JOINT INSTITUTE FOR NUCLEAR RESEARCH
Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Simulations for the BMD in the MPD-NICA project

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Summer visit:

July 08 - September 01

Dubna, Russia, 2017

Abstract

In this document I report on the main task that I was in charge of, during the summer visit to NICA: to estimate the centrality of the collisions in the NICA range of energy, that is from 4 GeV to 11 GeV. In order to determine centrality one important activity was to correlate multiplicity in the Beam Monitoring Detector (BMD) with the impact parameter of the collision. I found that some detector rings are good for 4 GeV but not good for 11 GeV and vice versa. For the simulations I used URQMD generations of 4970 events $Au + Au$ at 4 GeV and at 11 GeV in the CMS with impact parameter from 0 to 14 fm. I made studies using the MPDROOT framework, considering the Beam Monitoring Detector (BMD), the Time Projection Chamber (TPC) and the magnet of the Multi Purpose Detector (MPD).

1 Introduction

Nuclei are basically a bound state of protons and neutrons which, collectively, are called nucleons. Nucleons are formed by quarks which interact strongly and are confined. This means that particles with color charge, such as the quarks, can not be observed in isolation. That is the reason why is complicated to study the internal structure of hadronic matter. Nevertheless, the quark-gluon plasma (QGP) is a state of strongly interacting matter which consists in quarks and gluons not confined. This state of matter exists in the conditions of temperature and density that were present shortly after the Big Bang, at high temperature and/or density. QGP has been created in some laboratories at different conditions. In the figure (1) we see a phase diagram of hadronic matter and QGP. There is a critical point in the temperature T_c from which quarks and gluons are not confined. In the same way there is a critical point N_c for the baryonic density from which quarks and gluons are not confined. The curved line between the critical points refers to the phase transition between these both states of strongly interacting mater. One of the main reasons to construct experiments in laboratories such as NICA (Nuclotron-based Ion Collider fAcility) is because we are interested in studying the phase diagram of strongly interacting matter [1]. NICA is a new accelerator designed at the Joint Institute for Nuclear Research (JINR) to study properties of dense baryonic matter. The range of energy of NICA is supposed to be in the range where the phase transition is present [2]. Experiments are characterized by some important factors:

- What we are colliding and the way of doing it: beam-beam collision or a beam with a fixed target.
- Energy of the collision.
- The capabilities of the detector.

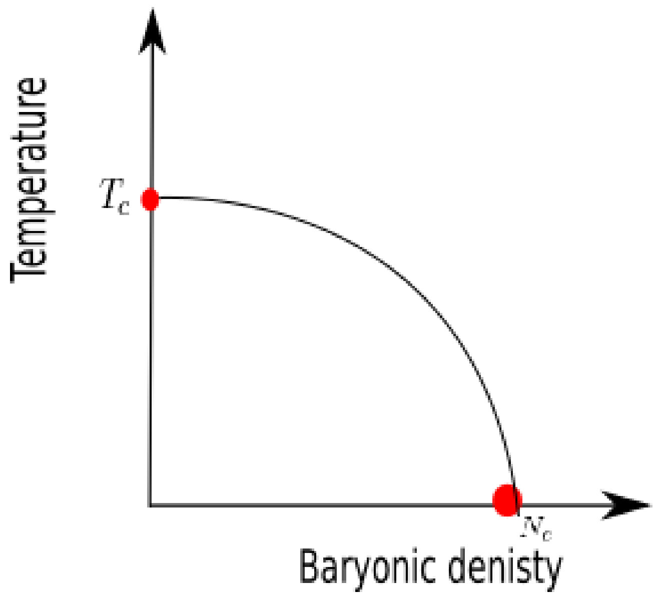

Figure 1: Phase diagram of hadronic matter and QGP. There is a critical point in the temperature T_c from which quarks and gluons are not confined. In the same way there is a critical point N_c for the baryonic density from which quarks and gluons are not confined. The curved line between the critical points refers the phase transition between these both states of strongly interacting mater

