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Performance of the BEam-BEam monitoring detector proposal for the MPD-NICA experiment at JINR

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Abstract

Here we present the physics performance of the proposed BEam-BEam (BE-BE) monitoring detector for MPD at NICA. We focus on multiplicity studies with BE-BE for Au+Au collisions at $\sqrt{s} = 11\ GeV$. We simulated 98,000 minimum bias lead-lead collisions events. The simulations were done with the Ultra-relativistic Quantum Molecular Dynamics model (UrQMD) within the MpdRoot framework. We also show a time resolution study for BE-BE with Geant 4.

Introduction

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

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

Nuclei are a bound state of protons and neutrons which 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't be observed in isolation. This is the reason why is the study the internal structure of hadronic matter is complicated. Yet, the quark-gluon plasma (QGP) is a state of strongly interacting matter which consists in quarks and gluons which are not confined. [1]

This state of matter could be found in the conditions of temperature and density that existed shortly after the Big Bang, at high temperature and/or density. QGP has been created in some laboratories at different conditions. In Figure 2 a phase diagram of hadronic matter and QGP is shown. 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 in between the critical points makes reference to the phase transition between the states of strongly interacting matter. 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 [2].

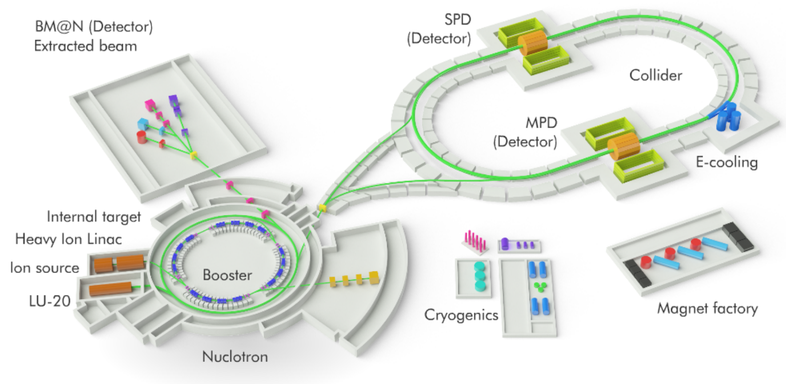


Figure 1: A picture of NICA. It is shown the three experiments and the rest of the components. Image taken from http://nica.jinr.ru/complex.php

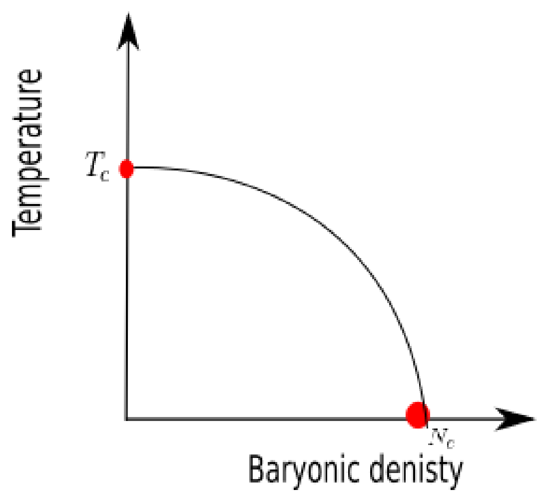


Figure 2: Phase diagram of hadronic matter and QGP. There is a critical point in the temperature T c in which the quarks and gluons are not confined. In the same way there is a critical point N c for the baryonic density from which quarks and gluons are not confined. The curved line between the critical points refers the phase transition between these both states.

To make the MPD measurements more accurate, a new detector is proposed: The BEam-BEam monitoring detector (BE-BE), which will consist of two scintillator detectors. The main goal of this detector is to provide a fast level 0 trigger signal for MPD. Furthermore, BE-BE is suitable for:

- Optimization of events: event plane resolution
- Centrality: interaction point location
- Multiplicity reference estimator
- Trigger system
- Beam monitoring

- Discriminate centrality events from background an beam-gas interaction.
- Determinate the absolute cross section of reaction process.

The BEam-BEam monitoring detector

The MexNICA group [4] is a consortium conformed by students and researchers of six Mexican Universities and Institutes. The goal of the MexNICA group is to make a contribution to the MPD-NICA experiment with the design and construction of a detector consisting of two pieces, each one located 2 meters apart on both sides of the interaction point along the beam pipe. The name given to this detector es BEam-BEam (BE-BE for short).

The inclusion of a detector capable to monitor the beam activity is desirable in collider experiments, during commissioning or regular operations. With the information provided with the detector, it could be possible to setup a trigger system to identify and to discriminate beam-beam minimum bias or centrality events from background and beam-gas interactions. In addition, these types of systems can be used to aid the reconstruction of physical observables of interest in heavy-ion collisions such as:

- Multiplicity of charged particles.
- Luminosity measurement, used to determine the absolute cross section of reaction processes.

The proposal for the BE-BE for the MPD-NICA Collaboration was based in a previous version, on an hybrid geometry consisting of tree rings of a granular hexagonal plastic scintillators array and light sensors, and two rings circular array of plastic scintillators, called Hybrid Geometry. Currently the proposal consists of an array of granular hexagonal plastic scintillators and light sensors, called Panal Geometry. Also, the BE-BE detector will consist of two detectors located at a distance of 2 meters, on each side of the interaction point of the MPD. The pseudorapidity coverage of BE-BE would be $1.69 < |\eta| < 4.36$.. In Figure 3 and 4, it is shown the proposed geometry for the BE-BE detector.

