JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veskler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAMME

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Detection improvement of ZDC with MiniBEBE implementation

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1 Abstract

In this work we compare the particle detection efficiency in MPD using the ZDC detector and implementing the proposed miniBEBE detector generating UrQMD events simulations of Bi+Bi collisions at 9GeV in the MPD-NICA. In a collision experiment, the initial geometric conditions of the collision cannot be obtained from the experiment, but by calculating the ranks of centrality, a relationship can be established between the geometric parameters of the collisions and the observables detected from the experiment. With better detection efficiency we can perform more accurate centrality calculations in MPD.

Contents

2 Introduction

Making certain types of changes in the conditions of matter, it is expected that consequently there will be changes in its characteristics, for example, one expects that when heating water to 100°C at a particular pressure, the water will go from liquid to gas, on other hand if we take its temperature to 0°C we expect it to change its state from liquid to solid, etc., the problem is that it is not so simple to achieve, to make new discoveries about the fundamental structure of matter, it is necessary to carry out particle collisions at very high energies, for which it is necessary to build large and precise experimental complexes.

In this type of collision of atomic nuclei at high speeds, it is normal to expect that at the moment of the collision we have a highly compressed body at a very high temperature that we call QGP (Quark-Gluon Plasma).

The collision of particles at relativistic speeds ends in the production of the QGP, which recreates the conditions of matter existing during the first microsecond of the life of the universe, an instant in which the temperature of the universe was too high to allow the existence of hadronic matter, then by colliding particles they will be able to study this phase transition of matter between the QGP plasma produced by the collision and the production hadronic matter.

In order to learn and understand more about QGP we can describe the physics of heavy ion collisions by using phenomenological models that can be categorized as thermal, hydrodynamic and transport models.

- **Thermal models**, these models assume that there is a global thermal equilibrium and give us information about the integrated abundances of hadrons.
- **Hydrodynamic models**, these models, unlike the thermal ones, are based on the assumption that there is only a local thermal equilibrium and focus on the fluid and group behavior of matter, allowing us to explore abundances and spectra.
- **Transport models**, which do not make assumptions about equilibrium at all, but are based on kinetic theory and allow the study of yields, spectra, dynamic fluctuations and correlations.

These models are implemented in event generators which are software that allow us to simulate heavy ion collisions by events. With this we can compare experimental results with our theoretical predictions or even make new predictions for future experiments.

3 UrQMD Generator

UrQMD (Ultra-relativistic Quantum Molecular Dynamics) is a microscopic type event generator (a transport model) based on an explicit propagation of all hadrons in classical trajectories combined with stochastic binary dispersions, color string formation and resonance decay. This model represents the Monte Carlo solution of a large set of coupled partial integral/differential equations for the time evolution of a variety of phase space densities $f_i(x,p)$ of particle species $i = N, \Delta, \Lambda$, etc., which non-relativistically assumes the Boltzmann form:

$$\frac{df_i(x,p)}{dt} \equiv \frac{\partial p}{\partial t}\frac{\partial f_i(x,p)}{\partial p} + \frac{\partial x}{\partial t}\frac{\partial f_i(x,p)}{\partial x} + \frac{\partial f_i(x,p)}{\partial t} = Stf_i(x,p) \tag{1}$$

Where x is the position and p is the momentum of the particle and $Stf_i(x,p)$ denotes the source of these particle species, which are connected to any other particle species f_k.

4 Collision centrality

Centrality is a physical observable that is related to the region of interaction of colliding atomic nuclei. This concept is closely related to the impact parameter (denoted as b), which is defined as the distance between the centers of mass of the atomic nuclei that are on a collision course, since it is the impact parameter that determines the size and shape of the interaction region of the nuclei, since at low values of the impact parameter (a smaller distance between the centers of mass) implies a greater number of particles participating in the collision and, in turn, a greater parameter of impact (a greater distance between the centers of mass) implies a smaller number of participating particles and a greater number of spectator particles. [1]

