

Studies of Short Range Correlations in inverse kinematics at BM@N at the NICA facility

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Abstract.

NICA-Nuclotron (Nuclotron-based Ion Collider fAility) is a new accelerator complex being constructed at the Joint Institute for Nuclear Research (Dubna, Russia) to study properties of dense baryonic matter. BM@N (Baryonic Matter at Nuclotron) is the first fixed target experiment at the NICA-Nuclotron facility. The aim of the experiment is to study collisions of relativistic ion beams of the kinetic energy from 1 to 4.5 AGeV with fixed targets. BM@N energies are perfectly suitable for strange hypernuclei investigation. This year BM@N started a new physics program aiming at studying the Short Range Correlations (SRC). SRC are brief fluctuations of two nucleons with high and opposite momenta, where each of them is higher than the Fermi momentum for the given nucleus, and the center of mass momentum is close to zero. The presence of SRC pairs within nuclei and their properties have important implications for nuclear physics, high energy physics, and astrophysics. The BM@N setup uses a carbon beam hitting a liquid hydrogen target, which makes it possible to detect the residual nucleus after hard knock-out of the two SRC nucleons. We present an overview of the main detection systems used for the SRC measurement as well as the first results from the tracking detectors.

1. BM@N Opens Up a New Physics Program Devoted to SRC

The aim of the NICA-Nuclotron accelerator complex is to study the properties of dense baryonic matter, strong interactions, search for signs of the deconfinement and critical point [1]. BM@N is the first experiment of the NICA project with fixed target. The purpose of the experiment is to study hot and dense matter in relativistic ions collisions up to Au. BM@N energies lie in the region of the production of the main strange hypernuclei and are perfectly suitable for this investigation [2]. Forty percent of the last BM@N data taking period were devoted to the first fully exclusive measurement of Short-Range Correlations (SRC) in inverse kinematics.

Approximately 20% of nucleons in a nucleus belong to strongly interacting, short-lived pairs, SRC pairs. Nucleons within these pairs have high absolute and low center of mass momentum (relative to Fermi momentum). Almost all high-momentum nucleons in nuclei belong to SRC pairs. About 90% of SRC pairs in a given nucleus contain a proton and a neutron, the remaining 10% is equally distributed between proton-proton and neutron-neutron pairs [3, 4, 5, 6, 7]. SRC pairs are an important part of the nuclear wave function and also the densest objects available



on earth. This makes them relevant for understanding of dense baryonic matter and neutron stars.

2. Reaction Kinematics and Experimental Setup

Traditionally, properties of SRC pairs are studied using hard knock out reactions, where the beam probe interacts with a single nucleon. In case the scattering occurs on an SRC nucleon, the pair breaks apart, and both the scattered and the knocked out nucleons can be detected. Since SRC nucleons have high momenta within the pair, the recoil partner is likely to emerge as well.

At BM@N the reaction kinematics is inverted: a carbon beam with momentum P_A hits a liquid hydrogen target. In this case the residual nucleus continues moving along the beam and therefore can be studied. This type of the SRC measurement was never done before. Figure 1 shows the reaction kinematics for SRC studies at BM@N. A proton with momentum P_{miss} from the SRC pair is scattered off a target proton. After the scattering, the leading (P_1) and the scattered (P_2) protons have a large angle with respect to each other. The correlated nucleon from the SRC pair emerges forward (P_{recoil}). The nuclear system with A-2 nucleons after interaction continues moving along the beam direction with momentum P_{A-2} .

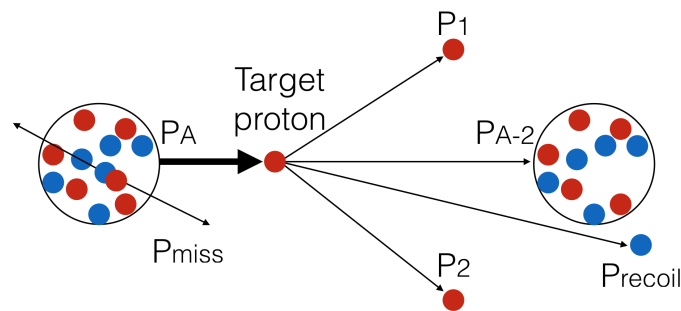


Figure 1. Hard scattering off an SRC-pair in inverse kinematics in the laboratory frame. An SRC proton (P_{miss}) in the nuclear beam scatters off a target proton. The scattered and knocked out protons (P_1 and P_2) have a large angle with respect to each other. The SRC-correlated partner (P_{recoil}) and the A-2 nuclear system continue moving approximately along the beam direction.