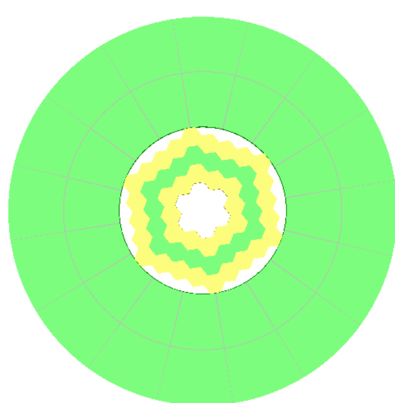


Figure 3: The Hybrid detector proposal Side A

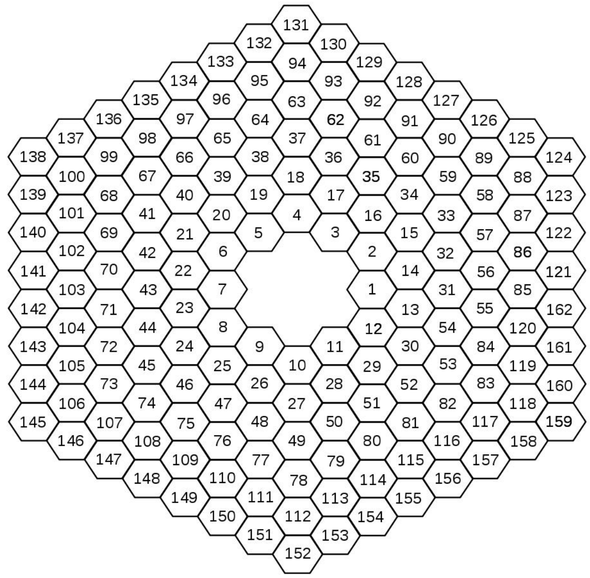


Figure 4: The Panal detector proposal Side A

Simulations and Results

Multiplicity analysis

We show some results for particles in BE-BE, the results are about the multiplicity, energy deposited by all the particles generated and also primary particles. A comparison between the previous geometry (Hybrid) and the new one (Panal) was done, in order to show the improvement of the detector.

We show first the multiplicity from the center of the detector to the outside of the detector. A sample of 98000 minimum bias events of Au-Au collisions at $\sqrt{(}s_{NN}) = 11\ GeV$ has been simulated using the Ultra-relativistic Quantum Molecular Dynamics model (UrQMD) within the MpdRoot framework [5, 7]. The UrQMD is microscopic many body approach which simulates multiple particle interactions, the excitation and fragmentation of colour strings and the formation of decay of hadron resonances in p-p, p-A and A-A collisions. It is based on the co-variance propagation of all hadrons on classical trajectories in combination with stochastic binary scatterings, color string formation and resonance decay. The TPC detector and the BE-BE detector has been included in the simulations. The produced particles has been propagated through the detectors using GEANT3 as transport package.

In Figure 5. We show a graphic that has the starting particles generated (the Kinematics), seen from above the detector. The particles that "hit" the detectors are in light blue, the BE-BE is located at Z=200 and Z=-200. The lines shown at Z=400 and Z=-400 belong to the NICA Calorimeter.

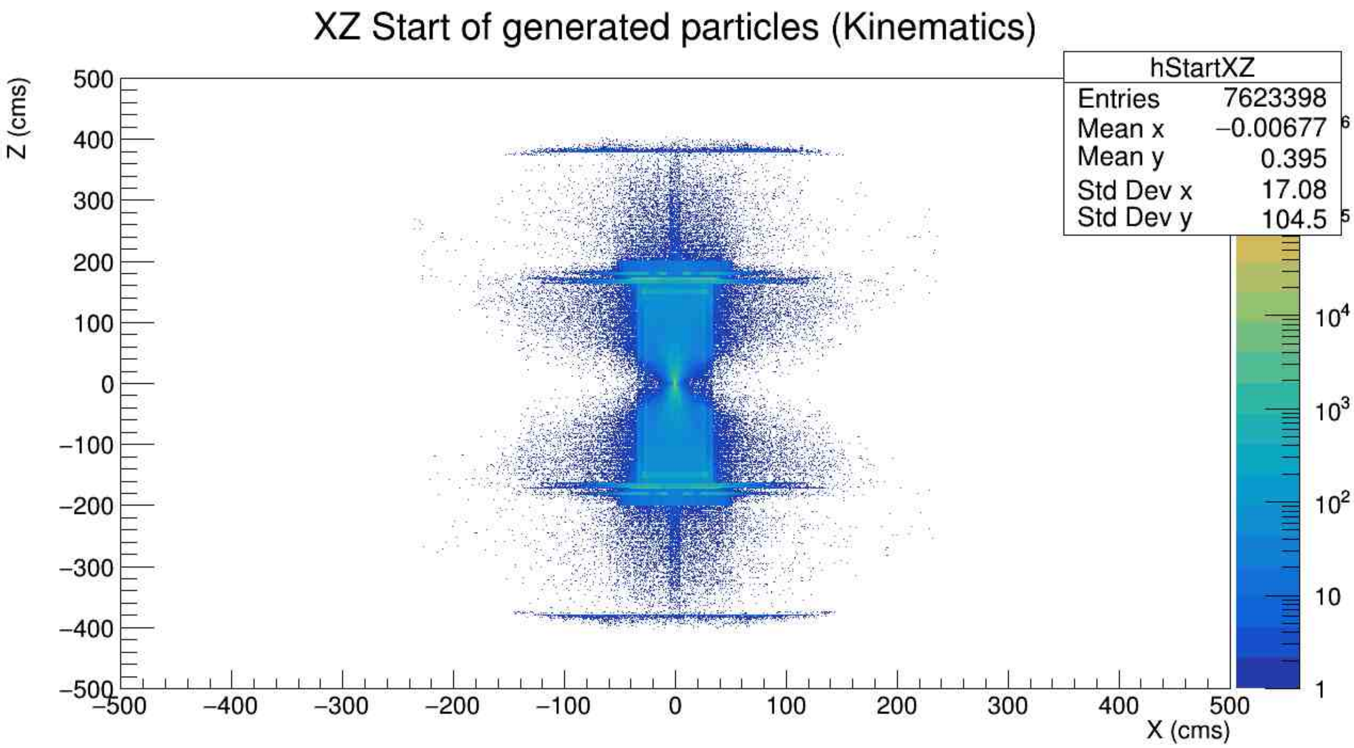
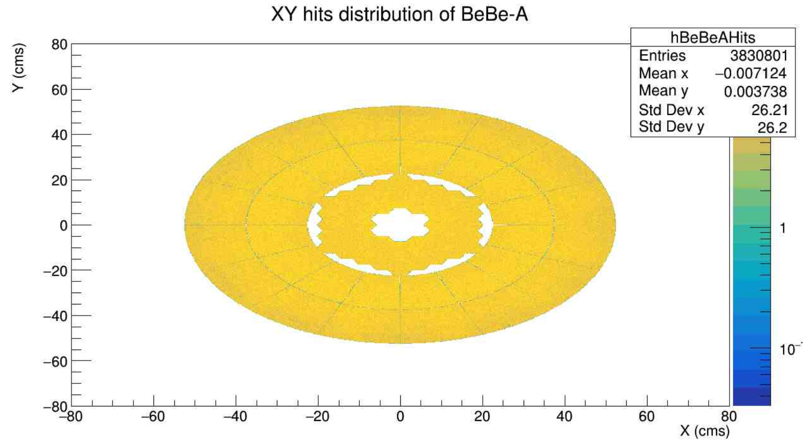