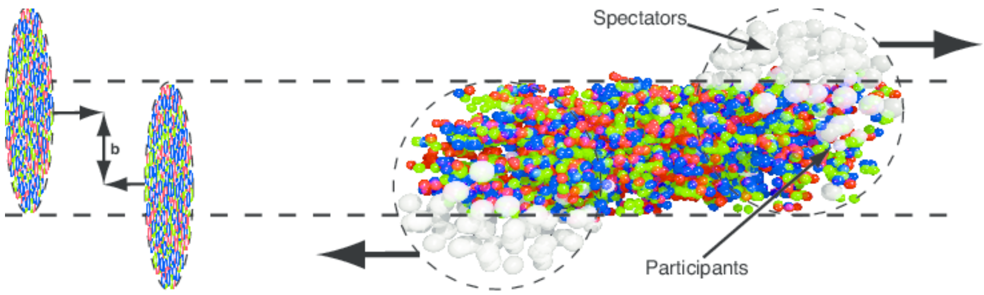

Figure 1: Diagram of the impact parameter and its relation with the region of interaction. [5]

To determine the impact parameter in the experiments it is necessary to measure the number of charged particles that reach the detector after the collision (multiplicity) [1], ideally it is expected that there is a linear relationship between the multiplicity and the impact parameter , a lower impact parameter should have a higher multiplicity and vice versa. Centrality is a very important property when conducting a study of the experimental results in collisions.

Centrality is usually expressed as a percentage of the total nuclear interaction cross section and is divided into different classes. We define the centrality classes c in collisions A+A with an impact parameter b in this way:

$$c = \frac{\int_0^b \frac{d\sigma}{db'} db'}{\int_0^{bmax} \frac{d\sigma}{db'} db'} = \frac{1}{\sigma_{AA}} \int_0^b \frac{d\sigma}{db'} db' \tag{2}$$

We are interested in modifying this expression, since we have an impact parameter distribution and this value cannot be obtained directly from experiments, it is necessary to find a way to reexpress this distribution in terms of an observable. Since there is a close relationship between b and the number of particles detected (N), the distribution of the impact parameter can be re-expressed as a distribution of the particles that reach the detector in this way:

$$\frac{1}{\sigma_{AA}}\int_0^b \frac{d\sigma}{db'}db' = \frac{1}{\sigma_{AA}}\int_{Ni}^{Nmax} \frac{d\sigma}{dN}dN \tag{3}$$

Thus, the centrality is expressed in terms of the particles detected per number of events, which are observable parameters that will help us determine the initial geometric parameters of the collision.

$$c_i = \frac{1}{\sigma_{AA}}\int_{Ni}^{Nmax} \frac{dN_{ev}}{dN}dN \tag{4}$$

5 Zero Degree Calorimeter (ZDC)

Zero Degree Calorimeter is a detector that aims to the classification of the events by centrality and using it for triggering purposes. ZDC is planned as two detectors located at 2.9m from the center of interaction each on the z-axis at the MPD caps with the purpose of receive the energy of the spectators during the collisions being the spectators protons, neutrons and nuclei fragments with different ratio of charge to atomic number.

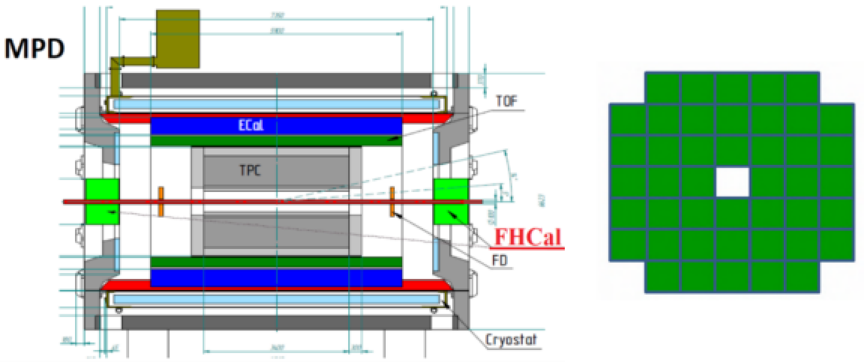

Figure 2: (Left) Schematic representation of the planned location of the ZDC detector inside the other MPD components. (Right) Front view of ZDC. [3]

Each ZDC will be assembled of 84 identi- cal modules. Each module with a lateral size of 5x5 cm consists of sandwiches of 16 mm thick lead and 4 mm thick scintillator tiles with embedded WLS fibers. The fibers from each group of 6 consecutive scintillator tiles are collected together and viewed by a single photodetector at the end of the module. [2]

6 MiniBEBE

MiniBEBE is a detector proposed by the MexNICA collaboration to be added to the Multi-Purpose Detector (MPD) and is designed to provide a wake-up trigger signal for events ranging from low to high multiplicities for the time of flight system (TOF). [4]

