Study of the trigger on nucleus-nucleus interactions for the BM@N experiment using a Geant4 + QGSM software package

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Study of the trigger on nucleus-nucleus interactions for the BM@N experiment using a Geant4 + QGSM software package

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Abstract. Monte-Carlo simulation was used to study the background conditions which affect the performance of the trigger system of the BM@N experiment. A GEANT4 + QGSM software package was used for the simulation. The influence of the background from δ-electrons was estimated and measures to minimize this background were evaluated. Addition of lead shielding and a small change in the geometry of the target zone allow to reduce the background. The efficiency of the modified trigger system was calculated for Au+Au collisions as a function of the impact parameter. The efficiency is 100% for central and semi-central collisions.

1. Introduction

Several projects are currently being developed at the Laboratory of High Energy Physics of JINR at the NICA-Nuclotron accelerator complex [1] with the goal to investigate the properties of hot and dense baryonic matter. One of these projects is a fixed target experiment BM@N [2]. The main focus of the experiment is to study nucleus-nucleus collisions in the energy region 2.0 - 4.5 GeV / nucleon.

The trigger system of the BM@N experiment performs two key functions: generates a fast trigger on nucleus-nucleus interaction and provides a precise start signal for the time-of-flight system. The trigger system consists of beam counters, which detect each beam particle incident on the target, and multichannel multiplicity detectors, which register charged particles coming from the interaction in the target and generate trigger signal based on the number of fired channels. In previous physical data taking runs a large number of background events was observed in which trigger signals were generated even when incoming beam ions passed the target without interaction. In this report we present a simulation study of the detected background and changes in the design of the target region which are proposed in order to optimize the performance of the trigger system. The study was done using the GEANT4 software package [3] and the QGSM nuclear reaction model [4].

2. Trigger multiplicity detectors

The trigger system of the BM@N includes two multichannel multiplicity detectors, BD (Barrel Detector) and SiD (Silicon Detector), which are located near the target and detect charged particles emitted from the target in a wide range of angles. The geometry of the target area of the BM@N experiment is presented in Figure 1: on the left side - the configuration used in the 2018 run with Ar and Kr beams, on the right - the configuration proposed for future runs with heavy ion beams. The BD detector consists of 40 scintillation strips $150 \times 7 \times 7\text{мм}^3$, placed around the target at a radius of 46 mm from the beam axis [5].

The background observed in the 2018 run was attributed to δ-electrons making additional counts in the multiplicity trigger detectors. During the run, it was possible to partially reduce this background by placing a few millimeters thick Pb-shield inside the Barrel Detector. Based on the observations in the run and on the results of this study the BD-detector for future runs will be surrounded by Pb-shields placed both inside and outside the detector.

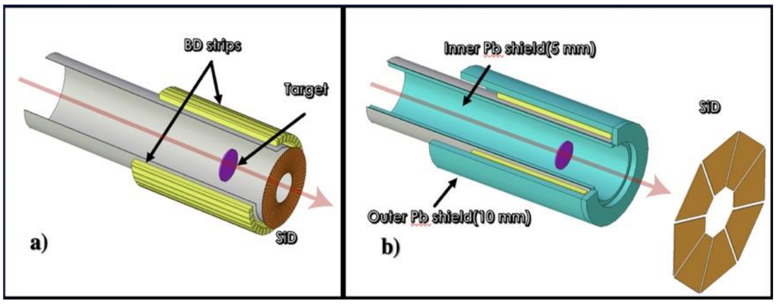

Figure 1. The geometry of the target area of the BM@N experiment: a) used in the 2018 run with Ar and Kr beams; b) proposed for future runs with heavy ion beams.

However, additional material may influence the trigger efficiency of the BD-detector for nuclear-nuclear interactions. Therefore, optimization of the thickness and positioning of these shields was one of the subjects of the present study.

The silicon detector SiD has a thickness of 525 microns and consists of 64 radial strips. The dimensions and geometry of this detector will be modified for the future runs, but the number of channels will remain unchanged. The granularity of the detector is chosen to provide a possibility to select nuclear interactions with different impact parameters.