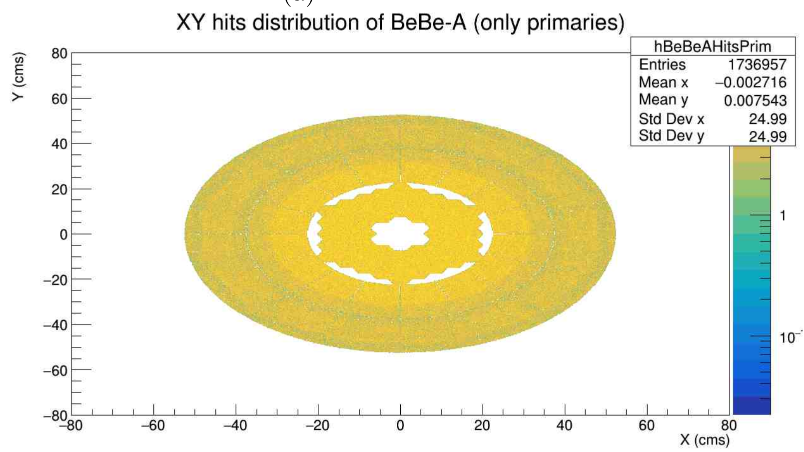
Figure 5: This figure shows the distribution of Kinematics, at the simulation with the BE-BE detector at both sides of the interaction point.

Hybrid Geometry

For the hybrid Geometry, Figure 6 a), the Hits Distribution of the Detector for both sides of it for all the particles generated, and in Figure 6 b) for only primaries.



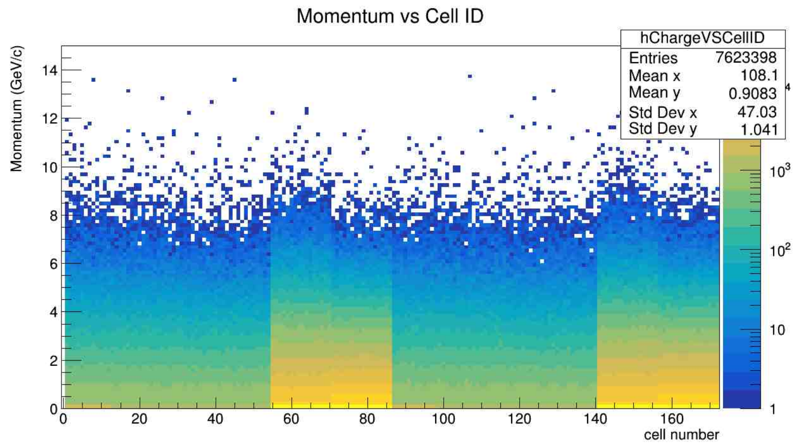
(a)



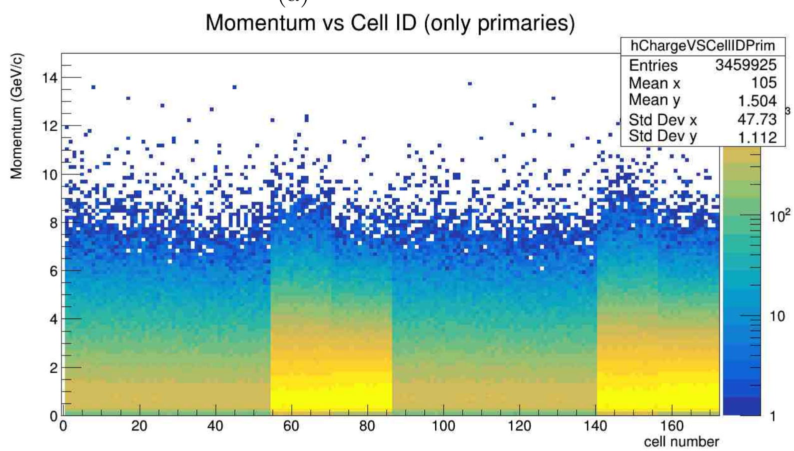
(b)

Figure 6: a) Hits Distribution for all the particles. b) Hits distribution only for primaries

In Figure 7 we show the plot of Momentum vs Cell ID of all the particles a), and for only primaries the graph b).The change of color refers to the energy distribution, within the yellow areas we found more energetic particles, which we can see are collected in the outside rings, not in the inner ones. In the analysis for the primary particles we can see a bigger area covered in yellow for the outer side of the detector, that means the most energetic particles will be collected in this areas.