In high energy physics we have access to initial conditions of a collision via measurement of observables in detectors. The basic components of modern detectors consists in an array of detectors structured according to the particles that should be identified. Multi Purpose Detector (MPD) is designed as a detector of charged hadrons, electrons and photons in heavy ion collisions. MPD is a complex detector and we can see its structure in the MPD website [3]. Beam Monitoring Detector (BMD) is a proposal to be part of MPD. BMD consists in two circular detectors, BMD-A and BMD-C, each of one conformed by 80 cells arranged in 16 sectors and 5 rings as we see in the figure (2). BMD-A is located at $-2m$ of the interaction point in the beam direction. BMD-C is located at $2m$ of the interaction point in the beam direction.

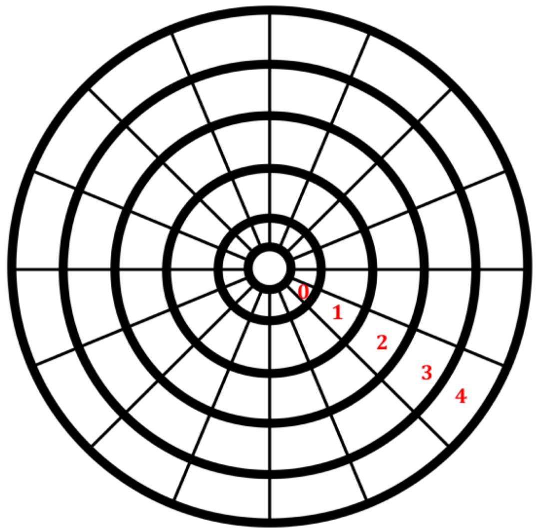

Figure 2: BMD consists in two circular detectors, BMD-A and BMD-C, each of one conformed by 16 sectors and 5 rings. BMD-A is located at $-2m$ of the interaction point in the beam direction. BMD-C is located at $2m$ of the interaction point in the beam direction.

Centrality is an important property of the collision that can not be accessed directly in the point of the collision in the experiment. But we know that centrality is correlated with the number of produced particles, the multiplicity. In this work we refer to multiplicity as the number of particles that arrive to the BMD. My main task is to estimate the centrality of the collisions in the NICA range of energy. In order to estimate centrality my first task was to correlate multiplicity with impact parameter in the Beam Monitoring Detector (BMD). Impact parameter is the distance between the center of the two colliding nuclei as we see in the figure (3).

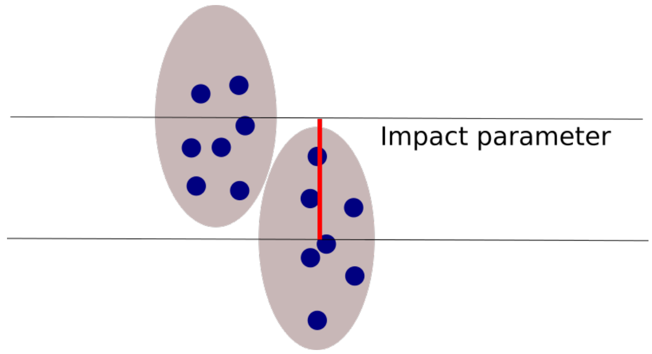

Figure 3: Impact parameter is the distance between the center of the two nuclei. We see two colliding nuclei with a b impact parameter.

We know that multiplicity depends in two important factors of the initial conditions of the collision:

- Energy: we know the energy of the collision and it is controlled in the experiment.
- Impact parameter: we do not know the centrality of each collision and it is not a controlled parameter in the experiment.

Nucleus-nucleus collisions are studied in terms of the nucleons of each nucleus. In a nucleus-nucleus collision, the interacting nucleons are called participants and the non-interacting nucleons are called spectators. In the figure (4) we have three $Au + Au$ collisions at different conditions. The left picture is at 4 GeV and the picture in the middle is at 11 GeV. We see that the overlap between the nuclei is smaller in the collision at 4 GeV than in the collision at 11 GeV, so if the overlap is smaller there are fewer participants and more spectators, and then a lower multiplicity will be expected. In the other hand, for 11 GeV the overlap is bigger, so, there are more participants and fewer spectators. In the right picture the collision is also at 11 GeV, but the impact parameter is larger, in consequence there are lower participants and the expected multiplicity will be lower.