In case of the SiD-detector, the option of placing additional Pb-shields near the detector in order to reduce the background from δ-electrons is excluded because material of these shields will affect detection of produced particles entering the forward spectrometer of the BM@N. However, since the target area is placed in the magnetic field and δ-electrons have relatively low momenta, the background can be reduced by shifting the SiD-detector downstream to a larger distance from the target. This opportunity was also investigated in the present study.

3. Study of the background conditions in the Ar + Cu reaction

In the simulation of the trigger system response in the Ar + Cu reaction, the conditions of the 2018 run were reproduced. A 3.2 GeV/n beam of Ar nuclei was incident on a Cu target with thickness of 1.67 mm and diameter of 34 mm. The trigger multiplicity detectors and target were placed in the air and in a magnetic field of 0.9 T. The SiD-detector was located at a distance of 70 mm from the target, as shown in Figure 1a.

Energy deposition from all the charged particles, which were generated in an event and intersected the trigger detectors, was calculated for every scintillation tile in the BD-detector and every strip in the SiD-detector. A signal from a certain channel of the BD-detector was considered as meeting trigger conditions if this total energy deposition in the corresponding strip exceeded 400 keV. The threshold for triggering channels of the SiD-detector was set to 30 keV. Both values approximately correspond to amplitude thresholds set in the trigger electronics during the actual experiment.

In order to estimate the count rate of false triggers and to determine main sources and characteristics of the background a set of events was generated with a condition that the incident nucleus passed the target area without interaction and the signals in the trigger multiplicity detectors were caused only by δ-electrons produced along the beamline in the beam counters and other upstream detectors, in the air and the target. Several configurations were studied: I) with the target, while the BD-detector has no Pb-shields; II) the same configuration, but the target is removed; III) with the target, when a 5 mm thick inner and a 10 mm thick outer Pb-shields were added to the BD-detector; IV) with the target, when only the inner shield is added. 10^4 events were generated for every configuration among which about 9×10^3 fulfilled the criteria that incoming ion passed the beam detectors and the target area without interaction.

The number of counts of individual channels in the BD-detector as a function of the channel number is presented in Figure 2. The observed asymmetry corresponds to deflection of negative particles by the magnetic field. Comparison of the count rate in configurations with and without the target shows that the main source of the background δ-electrons is the target itself. Addition of the inner shield helps to reduce the background only partially, because significant fraction of δ-electrons is emitted in forward direction and after turning in the magnetic field these electrons hit the BD scintillators from the outer side. Addition of the outer shield reduces the background to a greater degree, but also not completely. The remaining background is mainly caused by δ-electrons hitting the ends of the BD scintillators, and can be suppressed by an additional 10 mm thick lead ring, shown in Figure 1b.

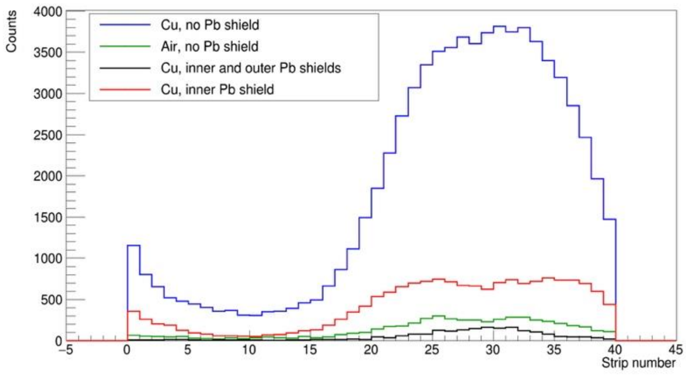

Figure 2. The number of background counts in individual channels of the BD-detector in the registration of Ar+Cu collisions.

The probability of background triggers depending on the threshold on the number of activated channels in the detectors is presented in Figure 3. For comparison, the probability of generating an interaction trigger on nucleus-nucleus collision in the target is also shown. The QGSM model was used to generate events with nucleus-nucleus collisions. All inelastic events were selected (simulating the minimum-bias trigger). The 3.5% probability of an inelastic collision of Ar nuclei in a Cu target of a selected thickness is reflected in the normalization of the presented distributions.