(a)

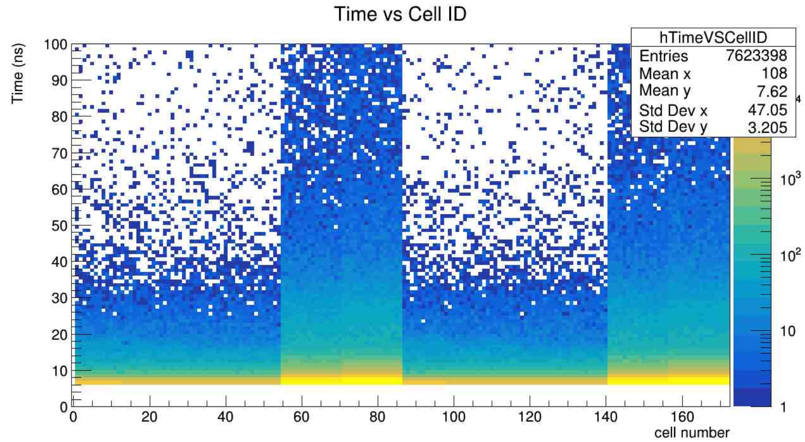


(b)

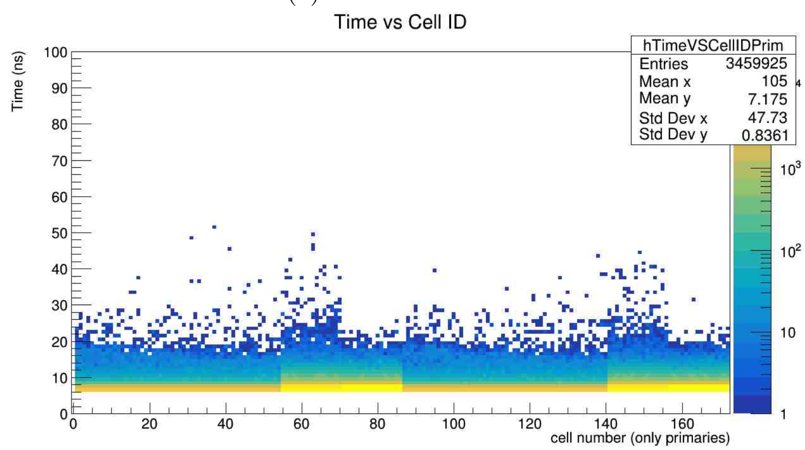
Figure 7: a) Momentum vs CellID for all the particles. b) shows Momentum vs CellID only for primaries

In Figure 8 we have the Time vs CellID plot. This analysis was made using the number of cell of the detectors, however, as we can see there it is the same as doing the analysis from the innermost ring to the outer ring.

For primary particles the most probable value for their time of flight is around 6.5 ns with a little tail, which grows at the end of the outside most rings. At the first graph, we see that with all the events simulated, we found the presence of background in all the detector.



(a)



(b)

Figure 8: The a) plot shows the Time vs Cell ID for all the particles. The b) plot shows only for primaries

In Figure 9, we have the Multiplicity plot obtained from innermost ring to the outermost ring, this graph is multiplicity against the cells of the ring. First the cells at the innermost ring. We see that for the fist part of the plot (corresponding to the ”hexagons based” part of the detector), this multiplicity is lower and maintains itself on the same values. Second part corresponds to the ”circular” part of the detector, this multiplicity is higher and has a little tail at the end, this two parts of the plots correspond to the first part of the BE-BE (side A). The third and the fourth are the same as the first two, because they correspond to the second part of the BE-BE (side C), which is something we would expect since both sides A and C, are equal.