The schematic of the experimental setup is shown in Figure 2. The scattered and the knocked out protons (P_1 and P_2 in Figure 2) are measured in the arms using position Gas Electron Multiplier (GEM) and Time-of-Flight (TOF400) detectors. A pair of position sensitive Multiwire Proportional Chambers (MWPC) is used to monitor the beam. The coordinate Si detectors and another pair of MWPCs determine the trajectory of the A-2 nuclear system before the analyzing magnet. The Drift Chambers (DCH) measure the position of A-2 after the magnet. The information about the number of tracks downstream the target, the sum charge of them (measured by the scintillator counters), the turning angle and the time of flight allow identification of the residual nuclear system. The turning angle can be defined using the straight trajectories upstream and downstream the dipole magnet.

3. The Main Detection Systems Used for the SRC at BM@N Experiment

3.1. Silicon Detector

Silicon detectors can work in conditions of high load up to 10^6 Hz/cm². Therefore, Silicon detectors are usually used for the tracking systems close to the interaction point, where particle flow is high. Three Double-Sided Silicon detectors are used for the BM@N experiment [8].

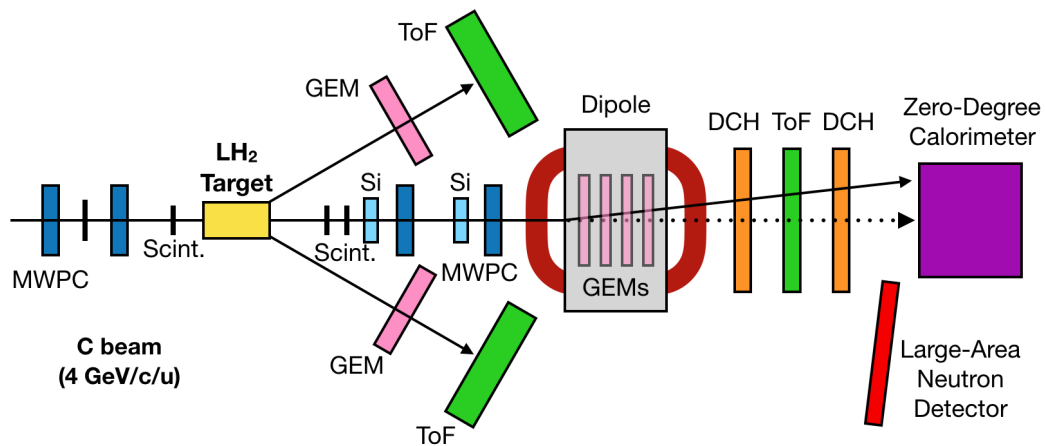


Figure 2. Schematic top view of the experimental setup. The beam is coming from the left and hits a liquid hydrogen target. The beam location/direction is monitored using a pair of MWPC chambers. The breakup of an SRC pair is tagged in the pair spectrometer consisting of the two GEM and two TOF stations in the arms. The A-2 nuclear system, which moves along the beam direction, is measured using a number of coordinate detectors (Si, MWPC, DCH), a TOF system, and a scintillator counter delivering its charge.

The principle of the detector operation is based on the measurement of the ionization charge generated by charged particles or photons. The contribution to the collected charge value is given by both electron and hole flow. The difference in the mobility of electrons and holes is not as great as for electrons and ions in gases. Usually 100% ionization charge is collected at a detector thickness in a short time around 10-15 nanoseconds. For the Double-Sided Silicon Detector, ionization signals from the passage of charged particle induce the same amplitude signal on both sides. Each detector has 640 straight strips with 0° and 640 tilted strips located at an angle of 2.5° . The particle coordinated is determined by the intersection of the straight and tilted strips. The pitches are $95 \mu\text{m}$ and $103 \mu\text{m}$ respectively. The thickness of the detectors is $300 \mu\text{m}$. In the setup, we used two sensitive planes with size of $12 \times 12 \text{ cm}^2$ at $z = 213.99 \text{ cm}$ with respect to the target, and one sensitive plane of size $24 \times 24 \text{ cm}^2$ at $z = 327.13 \text{ cm}$.

