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Performance of Beam Monitoring Detector (BMD): a beam beam counter prototype for the MPD-NICA experiment at JINR

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Abstract

In this report we show the arrival time resolution for the Beam Monitoring Detector. We made the study for Au+Au collision at $\sqrt{s} = 8$ Gev and a smearing of $\sigma = 300$ cm. The arrival time resolution we found is $\Delta\sigma = 57.982 \pm 0.509$ ps. As study completeness, we show the multiplicity and the energy distribution for a section of this detector.

1 Introduction

The Nuclotron-based Ion Collider fAcility (NICA) is a new accelerator at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia. Its field of study will be the properties of dense baryonic matter. NICA will have three experiments (or detectors):

1. The Baryonic Matter at Nuclotron (BM@N).
2. The Spin Physics Detector (SPD).
3. The MultiPurpose Detector (MPD).

Each one has its own physics of study. In Figure 1 is shown a representation of NICA.
In this report we show the work we did for MPD, which consisting of the implementation of a new detector (see sections below). For more information of the other two detectors see [1] and [2].
The MPD (as its name says) has several physics studies. One of the principal field is to measurements of the production of strange particles (particles conformed by the *strange* quark). This study is due to that they can give information about the medium and particle production mechanism [3].
The components of MPD are:

- Time Projection Chamber (TPC)
- Inner Tracker (IT)
- Electromagnetic Calorimeter (ECAL)
- Zero Degree Calorimeter (ZDC)
- Fast Forward Detector (FFD)
- Magnet

Each one of this components has an specific task [4].
To make MPD measurements more accurate, will be added a new detector: **The Beam Monitoring Detector (BMD)**, which will be two scintillator detectors. The main goal of BMD will be increase the pseudorapidity acceptance of MPD. Other measurements that BMD can do, are listed below.

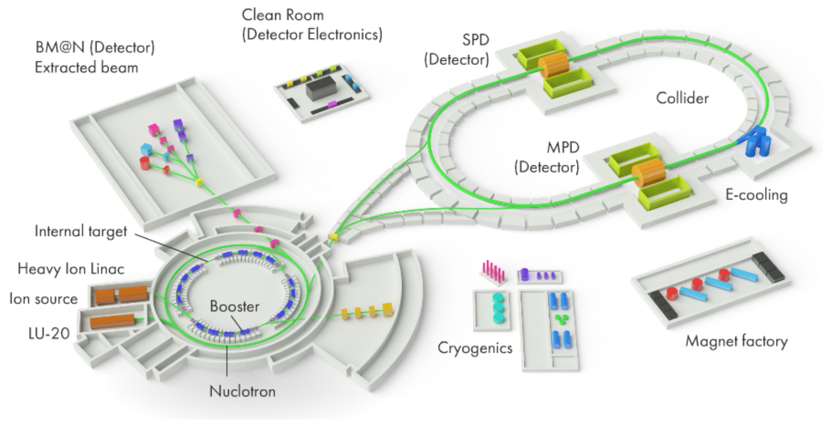

Figure 1: A picture of NICA. It is shown the three experiments and the rest of the components. **Image taken from http://nica.jinr.ru/complex.php**

- Optimization of events: Plane resolution.
- Centrality.
  - Interaction point location.
- Multiplicity reference estimator.
- Trigger system.
- Beam monitoring.
- Discriminate centrality events from background and beam-gas interaction.
- Determinate the absolute cross section of reaction process.

The name we will use to refer to the two detectors are "BMD-A" and "BMD-C". In the next section the properties of BMD will be descibed.

2 Characteristics of BMD

BMD-A and BMD-C will be located at -200 cm and 200 cm, respectively, with respect to the geometric center of MPD. For this study we used a circular geometry for each detector, whose minimum radius is 5.1 cm, maximum radius is 76.63 cm and the width is 1.25 cm, for each one. Each detector is divided in 5 rings and at the same time each ring is divided into 16 slices, giving a total of 160 scintillator pieces for all BMD. The radius of each ring are descibed in Table 1.

Ring	Minimum radius (cm)	Maximum radius (cm)
1	5.1	8.30
2	8.5	14.50
3	14.7	23.40
4	23.6	42.00
5	42.2	73.63

Table 1: Values of the maximum and minimum radius for each ring in BMD-A and BMD-C.

Note that between each ring there are 0.2 cm of separation. With this dimentions, is easy to know that the pseudo rapidity (η) region is $1.69 \leq |\eta| \leq 4.36$. Other advantages of using the BMD is the optimization of event plane resolution, which is an imaginary "plane" where the collision occurs and they can determinate the absolute cross section

of reaction process. Also, BMD can be used for a multiplicity reference estimator, i.e., the number of particles (from the collision) that arrive to them. In the trigger system and beam monitoring the BMD is going to bring more information, beacuse they will be able to discriminate beam-beam minimum bias or centrality events from background and beam-gas interaction. As we listed in previous section.
There are 4 important studies that we have to do for BMD:

- Time resolution and arrival time resolution.
- Centrality and multiplicity determination.
- Trigger efficiencies.
- Background reaction.

The results of these studies will be able to give us a good "way" to construct the real BMD. For the present work, we made the study for the arrival time resolution.