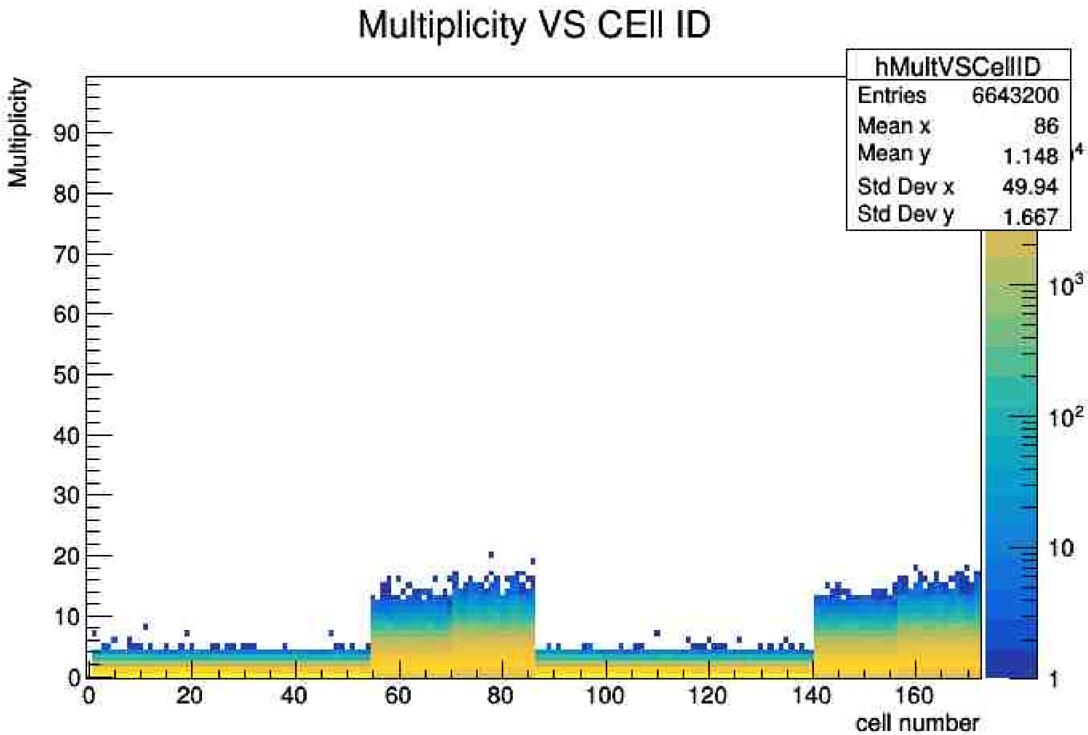
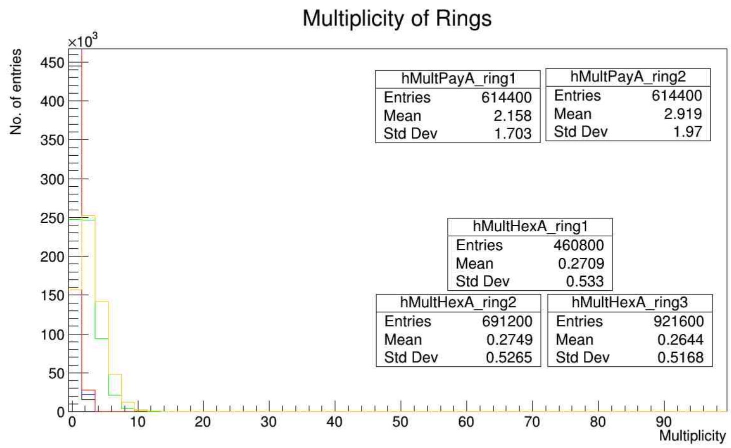
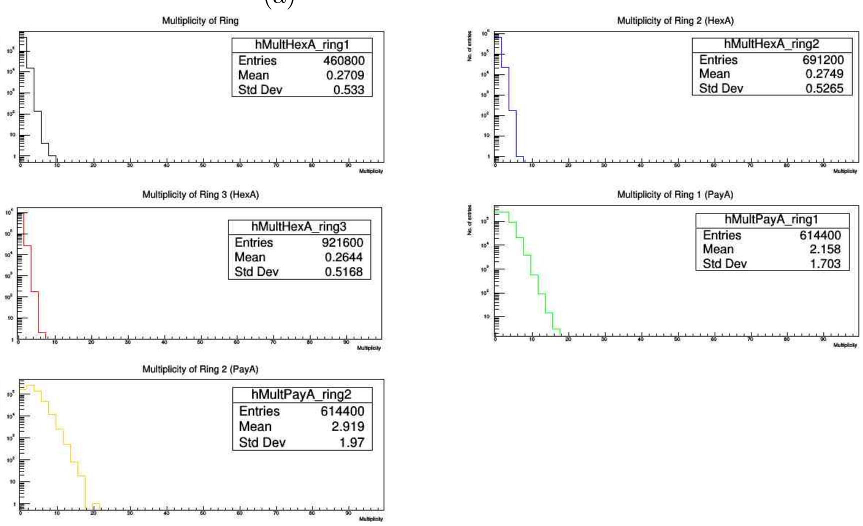


Figure 9: Multiplicity VS Cell ID

Lastly, Figure 10 shows the Multiplicity obtained per ring vs the number of entries in each ring. This plot shows only results for one side of the BE-BE. The Figure 10 a), shows the graphics overlapped, so we could see the similarities of the results. This results match the previous information obtained, since the inner hexagonal rings of the detector have similar multiplicities, but they are different from the two outside rings,this two last rings have a significantly bigger multiplicity that the inner rings.



(a)

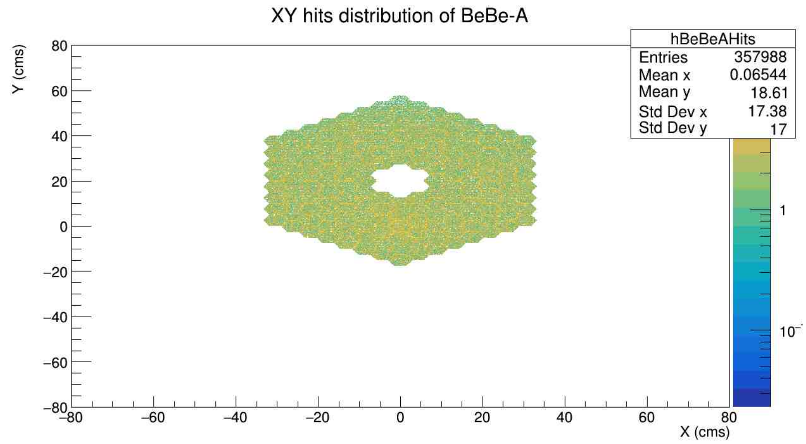


(b)