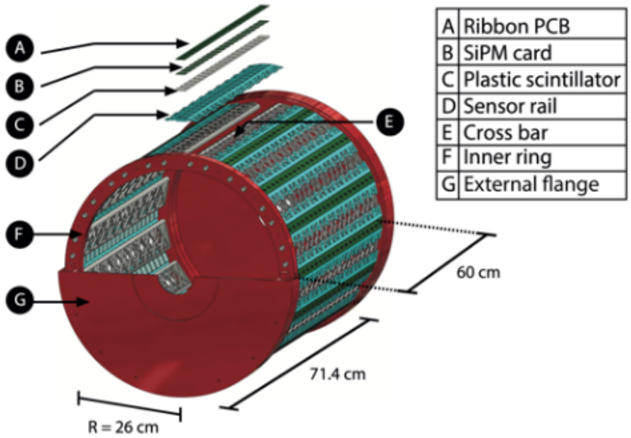

Figure 3: Illustration of the miniBEBE detector. [4]

The minibebe geometry consists of a barrel made up of 16 strips, each 600 mm long, which are made up of arrays, each composed of 20 scintillating plastic squares with dimensions of 2 x 20 x 3 mm^3, in total is made of 320 squared plastic scintillator cells and it covers an area of 128,000 mm^2. It covers a pseudorapidity range of $|\eta| < 1.01$ complementing the coverage of the rest of the MPD detectors.

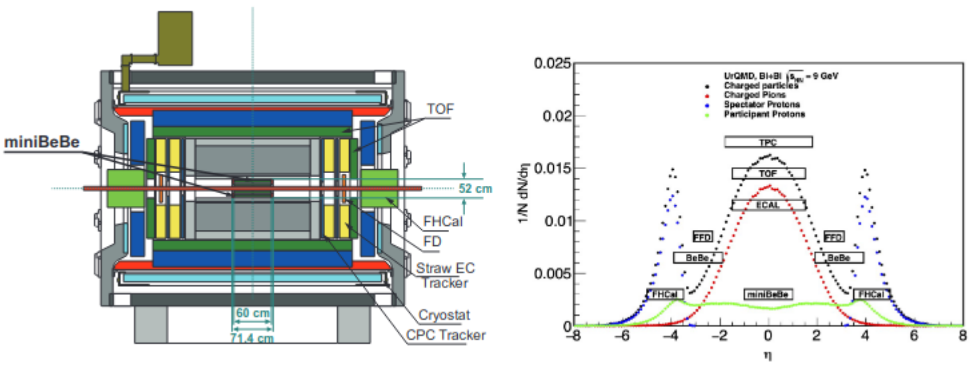

Figure 4: (Left) Schematic representation of the planned location of the minibebe detector inside the other MPD components. (Right) Pseudorapidity coverage of the miniBEBE detector (represented by width of the named box) compared to the nominal pseudorapidity coverage of the rest of the MPD components. [4]

7 Results

For the review and comparison of the efficiency of ZDC with and without miniBEBE implemented, a simulation of 150,000 events in UrQMD at 9GeV of p+p collisions was performed. After the simulations with UrQMD the data was transported to the detectors with MPDRoot framework. First a transport just using ZDC detector, then just using miniBEBE and finally with the two detectors at the same time.

