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Identification of Charged Particles Produced in Au+Au Collisions in STAR Experiment Based on Energy Loss and Passing Time Information

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Abstract

Identification of particles is one of the most important techniques needed in particle and high energy physics. However, hardware systems can not identify the type of particle in a direct way. The Time Projection Chamber (TPC) and Time of Flight (TOF) detectors at the STAR experiment in Relativistic Heavy Ion Collider (RHIC) are facilitated to study and detect the type of produced particles in heavy ion collisions. For that, energy loss and time of flight measurements present promising ways to identify particles precisely. In this project, analysis was made for Au+Au collisions at STAR with a center-of-mass energy of 19.6 GeV per nucleon. We found after performing the event cutting process that pion particles took place in the analyzed events. The particle type could be identified by using theoretical models depending on equations such as Bethe-Bloch and comparing it with the experimental results which we had obtained from the detector after performing analysis of data.

Acknowledgment

It is a pleasure to work with Dr. Alexey Aparin -my school supervisor, who helped me a lot during the period of this winter school, and it is also wonderful to work on a topic related to the STAR experiment, which I am interested to have some future work with its data. Many thanks to Mr. Alisher Aitbayev who provided me with some literature for this project. I would like to express my gratitude to the Egyptian scientific committee, our supervisors Prof. Walaa Seif and Prof. Medhat Ibrahim, and the Academy of Scientific Research and Technology for giving me the support and opportunity to come here and work with new teams. Last but not least, the JINR always gives chances to young researchers all over the world, such as online programmes, schools, and internships. That reflects the scientific goals and responsibility, in addition to the facilities which have been provided to serve the science. I thank all of the people working at JINR for their coop, generous and tremendous helpful assistance.

1 Introduction

The beginning of the universe still has an attraction to physicists; that is; in order to understand how the universe began and who matter formed after the Big Bang. The solution for that is to reproduce a similar process to that which leads to the formation of all the matter around us. This work is carried out in many places on Earth, such as the Relativistic Heavy Ion Collider (RHIC), with a maximum center of mass energy $\sqrt{SNN} =$ 200 GeV per nucleon in Brookhaven lab at the USA and the European Organization for Nuclear Research (CERN).

1.1 STAR Detector

The STAR [1] experiment is the Solenoidal Tracker at RHIC. The main purpose of STAR is to simulate the beginning of the universe after 10^{-6} sec. from the Big Bang [2]. This could be possible through creating a similar medium by colliding heavy ions; to study the Quark Gluon Plasma (QGP) phase of matter and to understand how hadrons interact in higher, dense energy [1, 3, 4, 2]. Due to heavy-ion collisions, the hadrons undergoes a melting process at this extreme temperature and we then have medium which contains quarks and gluons similar to a sea of particles [3].
The following pictorial [5] in Figure 1 shows STAR Detector construction.