3 BMD simulation and results

3.1 Preliminary results

As a preliminary results, we show some results for particles in BMD, the results are about the multiplicity, energy deposited by primary particles.
We show first the multiplicity in each ring for two ranges of the impact parameter b <9 fm and b >9 fm. We generated 200 events using UrQMD package [5] Au+Au collision at $\sqrt{s}$ = 8 GeV. We do not restrict that the collision occurs at the origin, i.e., we let the collision occurs with a Gaussian distribution whose center is the geometrical origin and has a sigma of 40 cm, this is called "smearing". We used the mpdroot framework [6] for the MPD simulation. The TPC was a detector that also was condidered in this analysis. To use our detector was necessary to add the BMD code in the mpdroot framework [7]. The results are shown in Figure 2, for BMD-A we found the same shape. Clearly we can observe the central and peripheral collisions.
Due to the shape of the detector, we can study the energy deposited, the arrival time, etc. In each Ring. For this study, we only choosed the Ring 2 to obtain the energy and time distribution for primary particles, as well as, we choosed the events where $b < 9$ fm. These results are shown in Figure 3. It is possible to know the percentage for primary and particles, which respectively is $95.65 \pm 9.78\%$ and $4.35 \pm 2.09\%$, for BMD-C. An anlysis similar to BMD-A can be done. The percentage of secundary particles is almost the 100%, possibly there are neutrons that ionize the material and those particles can be counted as secondary. A more detailed study should be carried out.

3.2 Arrival time resolution measurement

For this part of the study we considered more events than in previous to get more statistics, because we worked with the fastest particle of each event.
We simulated Au-Au collision at $\sqrt{s}$ = 8 GeV with an impact parameter in the range (0,12) fm. We used a "smearing" gaussian of σ = 300 cm. We are interested in the analysis for the arrival particles to BMD-A and BMD-C. In this section we will describe the technique we used to calculate the *arrival time resolution* for BMD.
In Figure 4 are shown arrival time distributions for BMD-A and BMD-C. We believe that the greatest peak refers that some material, inside MPD is creating particles due to the interaction (possibly the TPC).

The first result is the behavior that has the addition and difference time of arrival when the collision occurs inside and outside of BMD. There are four zones and are illustrated in Figure 5. As an example let's take Z_3. The two arrival times for BMD-A and BMD-C

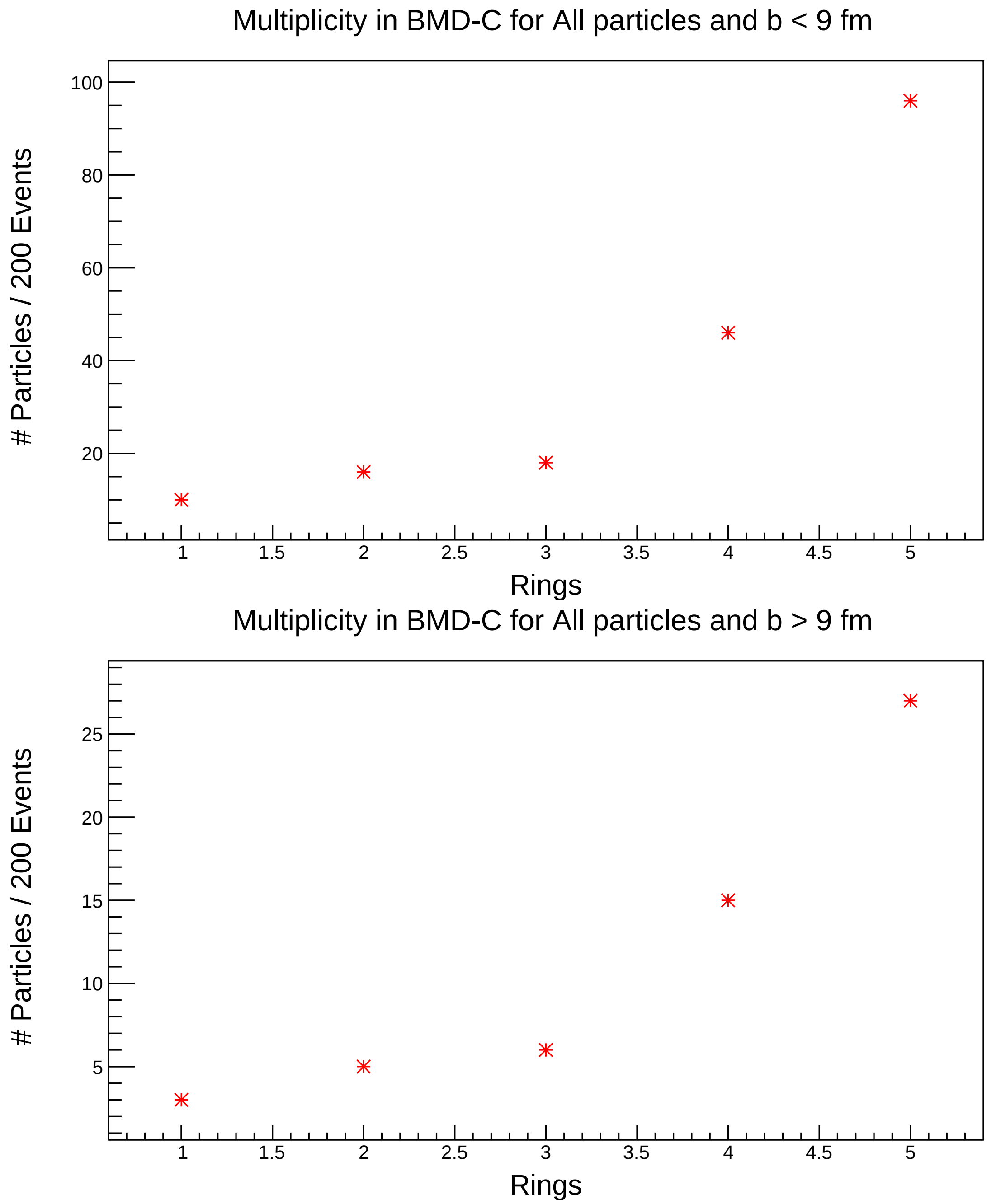

Figure 2: Comparation of multiplicity for each ring at two different values of the impact parameter for BMD-C. Up: $b < 9$ fm. Down: $b > 9$ fm.