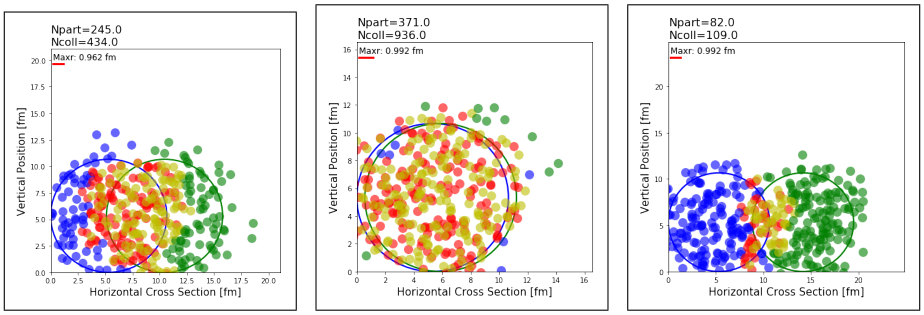

Figure 4: Collisions $Au + Au$ at 4 GeV (left) and at 11 GeV (center and right). The left and the center are for a central collision. The right one is for a peripheral collision. Red and yellow points are participants and blue and green points are spectators. These quantities were generated with the Monte Carlo Glauber code of open source in GitHub [5].

It is usual to express the overlap of the colliding nuclei as a cross section:

$$\sigma(b) = 2\pi \int_0^b bdb = \pi b^2, \tag{1}$$

a total cross section between the colliding nuclei is:

$$\sigma_{total}(b) = 2\pi \int_0^{2R} bdb = \pi(2R)^2, \tag{2}$$

where R is the nuclear radius. Centrality is usually expressed as a fraction of the total cross section (2) and the cross section of the colliding nuclei (1):

$$\frac{\sigma}{\sigma_{total}} \tag{3}$$

These fractions are expressed as percentages and called centrality classes [4].

2 Results

The first task was to correlate multiplicity of both BMD-A and BMD-C with the impact parameter for 4 GeV and 11 GeV. In the figure (5) we see the correlation for 4 GeV. In this case there is a increasing trend of multiplicity when impact parameter increases. The reason is that for lower energies there are fewer participants and more spectators, more nucleons that do not do not interact in the collision, but they arrived to the detector.

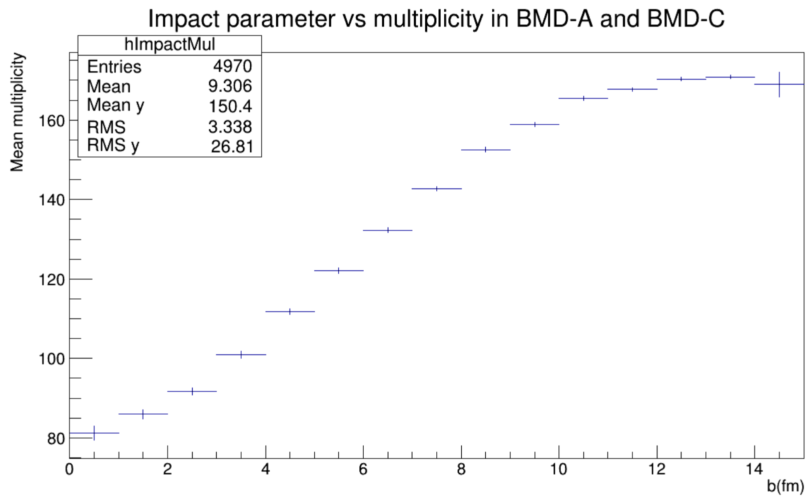

Figure 5: Mean multiplicity vs impact parameter in both BMD-A and BMD-C. 4 GeV.