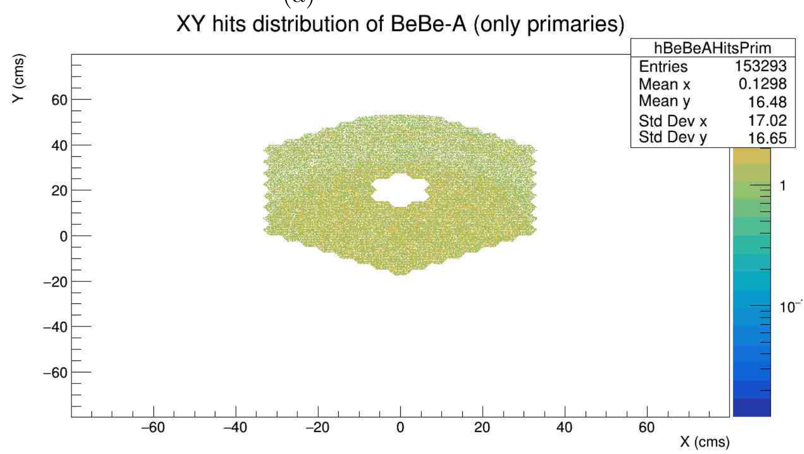
Figure 10: The a) plot shows a graph of Number of entries vs Multiplicity of each of the rings of the Hybrid proposal. The b) plot shows the Number of entries vs Multiplicity for each ring independently.

Panal Geometry

For the Panal geometry, we see in Figure 11, the Hits Distribution of the Detector for both sides of it for all the particles generated, and in Figure 11 for only primaries. The difference of course is that for all the particles we see more green points at the detector.



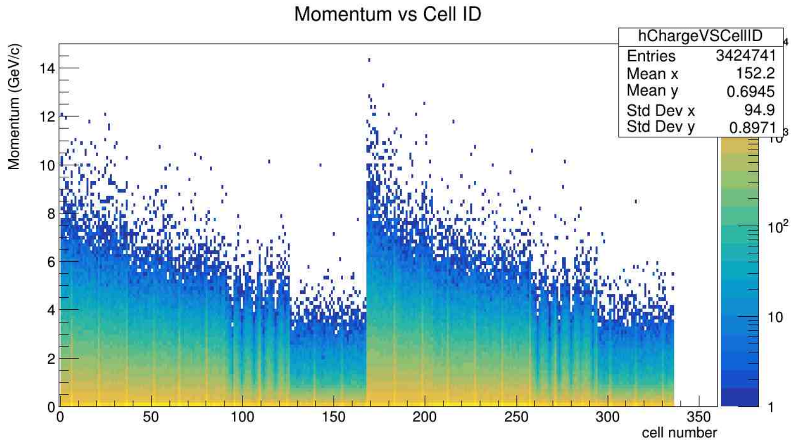
(a)



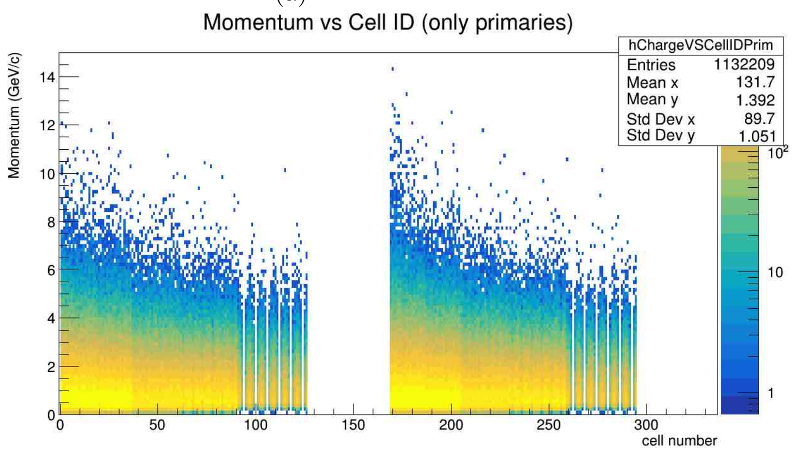
(b)

Figure 11: a) Shows the Hits Distribution for all the particles. b) Shows only for primaries

In Figure 12 we see the plots of Momentum vs Cell ID of all the particles on a), and for only primaries the graph on b). This results show us that near the center of the detector we found more energy collected. Since the areas covered in yellow show a bigger amount of energy in comparison with the blue areas. collected for both analysis.



(a)

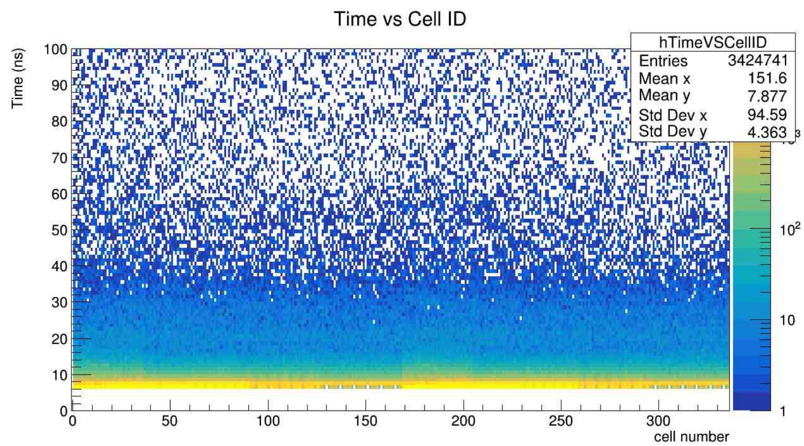


(b)