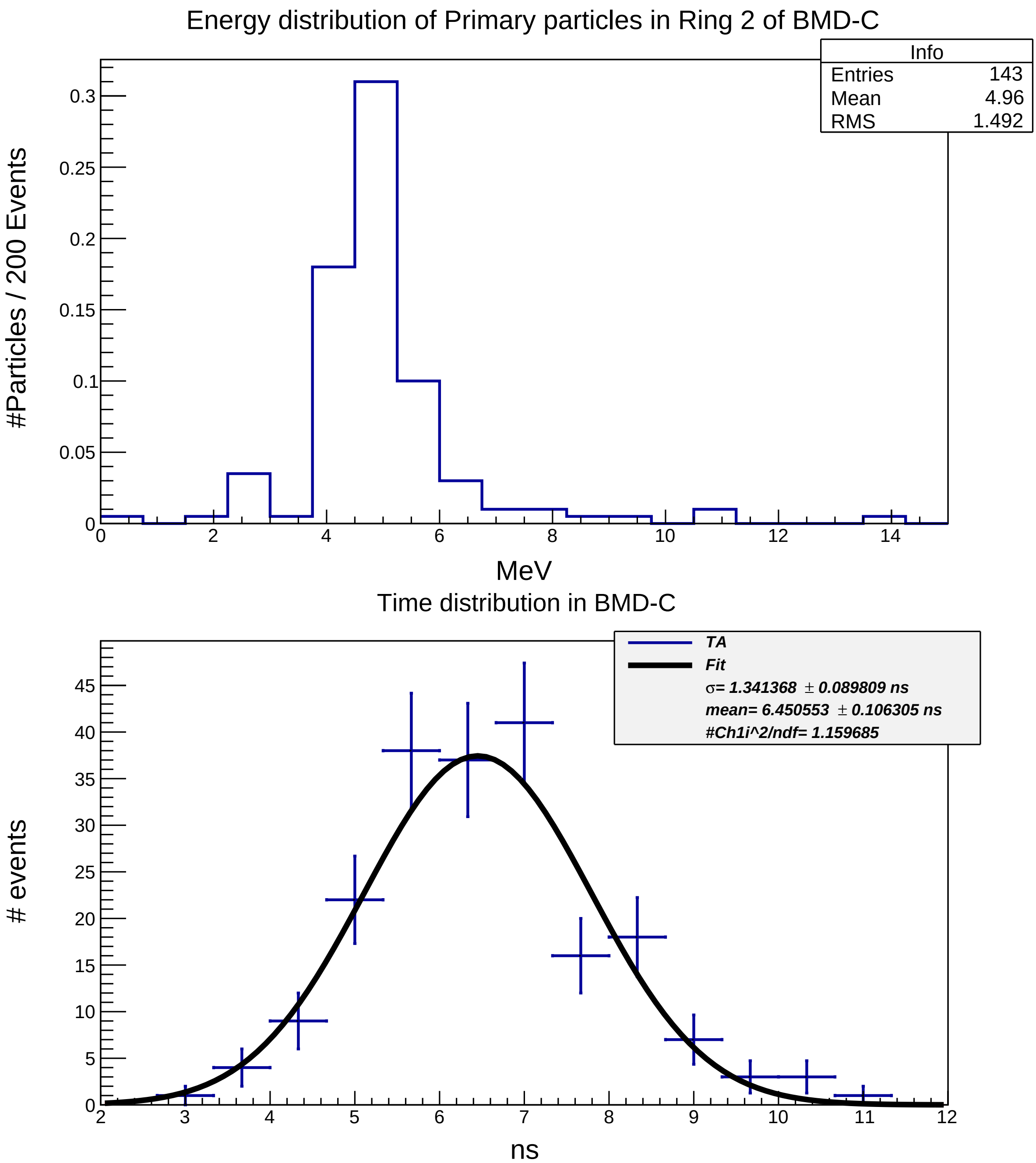

Figure 3: Energy (up) and Time (down) distribution for primary particles that arrive to Ring 2.