3.2. Gas Electron Multiplier Coordinate Detector

For the SRC/BM@N experiment we use triple GEM detectors [9]. Each chamber consists of three GEM multipliers with the following gaps between the electrodes: the drift gap of 3 mm, the first transfer gap of 2.5 mm, the second transfer gap of 2 mm and the induction gap of 1.5 mm. The GEM multiplier is a thin polymer foil coated with metal on both sides and perforated with a large number of holes. When it is placed between a drift cathode and a readout anode plates and suitable potentials are applied, the GEM behaves like a charge amplifier. Gas amplification is about $1-2 \times 10^4$. Primary ionization electrons emitted in drift region move toward the GEM. Getting in a region of high field in the holes, electrons gain enough energy to produce ionization in filling gas. Working gas mixture is Ar/Isobutane (90%/10%). A two-dimensional projective readout of the electron charge signal is performed on a readout board with two sets of parallel metal strips: the X (0°) and X coordinates (with the inclination angle 15°). The strip pitch is $800 \mu\text{m}$ for both layers. For the SRC experimental setup $660 \times 412 \text{ mm}^2$ chambers are used. Four GEM chambers are located in the arms at a distance of 235 cm from the target. The advantages of GEM Detectors is high spatial and momentum resolution, high geometrical efficiency (better than 95%). The detector coordinate resolution without magnetic field is $120 \mu\text{m}$.

3.3. Time of Flight Detector System

The advantages of Time of Flight Detector System in the accuracy of determining the particle time of flight and the relative low production cost. The ToF400 wall consists of two part are placed symmetrical to the beam. Every part consist of two gas boxes, which content five multi-gap Resistive Plate Chambers (RPC) each. This type of the detector is the best choice for a Time-of-Flight (TOF) system of large area. It provides good efficiency of registration and time resolution better then 50 ps [10, 11]. The RPC is a gas filled parallel plate chamber with resistive electrodes. A particle passing through the RPC creates ion-electron pairs in the gas gaps. Electrons are accelerated in the electric field and produce electron avalanche, which stops by resistive electrode. The electron avalanche induces a signal on pickup electrodes which look like long strips (10*300 mm with a pitch of 12.5 mm). The signal are read from both side of the strip. It provides determine the particle position along the strip there it crossed the detector. Each RPC has 48 strips, so total number of strips of ToF-400 is 960. It is 1920 electronics channels. Description of the front-end electronics can be find in [12].

3.4. Multi Wire Proportional Chambers

The MWPC chamber is filled with a gas mixture so that the charged particle passing through the working area causes the ionization of gas atoms [13]. The coordinate information in MWPC is read from the high-voltage equidistant anode wires. Between the counting planes, there are cathode planes on which positively charged ions of gas arrive. Born electrons are accelerated in the electric field of the chamber, leading to the ionization cascade around wires. This leads to the operation of the wire closest to the flown charged particle trajectory. Each MWPC station has six coordinate planes: two X, two U and two V planes inclined at the angles of 0° , $\pm 60^\circ$ to the vertical axis. The intersection of these planes defines the working area of the chamber. The coordinate resolution is 0.72 mm. The pitch is 2.5 mm. The spatial point was constructed from three fired wires of X, U and V coordinate planes [14]. This point should satisfy the following condition: $V + U - X = 0$.

4. First glance at the data

The data from the first and second pair of MWPC chambers was used to reconstruct the beam spot before and after the target (see Figure 3). The spot size is consistent with the expectations and online monitoring data. The coordinate resolution in the target area, calculated as the difference between projected tracks from the first and the second pair of MWPC detectors, is shown in Figure 4. The obtained sigma values are consistent with estimations based on the pitch value and the distance between the chambers.

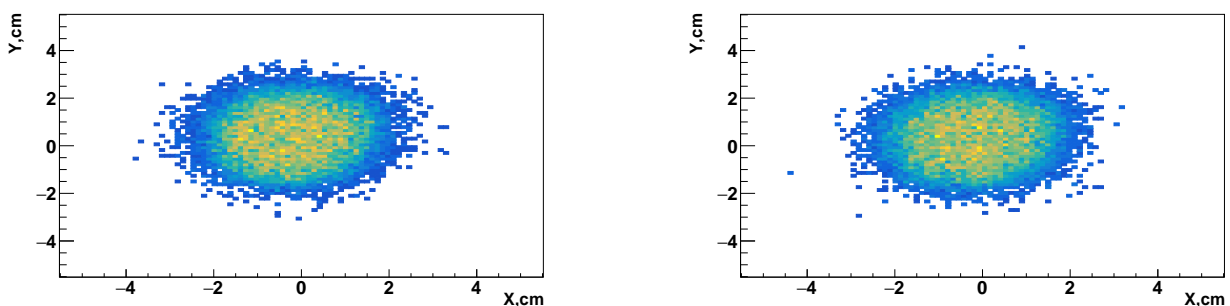


Figure 3. Reconstructed beam spot of the carbon ion beam before (left) and after (right) the target (using empty target data).

