher thresholds (number of particles hitting the detector(s)).

By taking the ratio of the detected events to all events, we obtain the efficiency of FIT as a function of event multiplicity considering, again, the detection conditions discussed above. The findings, shown in Figure 5 confirm those from Figure 4. An event with high multiplicity is more likely to be detected, more so by lowering the particle threshold, more so when using OR than AND.

To show this more clearly, we fix the multiplicity at 40 particles per event, and we plot, in Figure 6, efficiency against threshold. We can clearly see the efficiency is higher for OR than AND for all thresholds. We also see that the efficiency drops as a function of threshold, more rapidly for AND.



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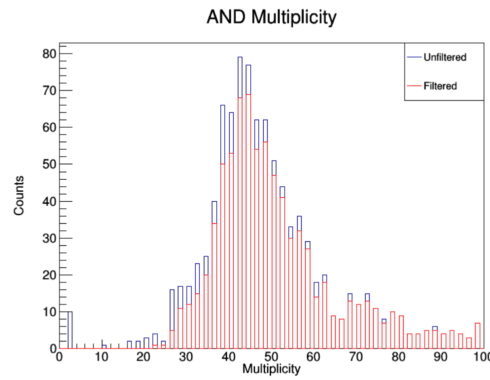

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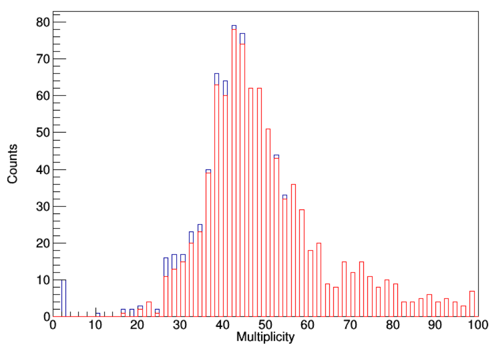

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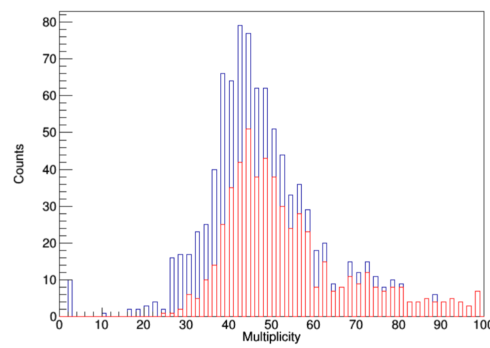

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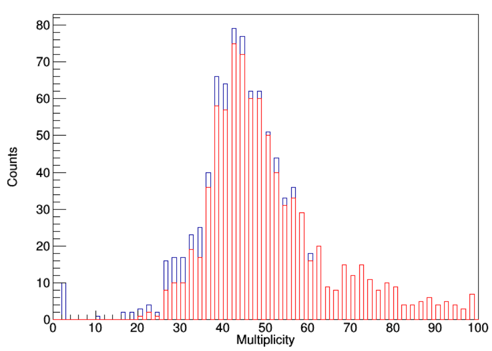

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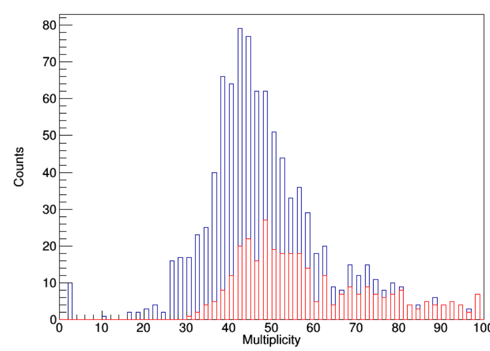

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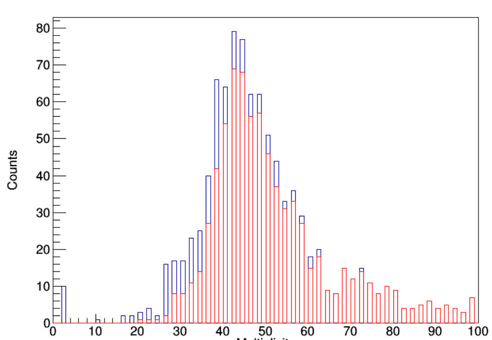