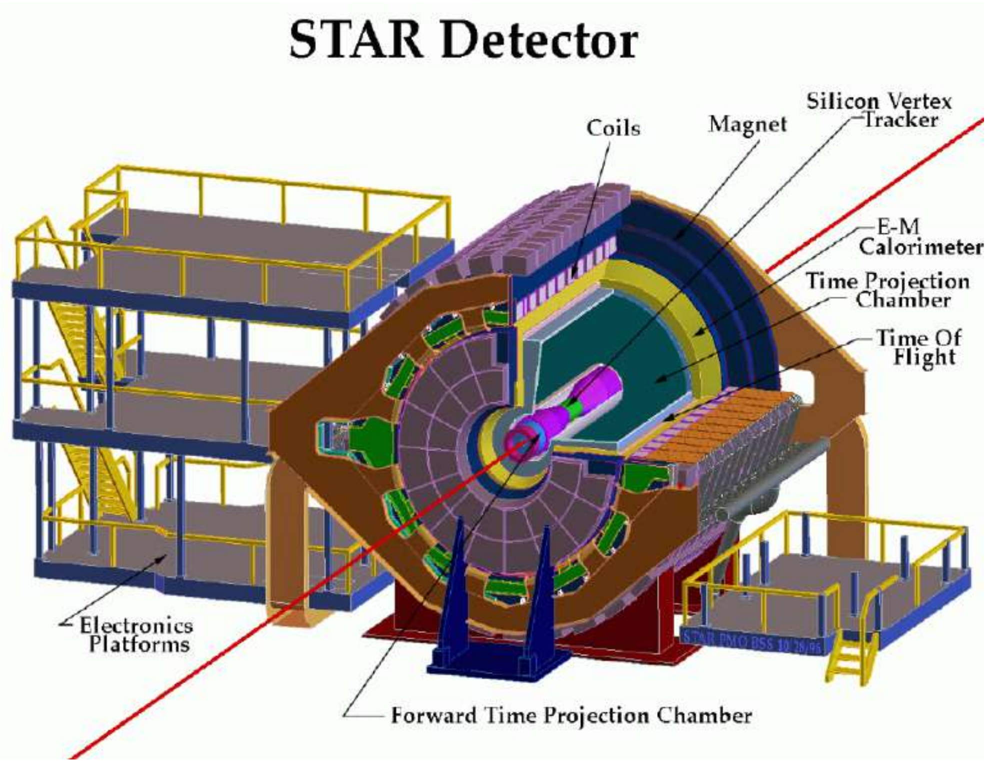


Figure 1: STAR Detector Facility

An overview of STAR is presented in [1], follow several articles about the other components:

- STAR Time Projection Chamber [6, 7].
- STAR Time of Flight System [4]
- Forward Time Projection Chamber in STAR [8].
- STAR Detector Magnet Subsystem (Coils) [9] .
- STAR Silicon Vertex Tracker [10].
- STAR Barrel and Endcap Electromagnetic Calorimeter found in [11] and [12].

1.2 Au+Au Collision at STAR

The ultra-relativistic collision of gold ions at RHIC is mainly used for particle identification studies. This may be a center of mass energy of 62.4 GeV, 130 GeV, and 200 GeV. Charmed lambda Λ_c, the most light charmed baryon is studied at $\sqrt{SNN}$=200 GeV and centrality of 10-60% [13]. Another study was made of the production of positive charmed baryon Λ_c, which was measured for the first time and charmed meson D^+ at $\sqrt{SNN}$=200 GeV in range of rapidity y lower than 1 [14]. The same center of mass energy, $\sum$ strange baryon resonance is studied [15].

1.3 Particle Identification in STAR

Identification of particles is a technique used to know the type of particle and its properties, as hardware can not directly help us to know information about particles that hit the detector. Hence, the detectors help in event reconstruction and measuring the energy of the particles, which varies as much as the particle moves. However, the type of particles (i.e. heavy, light, charged, neutral,..) expected to be produced in such an event or even from radiation sources need specific detectors which vary in design. For this reason, there are different detectors established to study specific types of collisions, such as STAR, PHENIX, PHOBOS and BRAHMS, and ALICE, ATLAS, CMS and LHcb in CERN. In the STAR experiment, the time projection chamber and time of flight detectors are used for detection of charged particles, whereas particles such as neutrons and photons are detected through the calorimeters [16].

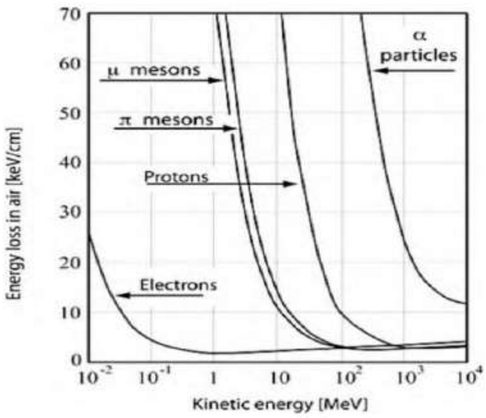
1.3.1 Identification of Charged Particles

The interaction of charged particles with the detectors yields an energy loss, which is well studied by Bethe-Bloch equation [17, 18]:

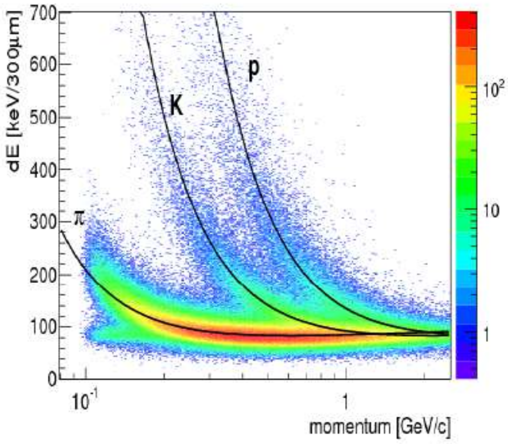
$$\frac{dE}{dx} = \rho \frac{Z_n}{A_r} \frac{Z^2}{\beta^2} [\frac{1}{2} \ln[\frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2}] - \beta^2 - \frac{\delta(B)}{2}] \tag{1}$$

This equation presents a description of the energy loss as a function of kinetic energy of the particle, which leads to an easy identification of the charged particle type, as illustrated in

Figure 2a [17] , which shows how energy of some charged particles vary in air depending on measuring their kinetic energy. Figure 2b presents the behavior of energy variation as a function of particle's momentum for proton, pion and kaon [19, 20].



(a) Energy Variation in Air of μ, α, π, e^{-} and p^{+} with kinetic Energy

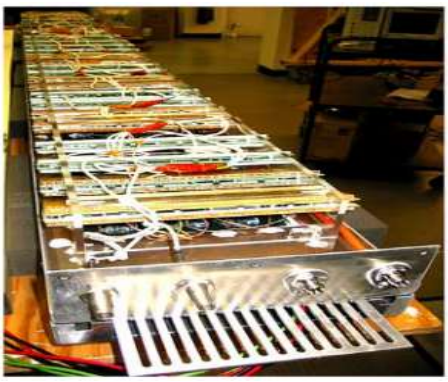


(b) Variation of Energy with Momentum of π, k and p^{+} with Momentum

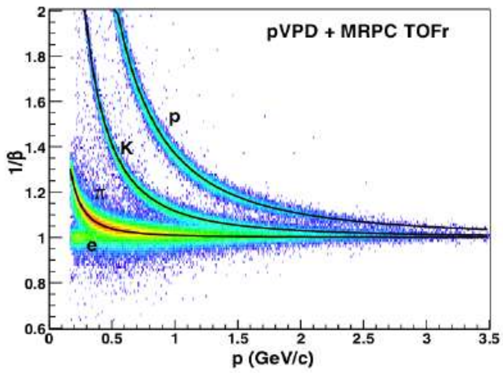
Figure 2: Identification of Charged Particles Due to the Energy Variation

1.3.2 Time of Flight (TOF)

The time of flight detector at STAR depends on measuring the velocity of particles. It has the ability to detect pions, kaons and protons in a time range of $10^{-}12$ and identify particles directly in the transverse momentum range 1.7-3.1 GeV/c [21].



(a) TOF After upgrading

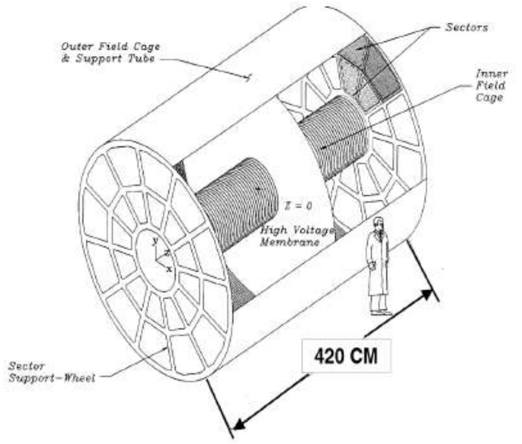


(b) Variation of Beta Factor inverse with Momentum of π, k and p^{+} with Momentum

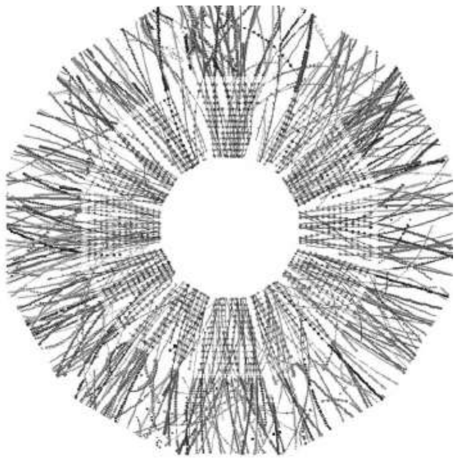
Figure 3: Time of Flight Detector and its Upgrading