In the figure (6) we have the correlation of multiplicity versus impact parameter for 11 GeV. In this case we see a decreasing trend of the multiplicity when the impact parameter increases. That because for lower impact parameter, more nucleons of each nuclei interact with each other, but for higher impact parameter, there are fewer participants. So, if there are more interacting nucleons in the collision, more produced particles will be expected.

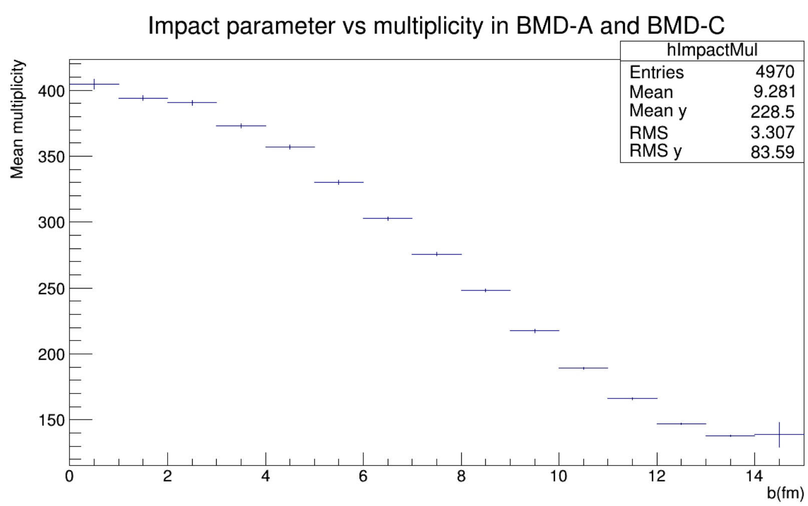

Figure 6: Mean multiplicity versus impact parameter in both BMD-A and BMD-C. 11 GeV

In order to study the centrality in more detail I made the same correlation of multiplicity versus impact parameter, but for the multiplicity of each ring of the BMD. We will see in detail that some rings of BMD are good for low energies and not good for high energies, and some rings are good for high energies but are not good for low energies. In the figure (7) we see the correlation of multiplicity of each ring versus impact parameter for 4 GeV. In the first three rings there is an increasing trend of multiplicity when impact parameter increases, this behavior is because there are more spectators at low energies. So, the first three rings have a good correlation for spectators. In the forth ring we have increasing and decreasing trend of multiplicity with the impact parameter, the increasing part from 0 to 10 fm is because of the spectators and the decreasing trend from 10 to 14 fm is because of the participants, so this is not a good ring to estimate centrality. In the fifth ring there is no correlation between multiplicity and impact parameter from 0 to 6 fm. But for 6 fm to 14 fm we see that multiplicity decreases when impact parameter increases. So, this ring is not sensible to the centrality from 0 to 6 fm in consequence is not a good ring to estimate centrality at 4 GeV. We should use the first three rings for 4 GeV and not use the rings 4 and 5. The first three rings are well correlated with spectators.