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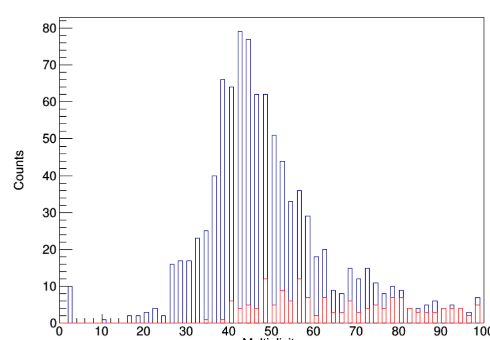

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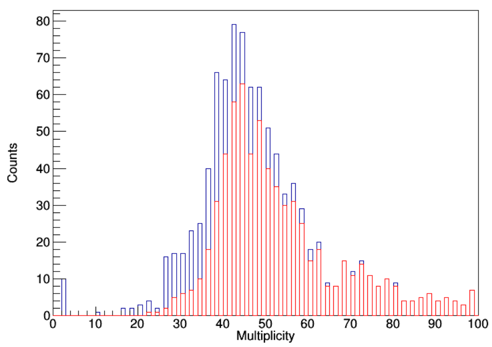

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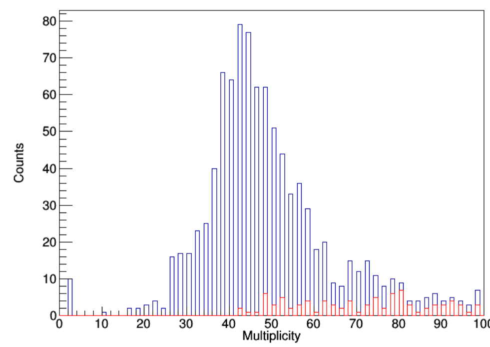

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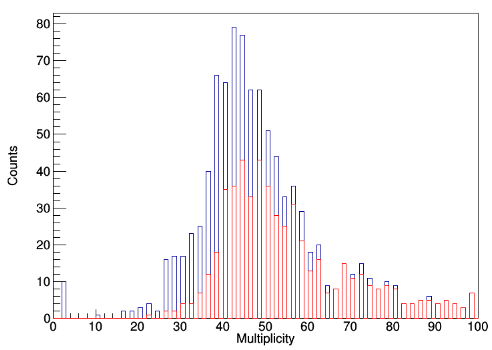

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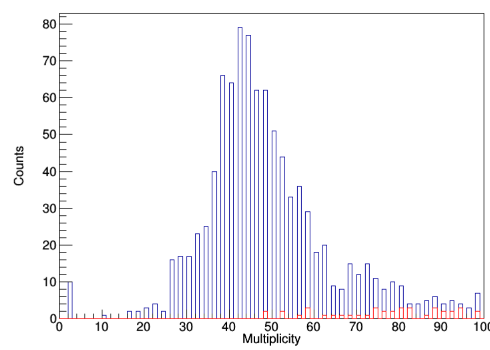
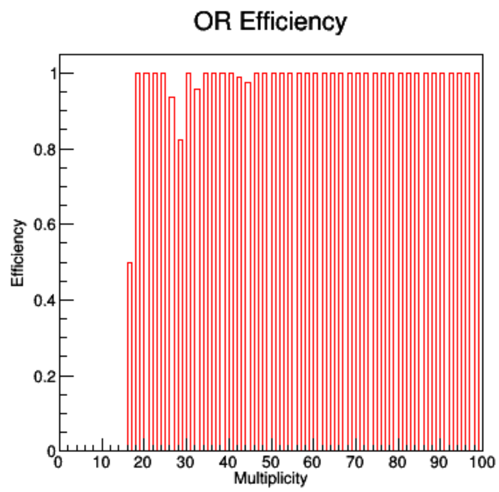


(l) $N > 5$

Figure 4: Multiplicity at varying detection thresholds for OR and AND filtering.