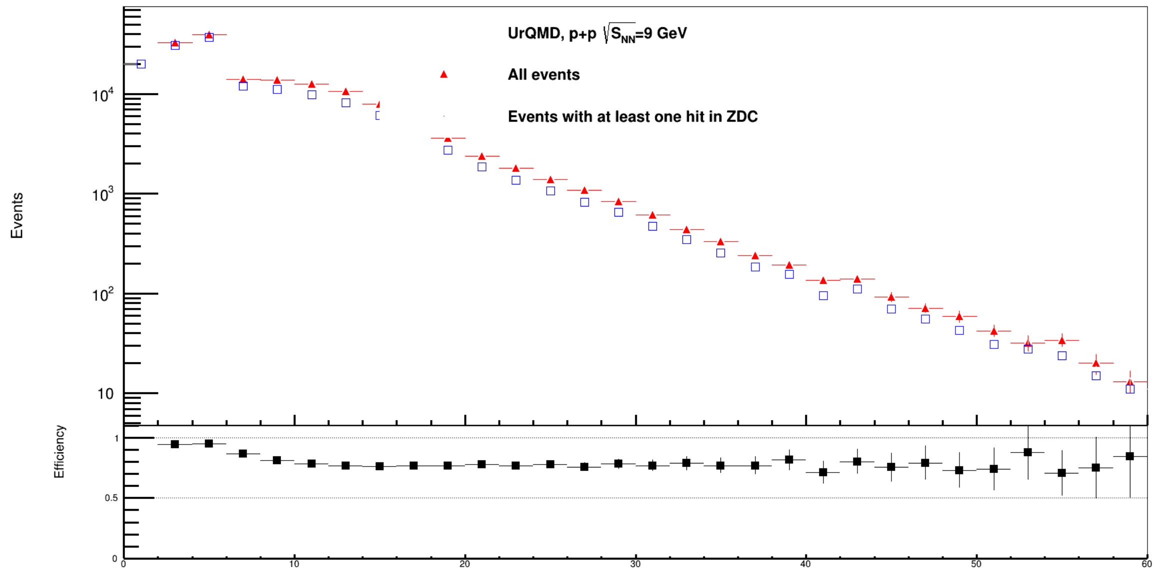

Figure 5: All events multiplicity vs Events with at least 1 hit in ZDC.

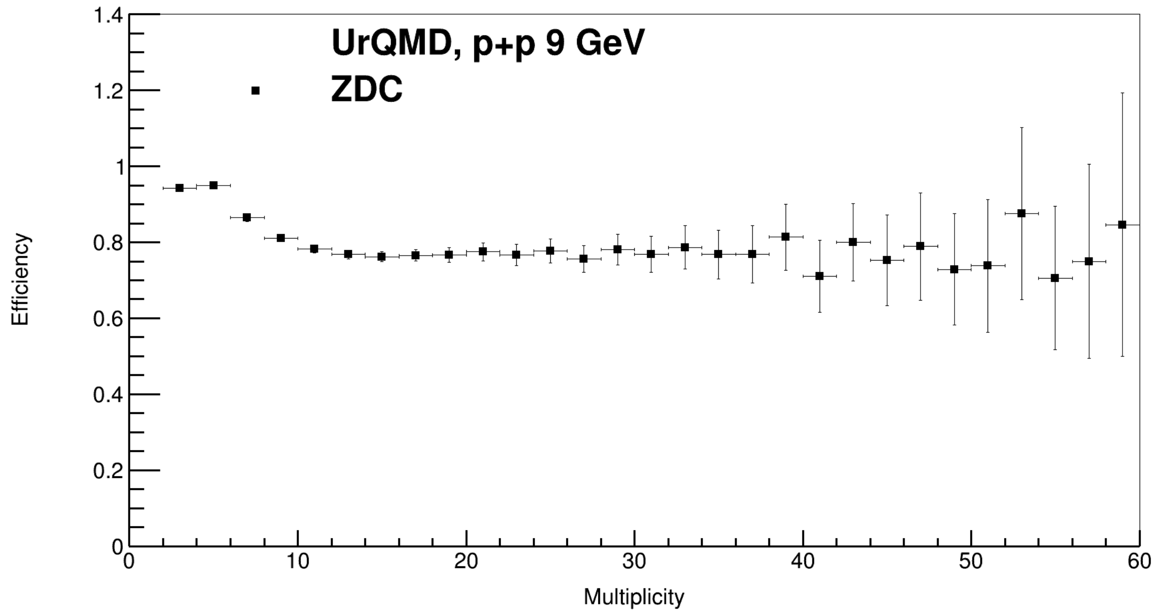

Figure 6: ZDC efficiency.