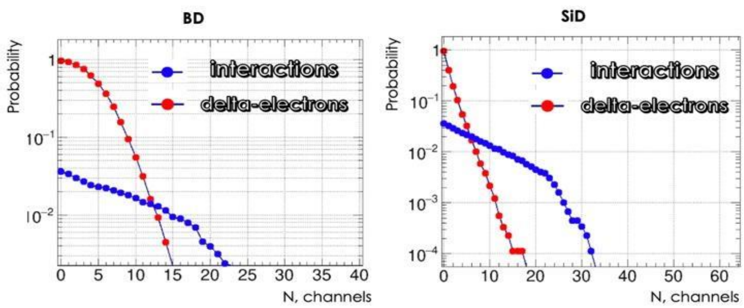

Figure 3. The probability of true (blue) and false (red) triggers in the registration of Ar+Cu collisions as a function of the threshold on the number of counts in the BD (left) and SiD (right) detectors.

One can see that at low trigger thresholds the rate of background events is very high, and at the same time setting higher thresholds will result in the loss of a significant fraction of physical events. It is worth pointing out that the selectivity of the trigger increases if thinner targets are used, because the number δ-electrons knocked-out from the target by a beam ion decrease with the reduction of the thickness of the target, while the number of secondary particles produced in a nucleus-nucleus interaction remains unchanged.

4. Optimization of the trigger detectors

The Au+Au reaction was chosen for the study of trigger response in the future experiments with heavier beam nuclei, because the background from δ–electrons is highest for the Au beam. A beam of gold nuclei with energy 4.2 GeV/n was incident on a Au target with a thickness of 300 μm (the probability of an inelastic collision is 1.3%). As it is planned for the upcoming runs of the BM@N experiment, the trigger detectors and the target were placed in a vacuum environment and in a magnetic field of 0.9 T.

As already mentioned, the background from δ-electrons in the SiD-detector can be reduced by shifting the detector along the beam axis further from the target. The probability of false triggers, i.e. when the beam ion passed the target without interaction, is shown in Figure 4 for two positions of the

SiD-detector: 70 and 120 mm from the target. The obtained result demonstrates a strong reduction of the background due to deflection of the δ-electrons by the magnetic field.

Suppression of the background in the BD-detector was achieved by adding Pb-shielding (see Figure 1b). The thickness of the inner shield was chosen to be 5 mm, it is limited by the inner diameter of the detector and the outer diameter of the vacuum tube. The thickness of the outer shield is 10 mm. The ends of the scintillation strips were protected by an additional 10 mm thick Pb-ring.

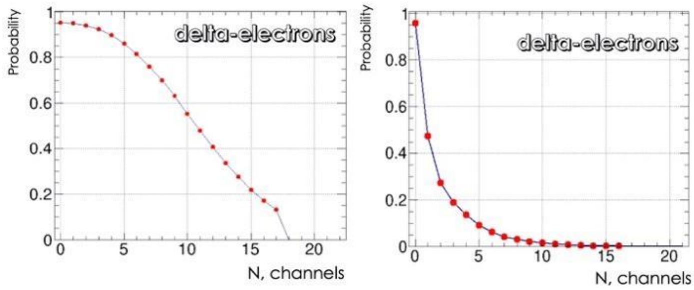

Figure 4. The probability of background triggers in the SiD-detector for Au+Au conditions and two positions of the detector: 70 mm (left) and 120 mm (right) from the target.

Probabilities of background triggers and triggers on interactions as a function of the threshold number of activated channels for the Au + Au reaction are shown in Figure 5. The expected beam intensity in the experiment is 10^6 per second, while the data acquisition system of the BM@N can record events with a frequency of the order of 10^4 Hz. Therefore, suppression of background triggers to a level of about 10^{-3}will be sufficient.

One can see that this level can be achieved with relatively low thresholds which will allow efficient detection of a large fraction of events with interactions in the target. It can also be noted that the granularity of the detectors corresponds to the expected multiplicity of secondary particles in Au + Au collisions.