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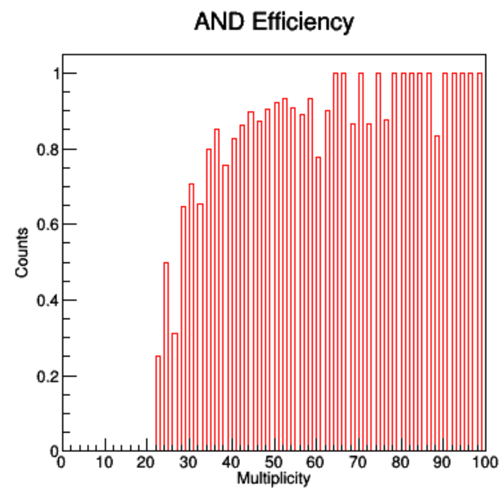

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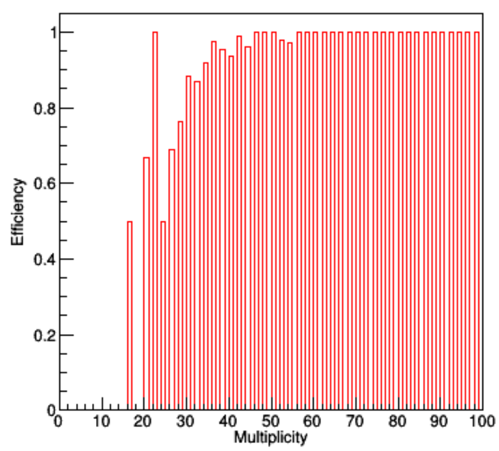

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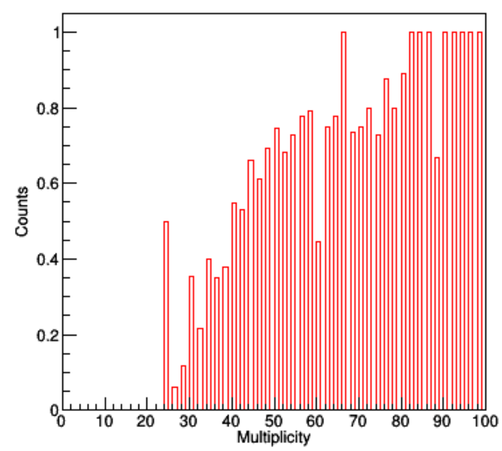

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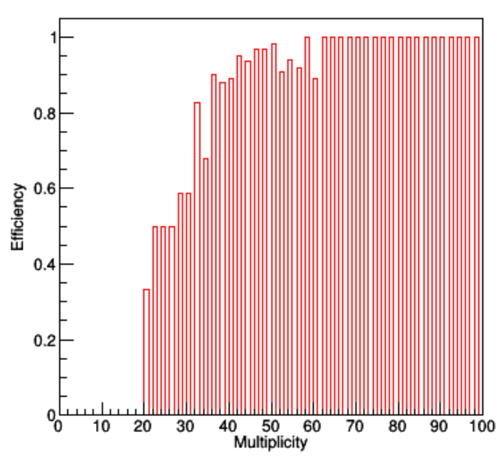

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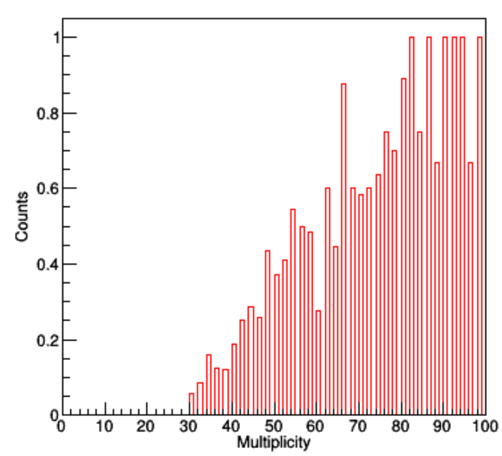