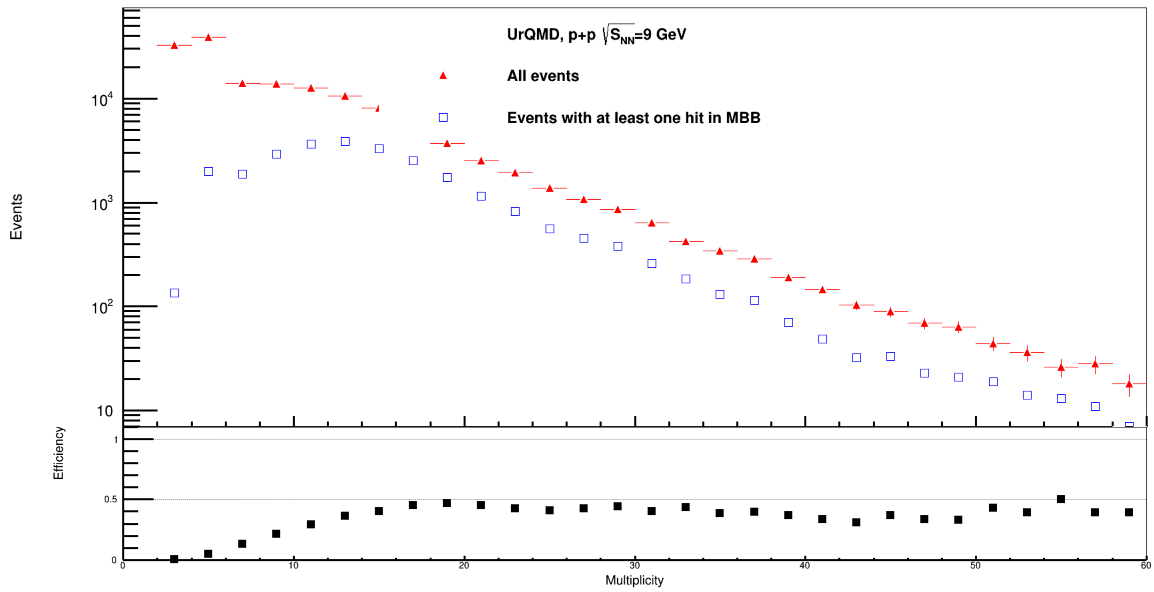

Figure 7: All events multiplicity vs Events with at least 1 hits in MBB.