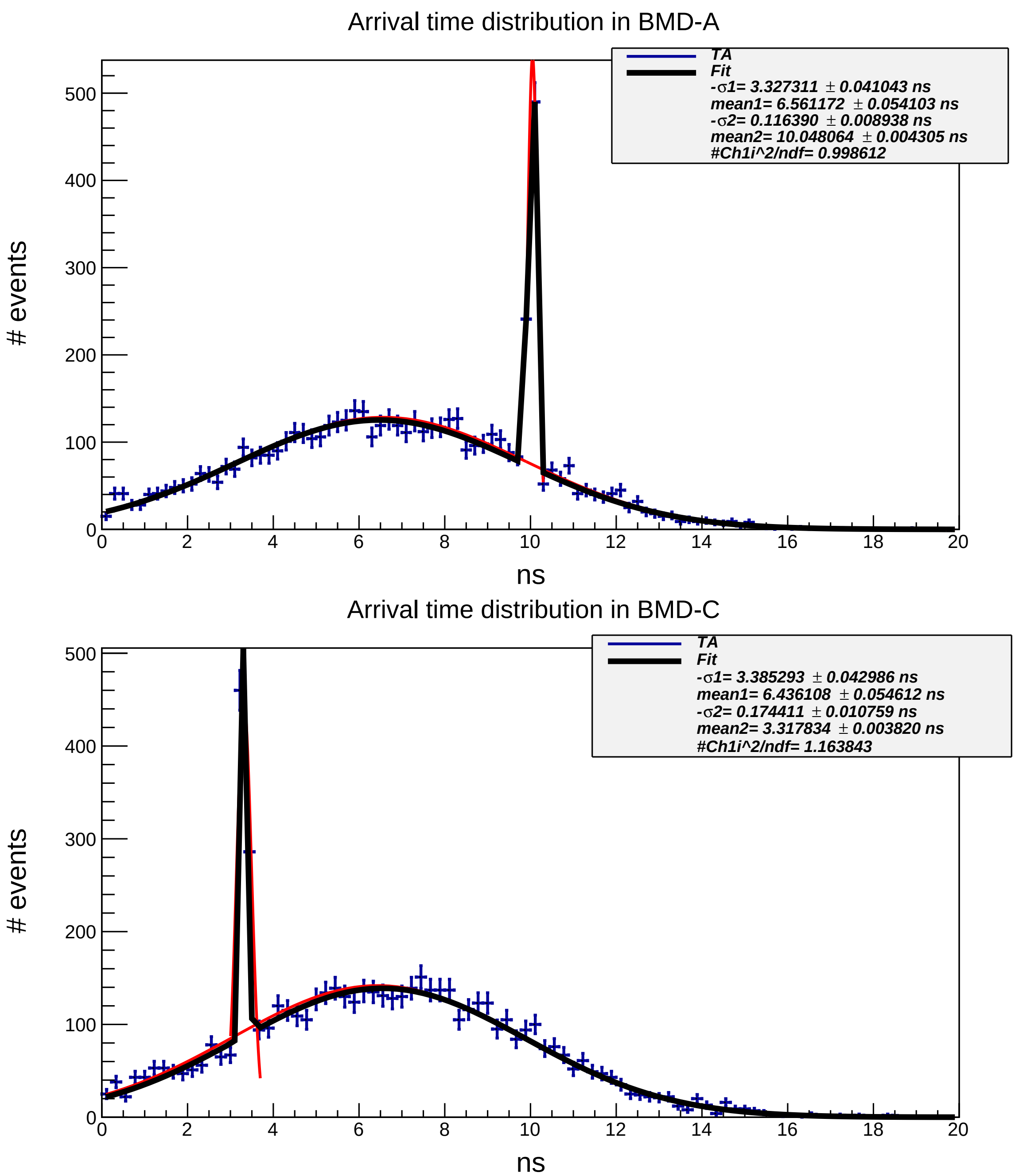

Figure 4: Arrival time distribution for BMD-A (up) and BMD-C (down).

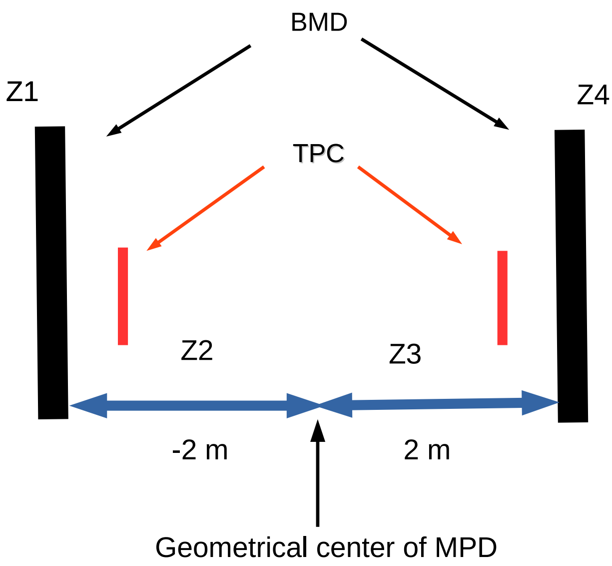

Figure 5: Interaction point distribution arround the geometrical center in MPD. The four Zones are: $Z_1 <$ -2 m, -2 m$\leq Z_2 \leq 0$ m, 0 m $\leq Z_3 \leq 2$ m, $Z_4 > 2$ m

are: $T_A = \dfrac{2m + Z_3}{nc}$ and $T_C = \dfrac{2m - Z_3}{nc}$, respectively, The quantity $n < 1$ represents the percentage of the velocity that the particles travel with respect to the speed of light. Z_3 are the points in this Zone. Then we have:

$$T_A - T_C = \frac{2}{nc} Z_3. \tag{1}$$

It means that the differences is propotional to de distance. If we take the Z_2 we will have the negative of Eq. 1. We see that the difference, in middle Zone, is linear with respect to the position of the interaction point. This simple calculation can be made for the other zones and for the sum. This theorical prediction are agree with the results obtained by MC, as is shown in Figure 6. We note that each operation has a different shape. Then, it is possible to distinguish if the collision occurs inside or outside BMD. As BMD has a width of 1.25 cm, if the collision occurs inside the material detector it will be a problem to distinguish if the collision occurs inside or outside, as can we see in Figure 6. This can be solved to choose a cut that does not affect so much the selection of events. BMD-A and BMD-C center is located at -200cm and 200cm, respectively, if we choose the range from -197cm to 197cm (Z_2 and Z_3) we obtain that:

$$\frac{N_{inside}}{N_{total}} = 96.5\%.$$

Where N_{inside} is the total arriving particles inside BMD (-200 cm to 200 cm) and N_{total} is the number of all arriving paritcles. This range was choosen in a “good feeling”. A more detailed analysis must be done in the selection of the effective range. The shape in