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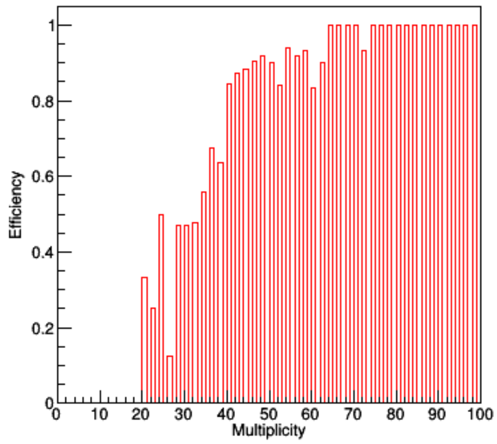

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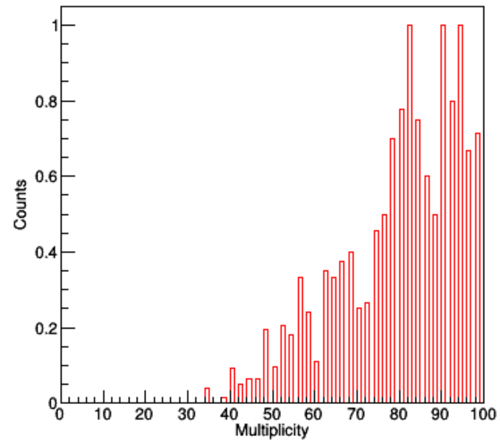

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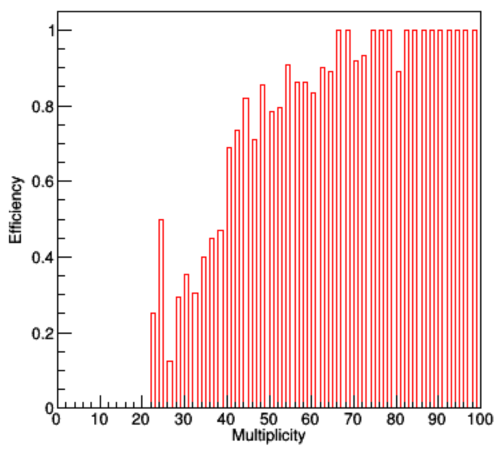

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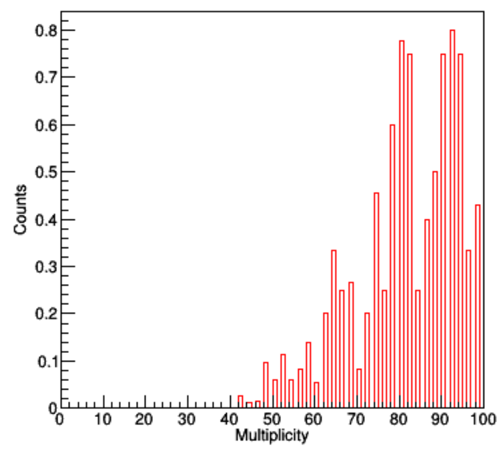

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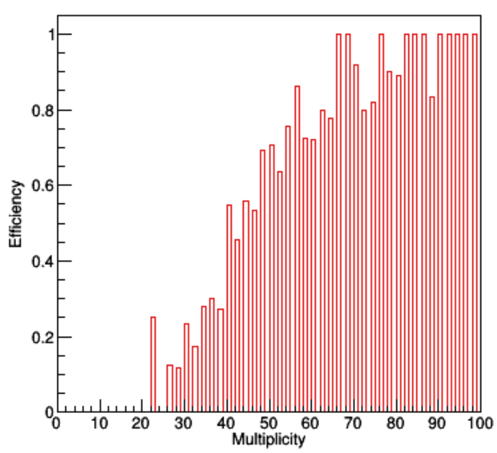