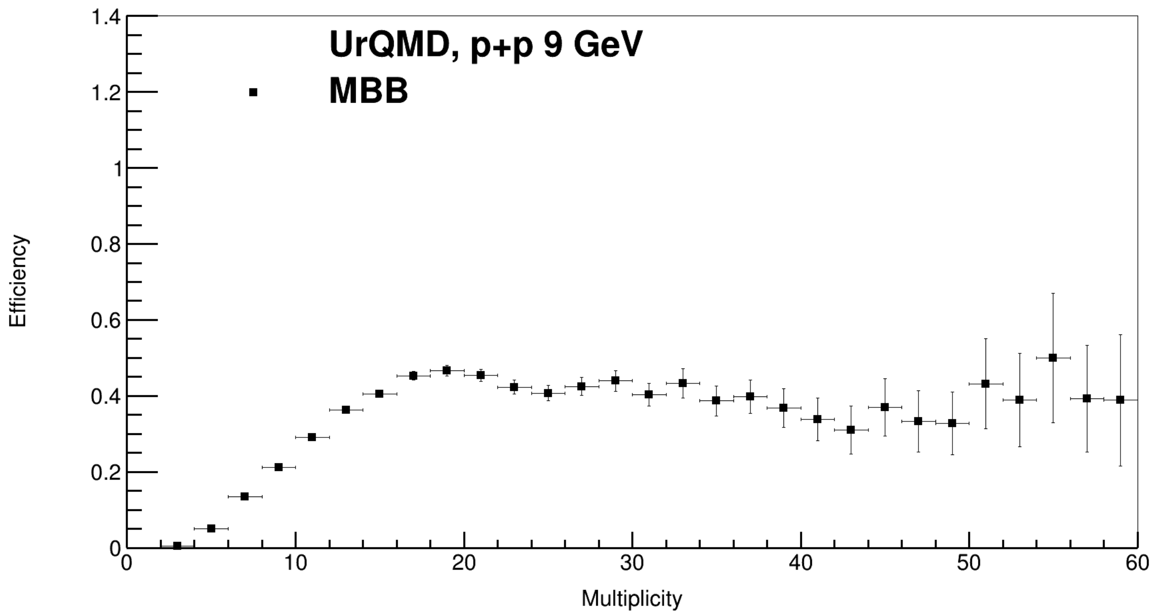

Figure 8: MBB efficiency

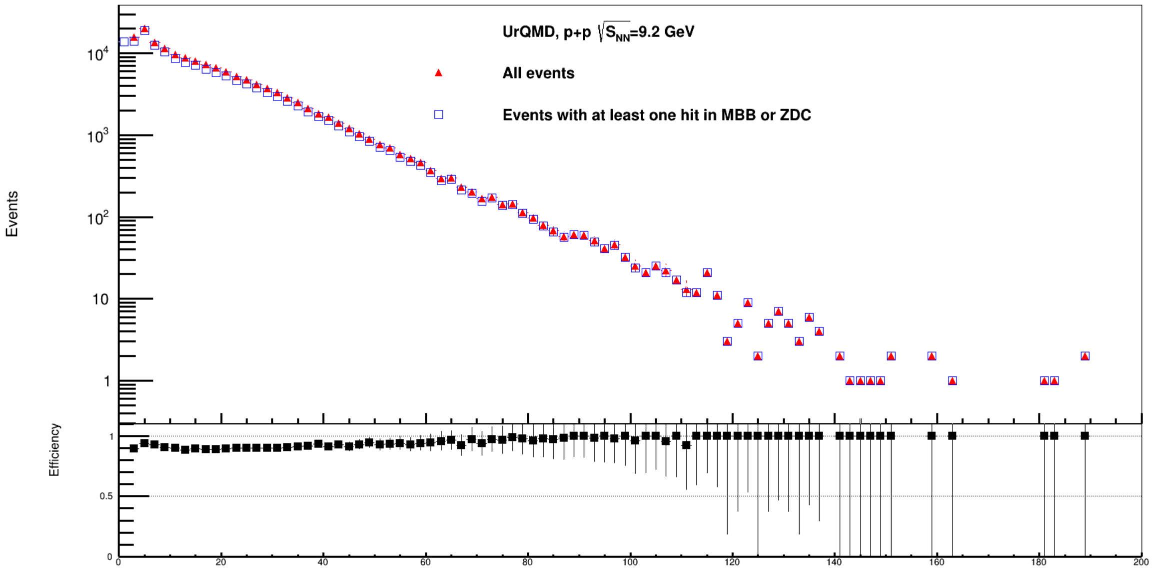

Figure 9: All events multiplicity vs Events with at least 1 hit in MBB or ZDC.

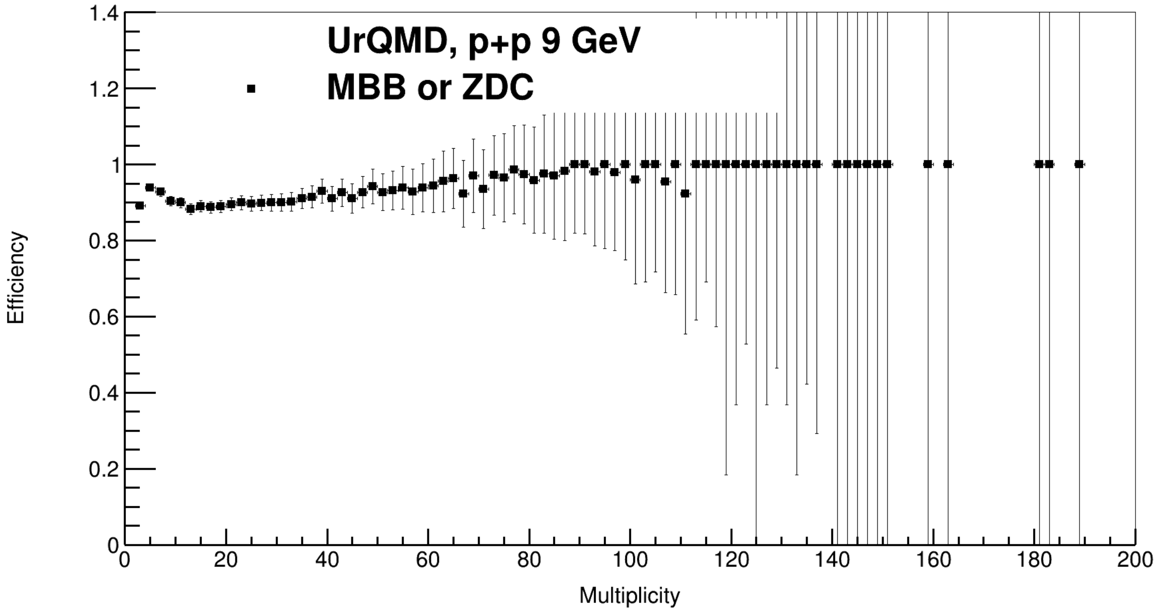

Figure 10: Efficiency when there is only one hit in MiniBEBE or ZDC.

An improvement in particle detection can be appreciated by comparing the graphs produced, the efficiency value is closer to 1 when the detectors are put together, by this we can say that miniBEBE appropriately complements the ZDC detector.

8 Conclusion and Further Work

Events for Bi+Bi collisions were generated with UrQMD at 9GeV and then they were transported to ZDC and MBB detectors. The particle detection efficiency was plotted and the results indicate that the detectors complement the detection range in the MPD and this may result in a more accurate centrality determination for triggering purposes. As a further extension of the project, centrality calculations can be performed by implementing miniBEBE to ZDC to verify the effectiveness of the detection, this testing other generators besides UrQMD.

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