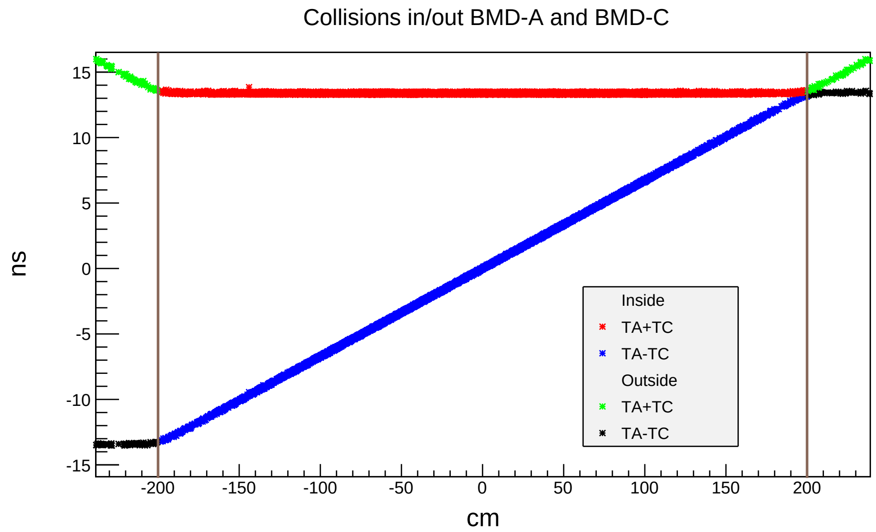

Figure 6: Comparation between TA+TC and TA-TC when the collision occurs inside and outside BMD. The vertical lines indicate the region of BMD-A and BMD-C.

Figure 6, refers in general to all particles that arrive, included the particles produced for the interaction with other detectors as we will see.

In Figure 7 is shown the difference time distribution inside BMD (Z_2 and Z_3). As we explained in Eq. 1, the time difference is proportional to interaction point position, then, this plot can be transformed in the interaction point distribution, as is shown in Figure 8. The greatest peak in both Figures (7 and 8), again, refers that some material, inside BMD, is creating particles due to the interaction. This property is inherited from the Figure 4.
Using the T_A and T_C fit information, from Figure 4, is possible to calculate the time resolution. The time resolution $\Delta\sigma$ is calculated by:

$$\Delta\sigma = |\sigma_A - \sigma_C| \tag{2}$$

Where σ_A and σ_C are the σs for the gaussian distribution for BMD-A and BMD-C, respectively. The result we found is

$$\Delta\sigma = 57.982 \pm 0.509 ps. \tag{3}$$

This quantity will help to the construction of BMD. The resolution time of all detector can be divided in three resolution times: 1) The arrival resolution times of particles from the collision (Eq. 3), 2) The arrival resolution time of the scintillator-photons created by the scintillator material of BMD and 3) The resolution time of the electronic. Reading this information must be done before the other event occurs. We expected that BMD will have a resolution time at most 50 ps.
In Appendix 1, we show the study for the data in previous subchapter, it is shown that for a smearing of 40 cm, the great peak is not appears.

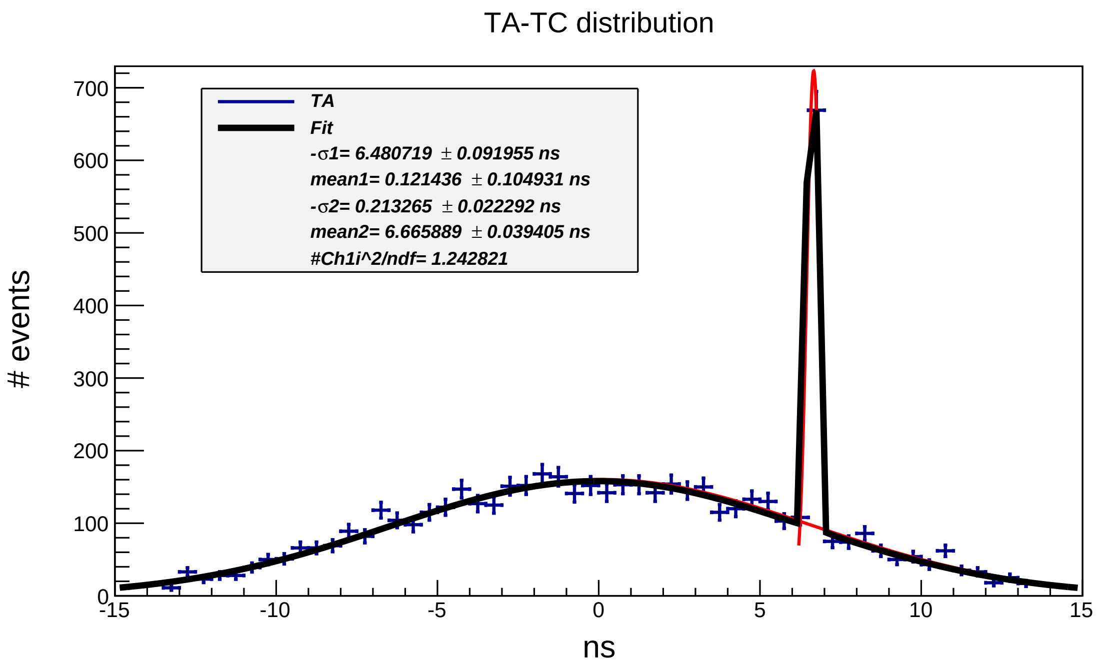

Figure 7: $T_A - T_C$ distribution in the middle Zone.