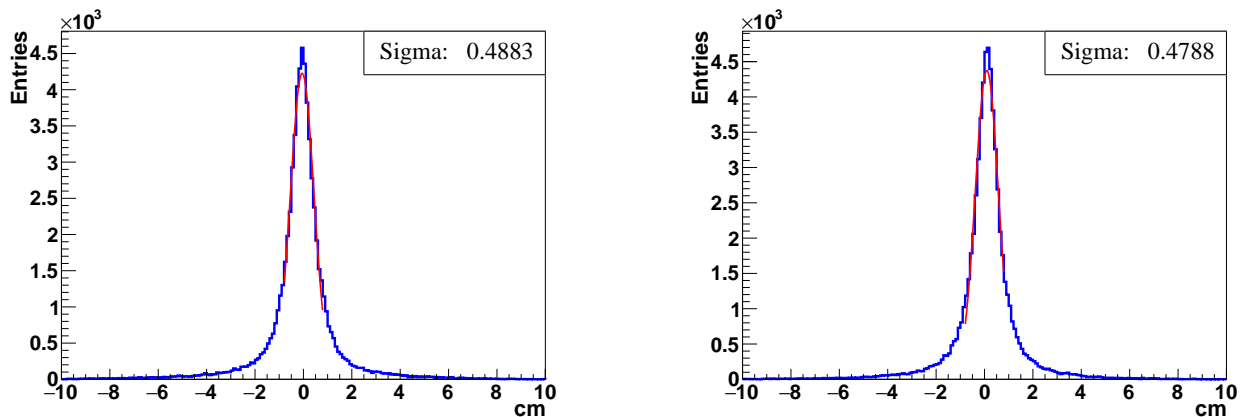


Figure 4. The difference between the track coordinates from different pairs in the target area for the X coordinate (left) and for the Y coordinate (right). The distributions are fitted with a Gaussian function, and the sigma values are shown on the plots.

The Figure 5 shows the amplitude spectrum of the scintillator counter after the target, where the X axis is the charge squared. The blue line is the spectrum for all events. The red line shows events where there are two particles in the arms and the time-of-flight information suggests they might be protons. The change between the blue and the red lines shows the carbon peak (which was a beam) decreasing, while the contributions of low-charge nuclei, such as alpha, lithium are increasing. This graph illustrates the ability to distinguish between different nuclei, which were formed after the interaction.

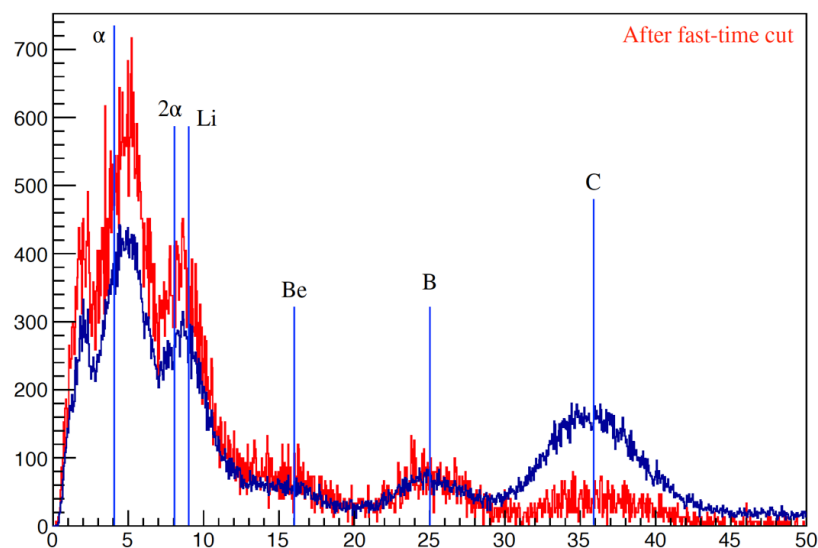


Figure 5. The spectrum of the scintillator counter after the target. The blue line is the spectrum for all events. The red line is events the where there were two particles in the arms and the time-of-flight information suggests they might be protons. Vertical lines illustrate the squared charge of different nuclei.

5. Conclusions

The BM@N experiment is the first experiment of the NICA project that has collected data regularly since 2015. This year, a new topic was added to the physics program of BM@N: studying of properties of the nuclear system remaining after the hard knockout of an SRC pair.

The BM@N spectrometer has all essential detection systems to measure the final particles in the events of interest: position sensitive detectors upstream and downstream the analyzing magnet and the time-of-flight systems. The Silicon and ToF detectors are based on the cutting-edge technologies and will be used for the future NICA collider experiments. The spacial coordinate resolution of 50 μm for the Silicon detectors and timing resolution better than 50 picoseconds for the ToF make it possible to reconstruct the SRC events of interest at BM@N and achieve important physics goals at the NICA collider experiments.

The data analysis is ongoing and the preliminary tracking data show a reasonable beam spot. The charge spectrum of the residual nuclear system looks interesting. This information will be combined with the other detectors data to provide identification for the A-2 system.

6. References

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