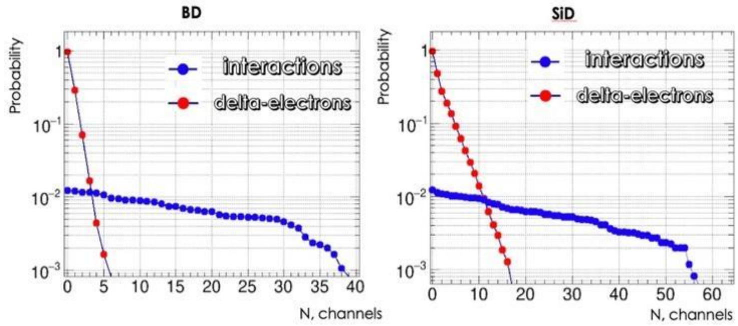

Figure 5. The probability of true (blue) and false (red) triggers in the registration of Au+Au collisions as a function of the threshold on the number of counts in BD (left) and SiD (right) detectors.

The 2D-distributions presented in Figure 6 show how the multiplicity of counts in the BD and SiD detectors depend on the impact parameter in Au + Au collisions. Threshold levels on the multiplicity in the BD and SiD detectors can be applied in the trigger logic either to individual counts in each detector, or to the sum of counts in two detectors. Trigger efficiency as a function of the impact parameter in Au+Au collisions, shown in Figure 7, was studied for the following threshold conditions: 18 channels in the SiD detector, 6 channels in the BD detector, and 18 channels for the sum of counts in two detectors. These thresholds correspond to the background suppression to a level of 10^{-3}. One can see that for all combinations the efficiency is 100% for central and mid-central Au+Au collisions.

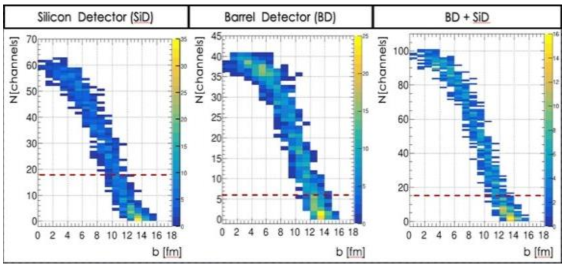

Figure 6. The number of counts in the trigger detectors (SiD, BD, BD+SiD) in the registration of Au+Au collisions depending on the impact parameter.

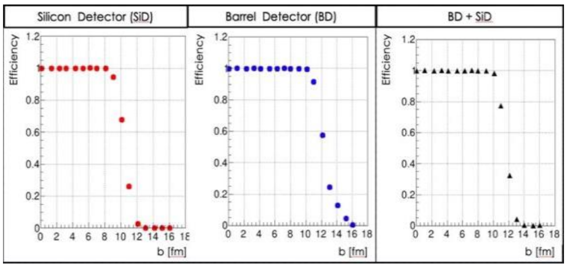

Figure 7. Efficiency of the trigger detectors (SiD, BD, BD+SiD) in the registration of Au+Au collisions as a function of the impact parameter.

5. Summary

The trigger system developed for registration of nuclear-nuclear interactions in the BM@N experiment includes two multichannel multiplicity detectors, scintillation BD and silicon SiD. The trigger system was tested in the 2018 run with argon and krypton beams. These tests demonstrated the existence of a strong background which caused a large number of counts in the multiplicity detectors when the beam ions passed through the target without interaction. The simulation studies presented in the current research showed that the main source of the background are δ-electrons knocked-out by beam ions from the target. In the BD-detector the background can be suppressed by using additional Pb-shields. The background in the SiD-detector decreases if the detector is moved further from the target along the beam axis. Based on the results of the simulation, the design and geometry of the target area of the experiment were optimized. Expected performance of the trigger system in the future runs with heavy ions was studied for the Au+Au reaction. With the background rate suppressed to a sufficient level, the efficiency of the trigger is 100% for central and mid-central collisions.

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