1.3.3 Time Projection Chamber (TPC)

The time projection chamber [7, 21], with a length of 420 cm and a radius of 200 cm, is shown in Figure 4a is used for identification of hadrons such as π^+, K^+, proton and their anti particles. It is considered as the essential tracking facility at STAR and provides us with data about the transverse momentum of resulting particles reaching $P_T = 1.1$ GeV/c. The energy loss as a function of the distance which the particles take in the material dE/dx is the technique used in TPC to detect the type of particle [22]. The value of dE/dx is determined by the Truncated Mean method [22, 23]. The range of pseudo-rapidity ranges from -1.8 to +1.8. The TPC triggering system consists of a plastic scintillator array surrounding the whole of the TPC, in addition to two calorimeters at a temperature of 0 ℃, the drift gas is composed of 90% Argon and 10% Methane and the magnetic field is 0.5 Tesla. These, besides the software analysis, help us to reconstruct a whole picture, such as in Figure 4b about what events look like inside the detector [7].



(a) Time Projection Chamber at STAR



(b) After Cutting

Figure 4: Time Projection Chamber (TPC)

1.3.4 Barrel and Endcap Electromagnetic Calorimeters

The Barrel electromagnetic calorimeter measures particles at rapidity range up to 1. It contains 120 calorimeters and facilitated for detection of photo-electrons [11]. The endcap electromagentic calorimeter provides a detection fo electrons, muons and photons resulting from the collisions at STAR in pesudorapidity range of $\eta = 1.08$ to 2.00 [12].

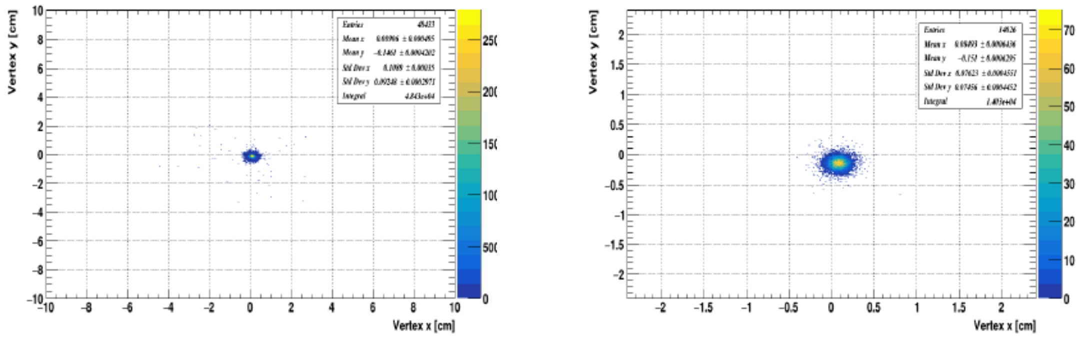
2 Experimental Analysis

2.1 Events Cutting

After a collision of heavy ions or particles takes place, we store the data to be analyzed afterwards. Event cuts are applied to obtain the best data from the detectors [7].