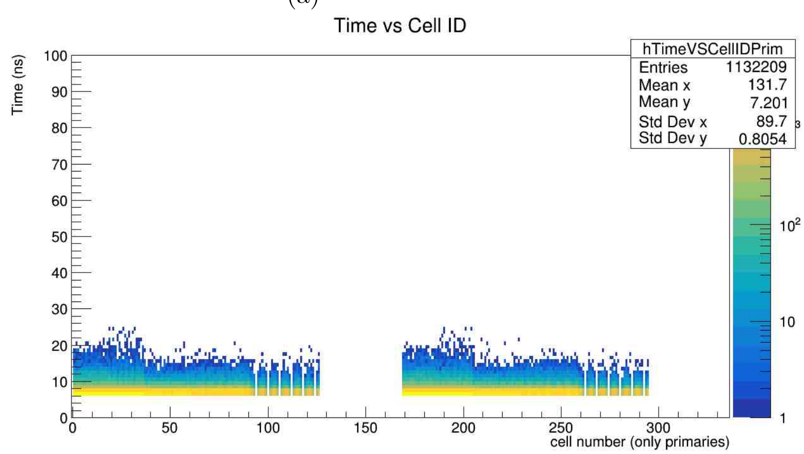
Figure 12: The a) plot shows the Momentum vs CellID for all the particles. The b) plot shows only for primaries

In Figure 13 we have the Time vs CellID. This analysis was made using the number of cell of the detectors, however, as we can see there it is the same as doing the analysis from the innermost ring to the outer ring.

In the primaries particle analysis we see that the most probable value for the time of fly is around 6.5 ns with a tail much smaller that the analysis made for the hybrid geometry, which does not exist at the end of the outside most rings, but grows near the first third area of the detector. At the first plot, we see that with all the events simulated, we found the presence of background in all the detector.



(a)



(b)

Figure 13: The a) plot shows the Time vs Cell ID for all the particles. The b) plot shows only for primaries

In Figure 12, we have the Multiplicity from innermost ring to the outermost ring. If the compare this graphic against the one with the Hybrid Geometry, we conclude that the Multiplicity at this proposal is higher in the center of the BE-BE, with values near 18-20; and the lows down a little at the outer part of the detector.

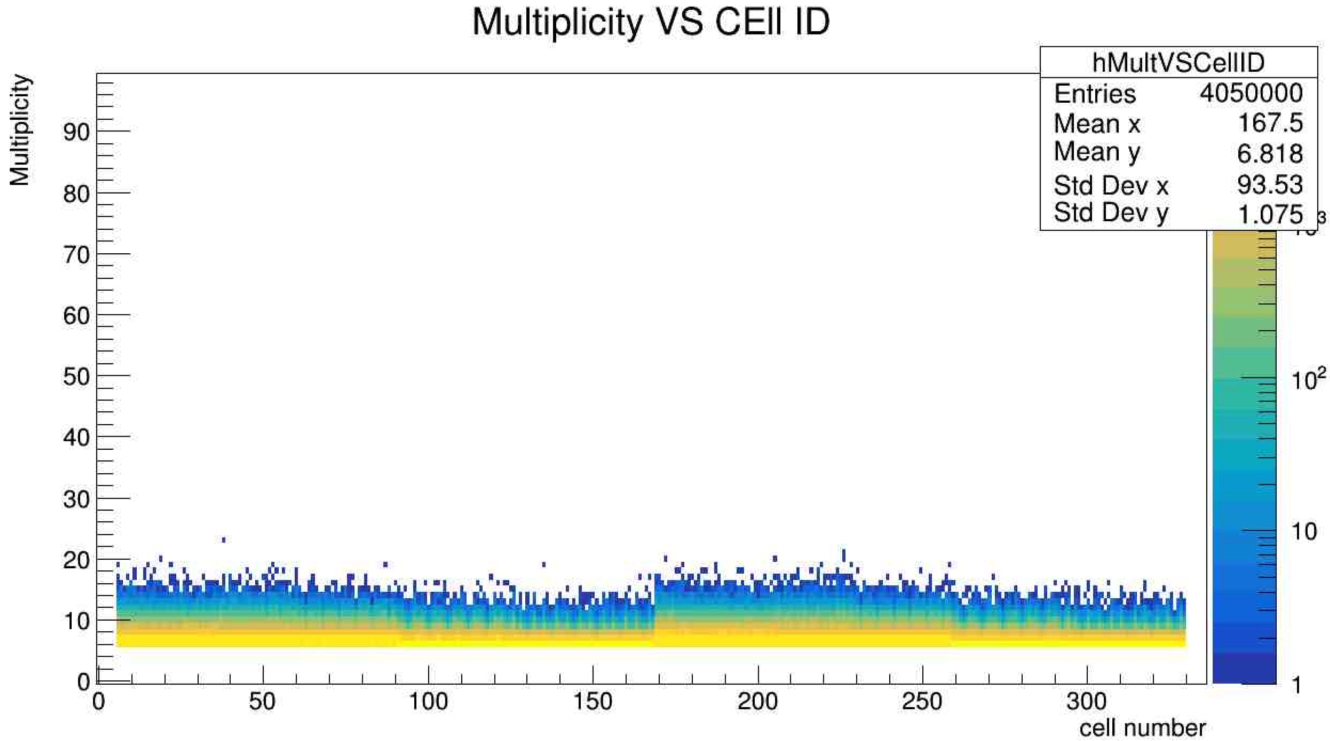
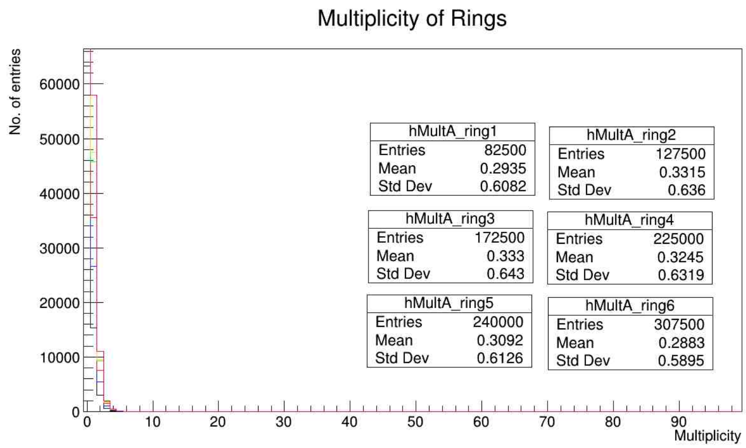
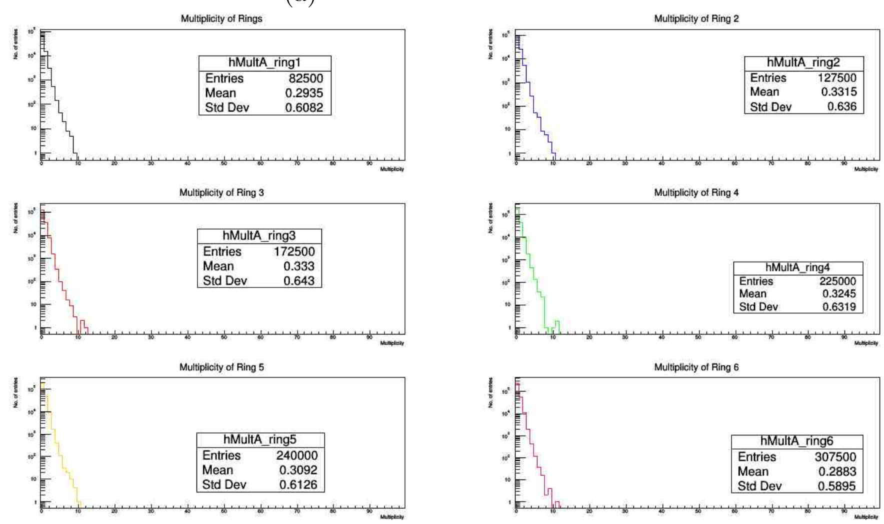