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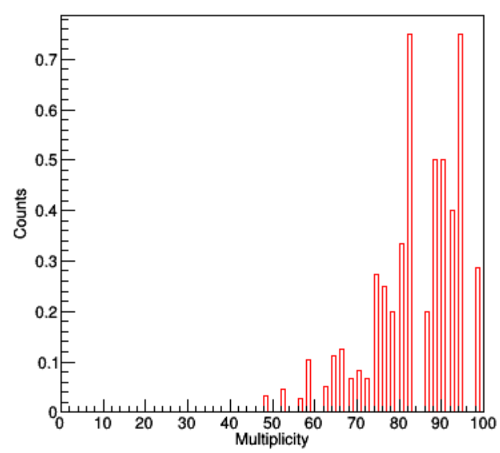

(l) $N > 5$

Figure 5: Efficiency at varying thresholds for OR and AND filtering.

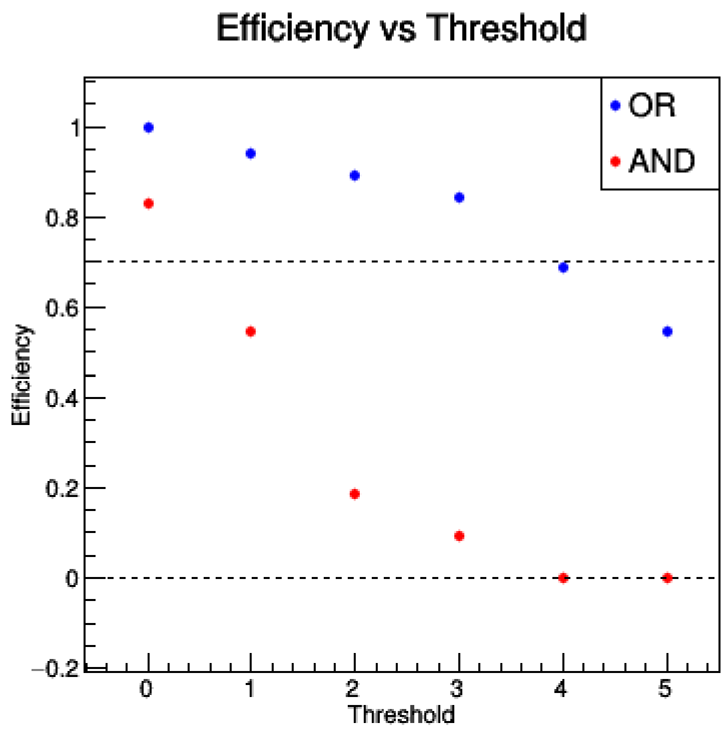

Figure 6: OR and AND efficiencies at multiplicity of 40 for all thresholds (number of particles detected).

This result may serve as a means to estimate a correction factor for studying events with low multiplicities. This may be done by calculating the efficiency at one multiplicity, knowing how many events were detected, then integrating over all multiplicities to arrive at some conclusion for all events, including those undetected.

4 Summary and Conclusion

This study examined the trigger efficiency of ALICE's FIT detector using PYTHIA 8.2 simulations, providing information about the geometric acceptance of FIT. This analysis may be used to develop correction methods for low multiplicity events to allow for obtaining more information about such events, and to contribute in the understanding of QGP.

Further work which allows for more detailed analysis may also contribute to the study of QGP. For example, future work could take into account the influence of the ALICE solenoidal magnetic field on the trajectories of produced particles. These magnetic fields alter the trajectories of charged, detectable particles, and thus, will affect the geometric acceptance of FIT. In this work, we examined AND conditions for equal number of particles detected by A-side and C-side. Further work can be done with different thresholds for each side. Additionally, to increase the statistical reliability of our results, the simulations may be run for a larger number of events. The same analysis can be applied to different PYTHIA configurations than those specified in the Methods section, such as different QCD processes as well as collisions other than p-p using other Monte Carlo event generators.

The hope of this work is to better understand the properties of QGP, which allows us to probe physics in the very high energy realm, as well as the early stages of the newborn universe.

References

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