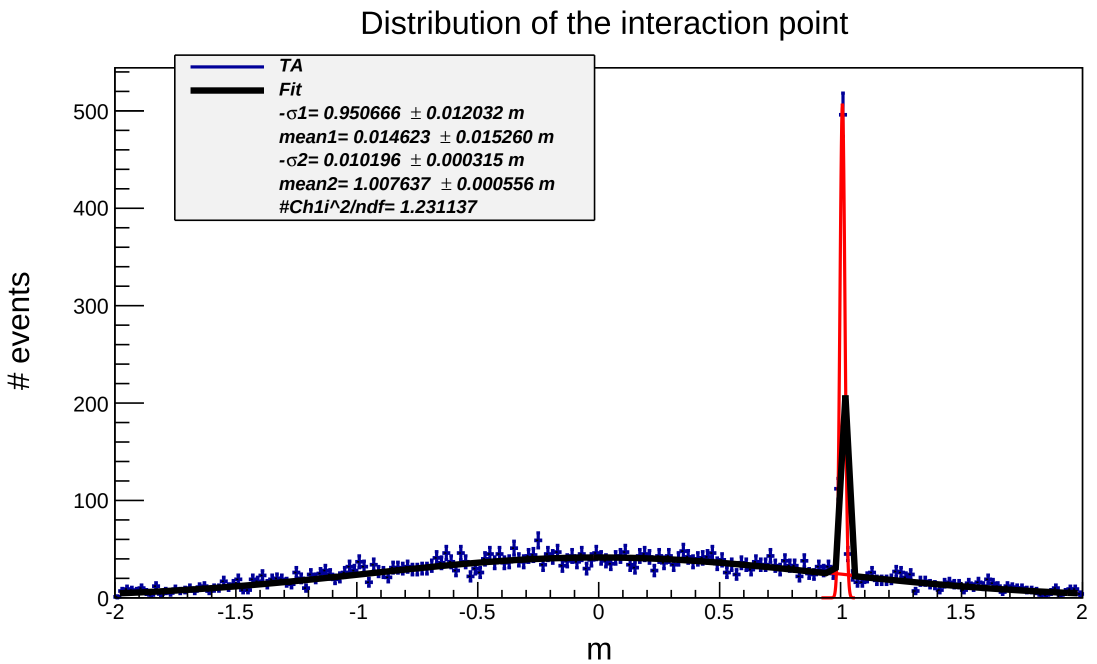

Figure 8: Interaction point distribution arround the origin in BMD for the middle Zone.

4 Conclusions

The implementation of BMD code in the mpdroot framework was successfully. With this new framework, we could calculate in first aproximation the time resolution for BMD. The circular geometry will not be the final geometry for BMD, however this results will not depend on it. Also, we showed that the BMD is able to determine the centrality of the collision and separate the collision inside and outside of BMD. We showed how other detector can modified the arrival time of particles, or, if the collision occurs in a great smearing, as we showed in Appendix 1.

We showed the multiplicity, energy and time distribution for both Ring 2 of BMD, despite the little statistics we can get an idea of the total of primary and secundary particles in that Ring. As we mentioned above this analysis could be done with more detail for each cell of each Ring in BMD. In fact the second result (arrival resolution time) can be done for each cell to and choose the better sections or cells to detemine the better arrival resolution time and improve the resolution time of BMD. Also, with this "puntual" study can be used to determine the centrality, interaction point position, etc. And obtain a better measurement.

There are some details to modify in the code. The geometry of the final detector is our actual object of study. In Appendix 2 is shown our first study using an hexagonal geometry. The geometry will not affect the arrival time resolution calculed in this work, because we used the distance between the detectors and the interaction point, in default, it will affect the determination of centrality and multiplicity, as well as the time resolution of the detector.

As you can see, dear reader, there are a lot work to do, we hope in a short time to have more studies of BMD, which will be an important detector of the MPD.

5 Acknowledgments

I want to thank my PhD thesis advisor Dr. Alberto Sánchez Hernández for his consent and support to came and work at JINR. To Dr. Eduard De la Cruz Burelo for the approval of economic support of the airplane. To the JINR for all expenses that I recived to can work in this project. To Dr. Vyacheslav Golovatyuk and Dr. Vadim Kolesnikov for allowing me to work in this experiement. To the Mexican group Dr. Luis Manuel Montaño Zetina and Alejandro Ayala for making my stay possible. The Dr. Mario Rodríguez Cahuantzi for their comments and tasks in order to learn more and Dr. Pedro Gonzalez Zamora for his work to the implementation of the BMD code in mpdroot.