Figure 14: Multiplicity VS Cell ID

Lastly, Figure 15 shows the Multiplicity obtained per ring vs the number of entries in each ring. In this plot we see that the number of multiplicity on every ring is really similar all over the detector. To mention also that this results are only for one side of the BE-BE. This results match the previous results obtained.



(a)



(b)

Figure 15: The a) contains all the graphics of each of the rings of the Panal Geometry proposal, all the six of them are overlaped, so we see that are similar. b) Contains the same graphics but shown individually.

Arrival Time resolution measurements

In this Section we describe the results obtained by Geant4 using the hexagonal geometry. The principal goal of our detector is to reach a time resolution of 30 ps. We simulated a hexagonal scintillator material which represent the cells of Be-Be and the APDs.

From a previous result [8] it was shown that with the dimensions of the scintillator material set at $10cm \times 10cm$ and $2cm$ of thick. Using BC404 as the material, considering π^+ as a primary particle, and working at 5MeV and simulating 100 events; we obtained $133.579 \pm 21.803ps \leq \Delta\sigma \leq 226.409 \pm 37.821ps$. This resolution time was too big for the ideal resolution time.

So it was is natural to think that if the cell was smaller, the time resolution will be lower. Here we show the results obtained.

We made the simulations setting the hexagons dimensions at $5cm \times Ncm$ and M APD's sensors at $6mm \times 6mm$ with BC404, simulating X number of events of π^+ with 5 GeV hitting at the center.

Te results found are:

Dimensions $= 5cm \times 2cm$	1 sensor	2 sensors	4 sensors
BC404	44.27±2.69	33.33±2.93	28.02±2.05
$\frac{\sigma_{1sensor}}{\sqrt{M}}$		(31.72±2.08)	(22.14±2.14)

Table 1: Results of σ

For this second results we also simulated the material BC422.

Dimensions $= 5cm \times 1cm$	1 sensor	2 sensors
BC404	35.07±4.07	24.79±2.9
BC422	28.66 ±3.44	19.88±2.61(20.26±20.43)

Table 2: Results of σ

As we can see the resolution time for this arrangement is really closed to the goal of 30 ps, which is obviously very good. Unfortunately we need to cover $1m \times 1m$ of area for each side of the Be-Be detector, that means using this dimensions for the hexagons will be expensive. More results of this study will be shown in a paper that is being prepared for publishing.

Conclusions

The analysis made using codes in the mpdroot framework was successful. With this framework, we made a complete analysis for the Multiplicity of the detector in two of the geometries that have been proposed.

The hybrid geometry will not be the final geometry for the BE-BE detector, but the Panal Geometry has shown to have more of the characteristics required for the MPD-NICA. A further analysis around the time resolution will be made by the MexNica collaboration it search for the ideal detector. This results will be arranged in an article in a near future.

We showed the multiplicity, energy and time distribution for the detector, with this big amount of statistics we got an idea of the total of primary and secondary particles in every ring and side of the detector. This analysis was made at the level of cells, from the inner part of the detector to the outer part in the detector so the approaches of the statistics shown in this report are quite accurate.

The second result, the resolution time, can be done for each cell of the detector, also we can choose the better sections or cells to determine the better arrival resolution time and improve the resolution time of BE-BE. Also, this "punctual" study can be used to determine other characteristics of the BE-BE, such as the centrality, interaction point position, etc. We can still "play" with the codes to obtain a better analysis, and better options for the construction, such as changing the dimensions of the cells and changing the materials and APD's position and number.

The geometry of the final detector is our actual object of study.

Dear reader, there is still lot work to do, in order to find the best proposal that fits the characteristics need for the detector. We are currently working on more analysis, to show in a short period of time, including more studies done to the BE-BE, which will be an important detector of the MPD-NICA.

Acknowledgments

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