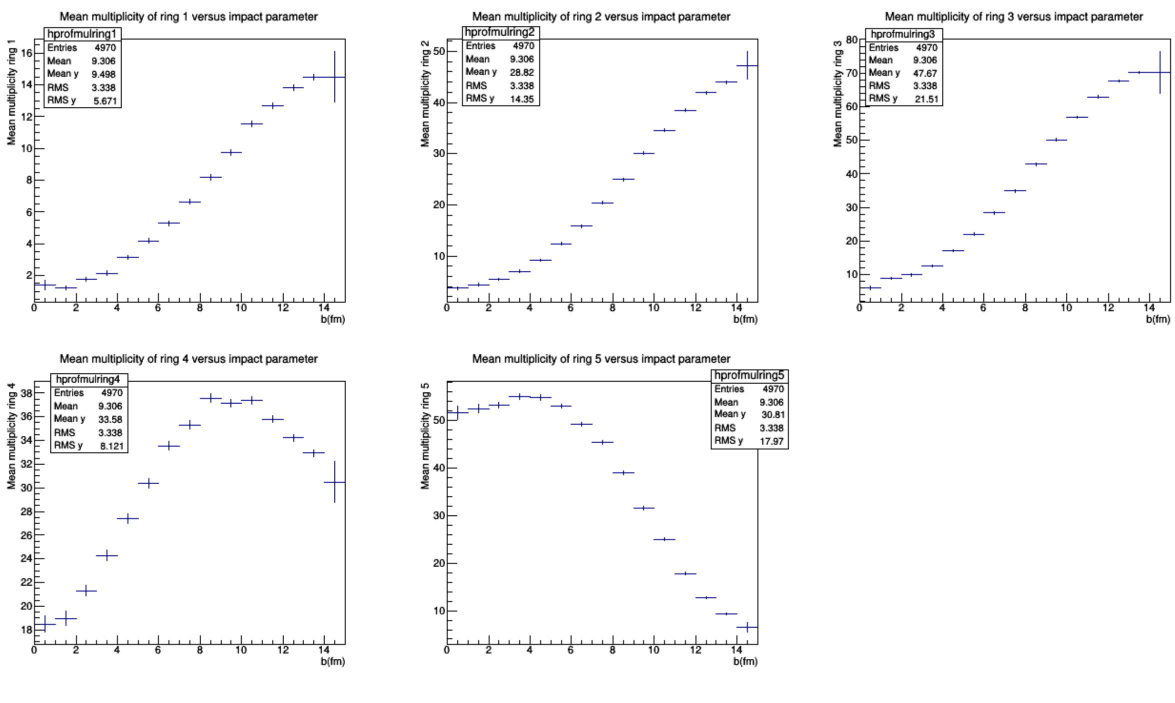

Figure 7: Mean multiplicity of each ring versus impact parameter. 4 GeV.

For 11 GeV, we see in the first ring the same behavior that we saw for all the detector at 4 GeV, a increasing trend of the multiplicity when the impact parameter increases because of the spectators. In the ring two there is increasing and decreasing trend, so it is not a useful ring. In the third ring we have a constant behavior from an impact parameter from 0 to 4 fm, so there is no correlation in that region, and for that reason the ring 3 is not good for central collisions, but for peripheral collisions it is good, from 4 to 14 fm. In the other hand the rings forth and fifth are good for this energy, we have the expected trend, multiplicity decreases when impact parameter increases. We should use rings 1, 4 and 5 for 11 GeV and do not use rings 2 and 3. The ring 1 is well correlated with spectators and the rings 4 and 5 with the participants.

To study in a more detail the centrality, the next step is to use the rings that better adapts for each energy.