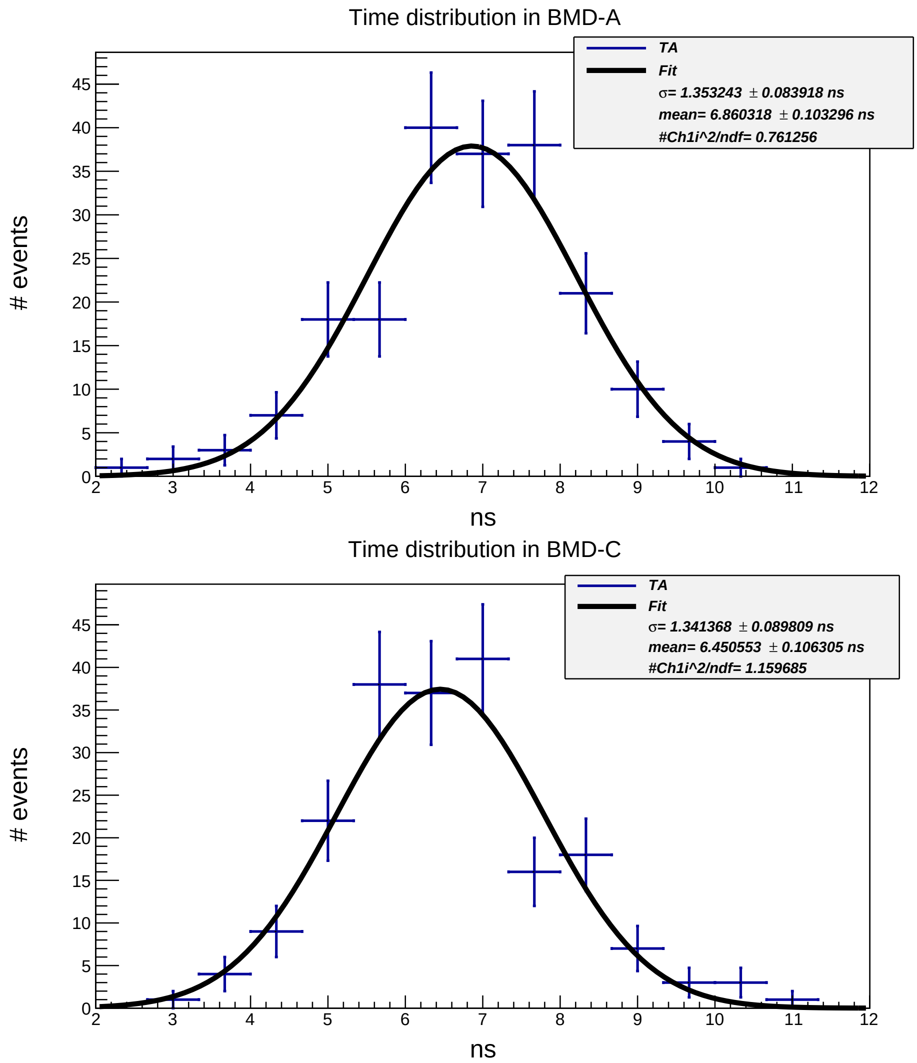

Figure 9: Arrival distribution for a smearing of 40 cm Up: BMD-A. Down: BMD-C.

6 Appendix 1

We show the results for the interaction point distribution with a smearing of σ =40 cm. Using the Au+Au collision at $\sqrt{s}$ = 8 GeV with 200 events.
The arrival time distributions for BMD are shown in Figure 9 for the fastest particle in each event. In Figure 10. The corresponding $T_A - T_C$ distribution is shown in Figure 11. Note that the peak that appears in Figure 7 is not found in this results. The difference is the smearing used in this study, we believe that the reason of the peak in Figure 7 is beacuse the interaction inside some material and produce more particles, the collision occurs between -1.2 m and 1.2 m, because the 99% of probability is arround 3σ, and there is no material in this zone. Finally using Eq. 2 and the information in Figure 9 we found that $\Delta\sigma = 11.875 \pm 5.891$ ps. Its value is less than the first configuration because in this case the collision is near to the geometrical center, it is more symetrical for BMD-A and BMD-C. Then, this result and the result in Eq. 3 are consistent.

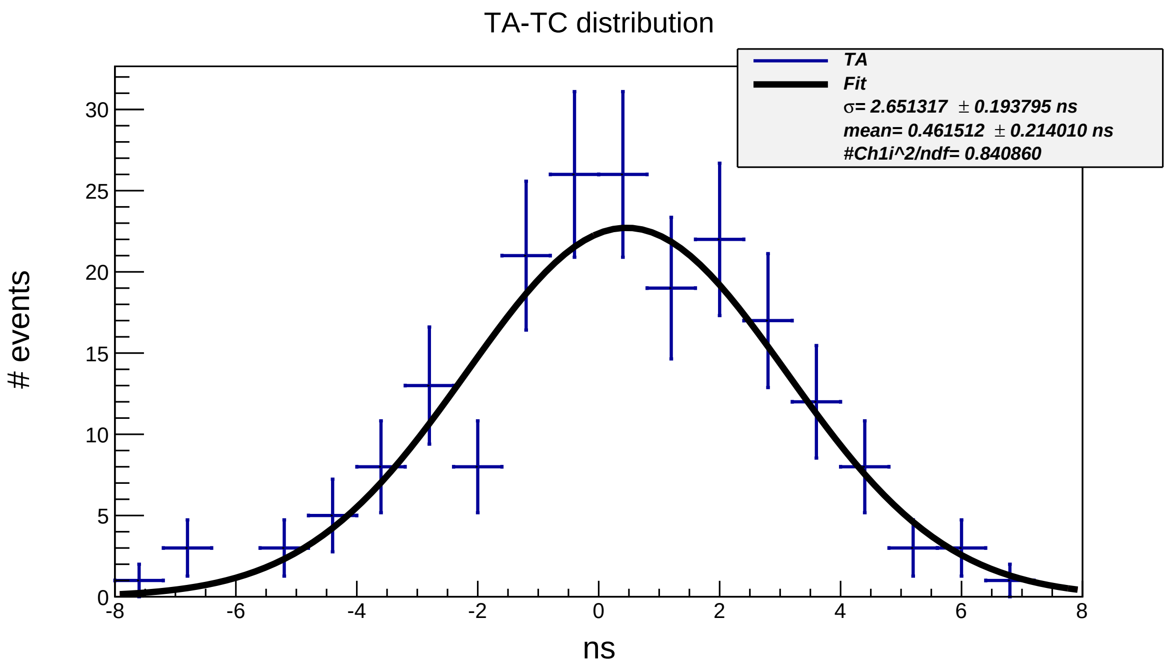

Figure 10: $T_A - T_C$ distribution for a smearing of 40 cm.