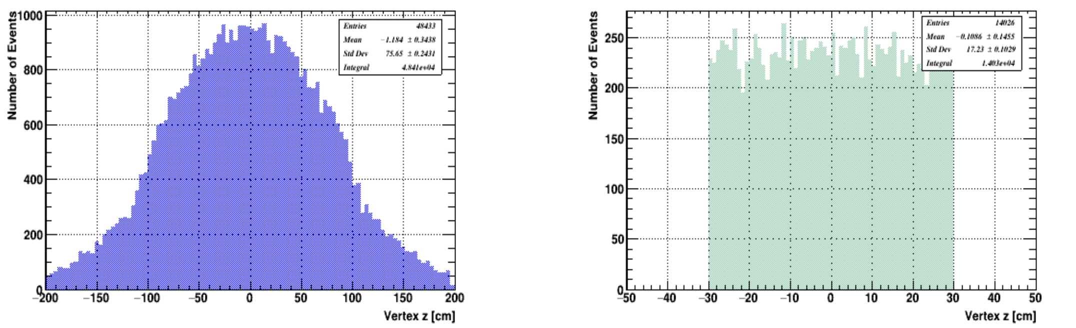
2.2 Analysis of Data and Histogramming

The following histograms show the XY plane of the detector, which shows the cross section of interaction as we look horizontally at the detector in the path which particles take to collide. Figure 5a depicts the events before cutting. In contrast, the x and y vertices data are cut down from [-10, +10] to [-2, +2]. In Figure 5b, we can find a more enhanced histogram for the produced events. In Figure 6, this time we look to the events from the perpendicular vertex on the XY plane, which is the Z one. The new cuts from [-50, +50] on the horizontal axis and containing only up to 250 events.



(a) Before Cutting (b) After Cutting

Figure 5: XY Vertices of the Detector



(a) Before Cutting (b) After Cutting

Figure 6: Z Vertex of the Detector

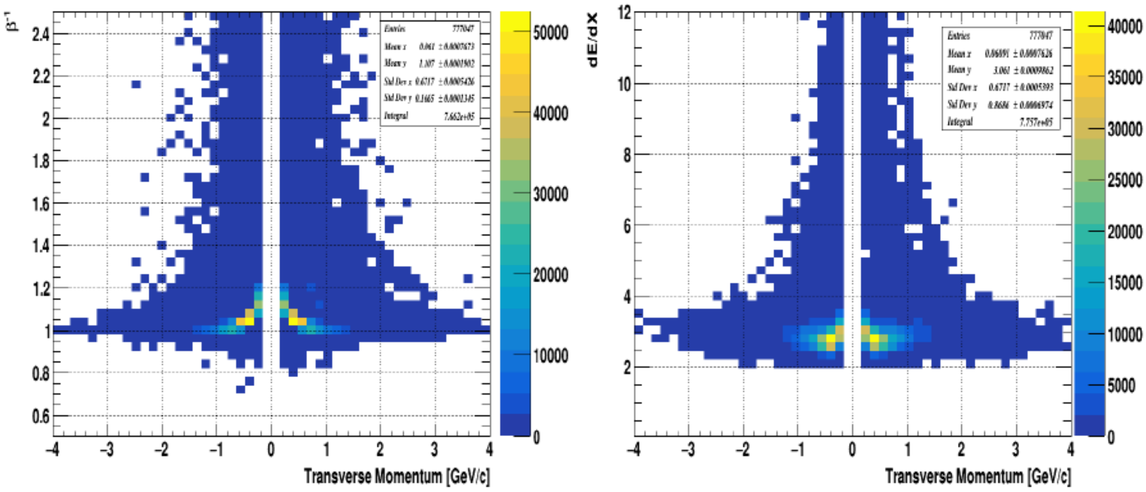
3 Results

3.1 Resulting Histograms

In order to identify the particles resulted in events we refer to histograms such as in the following figure. The histogram on the left is obtained from TOF detector, as it is able to give us information about the β factor which is given by:

$$\beta = \frac{v}{c} \tag{2}$$

Where v is the velocity of particle and c is the verlocity of light in space. On the other hand, for TPC, the particles are identified through their energy loss in detector as a function of the path that the particle takes $\frac{dE}{dx}$.



(a) After Cutting (b) After Cutting

Figure 7: Identification of Particles Histograms

3.2 Observation of π Particle

In both histograms Figure 7a and Figure 7b, even the lack of high resolution, which depends on how high is the number of events obtained, pions are observed. This is clear through the brighter points (yellow) found in both histograms after cut. These information are obtained by making a comparison between what we have got from the detector Figure 7a and Figure 7b, and standard histograms such as in Figure 3b and Figure 2b on order. By looking to those black lines in the two latter histograms, we can know the type of particle on the same path of these lines.

4 Conclusion

In heavy ion collisions, a lot of particles with different masses and energies are produced. These produced particles can be identified through detectors such as TPC and TOF in the STAR experiment, which may be possible by reconstructing events' tracks in order to recognize the primary particles produced initially through the secondary ones. Energy loss, momentum and velocity of particles help in its identification through performing some analysis depending on theoretical models and hypotheses. In this project, pion is detected from the Au+Au collision in the STAR experiment through the histograms shown above by using information such as transverse momentum, velocity and energy value as a function of the particle's path.

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