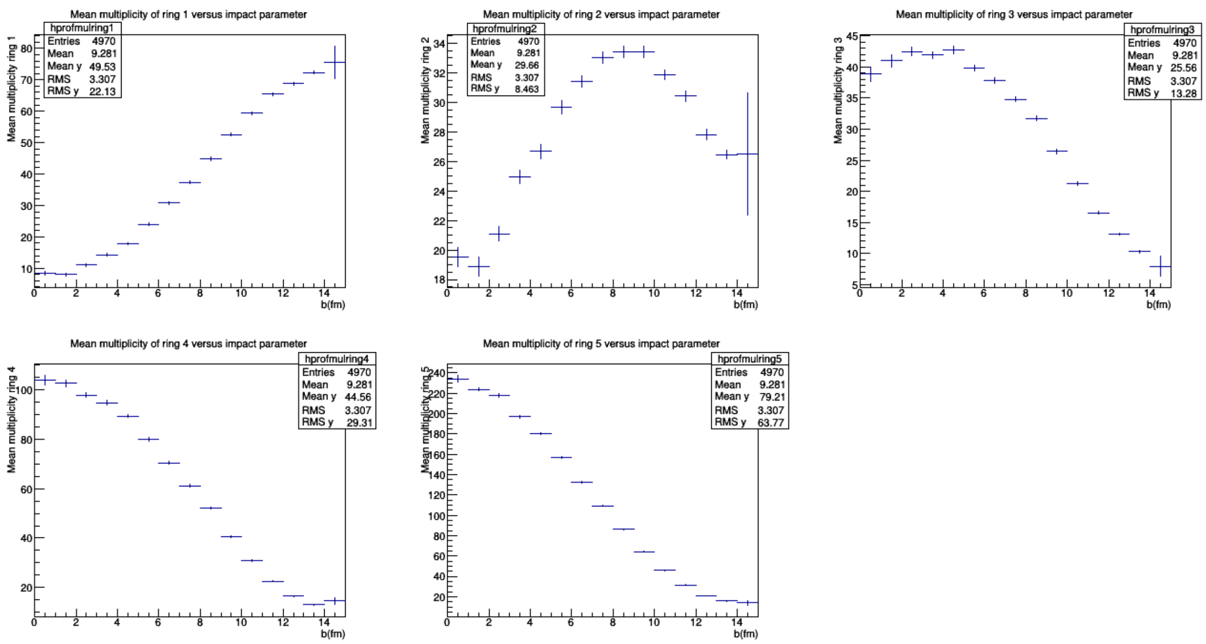

Figure 8: Mean multiplicity of each ring versus impact parameter. 11 GeV.

3 Conclusion

We see that some rings are good to estimate centrality at 4 GeV, but not for 11 GeV and vice versa. For 4 GeV we should use the rings 1, 2 and 3 and do not use rings 4 and 5. For 11 GeV we should use the rings 1, 4 and 5 and do not use rings 2 and 3. At 4 GeV there is a good correlation for the spectators. At 11 GeV there is a good correlation for the spectators in the first ring, and a good correlation for the participants in the rings 4 and 5.

Now we know what rings should we use to estimate centrality at 4 GeV and at 11 GeV, the next step is to use these rings for each energy and estimate centrality in terms of centrality classes. This is still work in progress and will be reported as soon as possible.

4 Acknowledgments

I would like to express my deep gratitude to my supervisor Dr. Vadim Ivanovich Kolesnikov for accepting me in his group, for allow me to learn from him and for his constant attention and patience all this time. I also wish to express my gratitude to Dr. Golovatyuk Slava for his attention and for welcoming us to the NICA/MPD project.

I am particularly grateful for the attention and help that I received by Katherin Shtejer and Sasha all this time at JINR. I would like to thank Elena Karpova and all the organizing committee for the excellent organization of the Summer Student Program.

I would like to thank Maria Elena Tejeda-Yeomans and all the MeXNICA members for all their support and the constant guidance.

Finally I would like to express my gratitude to the Joint Institute for Nuclear Research for give me the opportunity and financial support to participate in the Summer Student Program and to the División de Ciencias Exactas y Naturales at Universidad de Sonora for a travel grant.

5 Appendix

Part of my contributions during this time at JINR were to make the commit of the first version of the Beam Monitoring Detector (BMD) in the MPDROOT software of the NICA project. In order to made the commit of the BMD classes is necessary to have installed MpdRoot [6] with the BMD classes. After that, the basic instructions to made the commit are the following [7]:

If it is necessary to create a branch, use the command:

```
git checkout -b <branch name>
```

To update the local branch use the command:

```
git pull
```

To save the changes in local repository use the command:

```
git commit -a
```

A description of the changes in the commit will be required. To check the status of the commit use the command:

```
git status
```

If there are more files needed use the command:

```
git add <file or folder name>
```

To add all the files and folders use the command:

```
git add .
```

And Finally, to save the changes in the remote repository use the command:

```
git push
```

The commit of MpdRoot with the first version of BMD is located in the branch bmdv1 [8].

References

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[7] How to use GIT. http://mpd.jinr.ru/howto-use-git/

[8] MPDROOT Software with BMD commit. https://git.jinr.ru/nica/mpdroot/tree/bmdv1