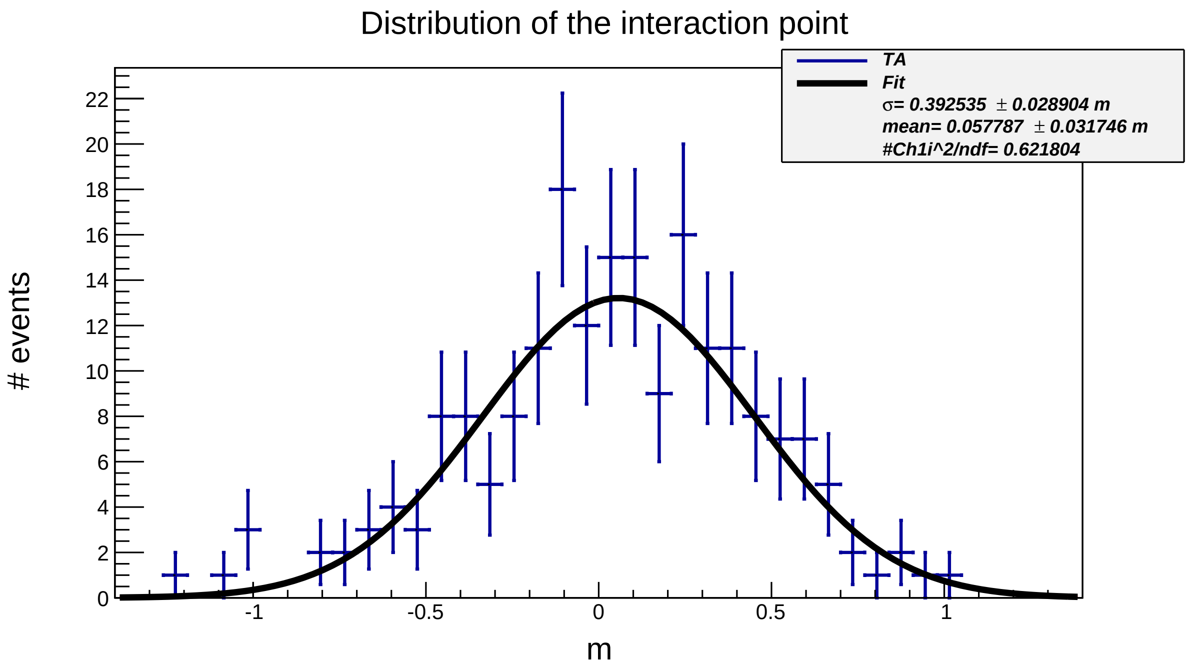

Figure 11: Interaction point distribution for a smearing of 40 cm.

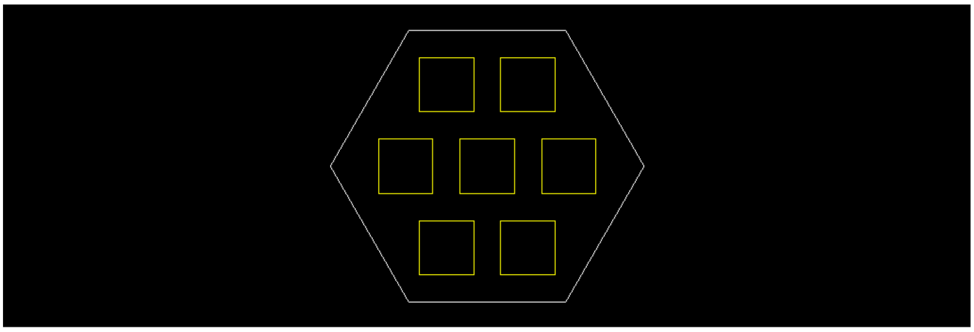

Figure 12: Ilustration for one scintillator cell of BMD-A and BMD-C. The yellow squares represent the APD to collect the scintillator photons. They are located behind the scintillator. Each one covers 2 cm $\times$ 2 cm of area.

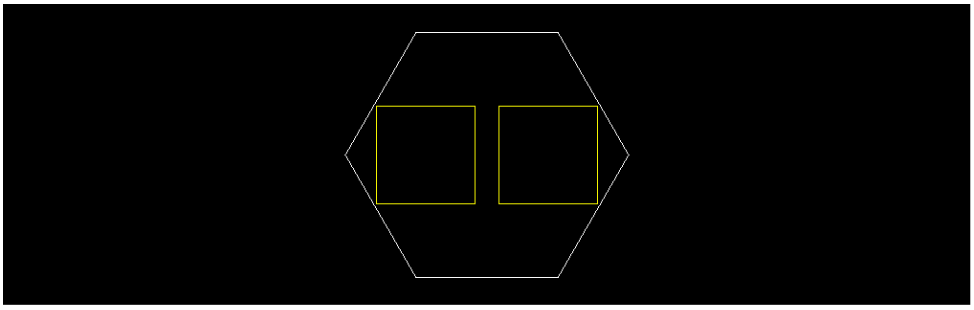

Figure 13: Same description like in Figure 12.

7 Appendix 2

In this Appendix we describe the results obtained by Geant4 using the hexagonal geometry. The principal goal of our detector is to have a resolution at most 50 ps.
We simulated a hexagonal scintillator material which represent each cell of BMD. In Figure 12 is shown the cell. The yellow squares are the representation of APDs. The dimentions of the scintillator material are 10 cm$\times$10 cm and 2 cm of thick. The material we used is Bc404. We considered a π^+ as a primary particle. The energy deposited is calculated by mpdroot and is arround 5 MeV, as it is shown in Figure 3. With this information was posible to make the simulation in Geant4. We considered 100 of events. We condired the fastest photon collectet by each APD and using the technique used in Eq. 2, we obtained that 133.579 ± 21.803 ps $\leq \Delta\sigma \leq 226.409 \pm 37.821$ ps. This resolution time is too bigger for the ideal resolution time.
It is natural to think that if the cell is more smaller, the time resolution will be lower. We made the simulation considering the dimentions 5 cm$\times$5 cm and 2 cm. Due to the dimentions, it is only possible to use two scorers, as is shown in Figure 13. The rsolution time for this arrangement is $\Delta\sigma = 12.908 \pm 4.762$ ps, which is obviously very good. However, we need to cover 1m$\times$1m of area, so, using this dimentions, will be expensive. We will continue to this study, finding the geometry to obtain the ideal resolution time.

References

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[5] https://urqmd.org/

[6] https://git.jinr.ru/nica/mpdroot

[7] https://git.jinr.ru/nica/mpdroot/tree/bmdv1