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RECONSTRUCTION OF SIMULATED AND EXPERIMENTAL DATA IN COORDINATE DETECTOR SYSTEMS UPSTREAM OF THE ANALYZING MAGNET OF SRC AT BM@N EXPERIMENT IN 2018

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Реконструкция моделированных и экспериментальных данных в координатных детекторных системах перед анализирующим магнитом в эксперименте SRC на BM@N в 2018 г.

Многопроволочные пропорциональные камеры и кремниевые детекторы были расположены перед анализирующим магнитом в установке SRC на BM@N во время измерения в 2018 г. Реконструкция для этих координатных детекторов была разработана как для моделированных, так и для экспериментальных данных. Разработанные алгоритмы были добавлены в официальное программное обеспечение. Результаты реконструкции данных 2018 г. сравнивались с моделированием. Были оценены и проанализированы основные характеристики координатных детекторов перед дипольным магнитом.

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Reconstruction of Simulated and Experimental Data in Coordinate Detector Systems Upstream of the Analyzing Magnet of SRC at BM@N Experiment in 2018

Multiwire proportional chambers and silicon detectors were located upstream of the analyzing magnet at the SRC at BM@N setup during the 2018 measurement. The reconstruction for these coordinate detectors was developed for both simulated and experimental data. The developed algorithms were added to the official software. The reconstruction results of the 2018 data were compared with the simulation. The main characteristics of the coordinate detectors upstream of the dipole magnet were evaluated and analyzed.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

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INTRODUCTION

BM@N (Baryonic Matter at Nuclotron) [1] is the first experiment on a fixed target within the NICA complex, which is being constructed in Dubna (Russia). SRC (Short-Range Correlations) [2–4] is a topic in the BM@N physics program aiming at studying the properties of local nuclear density fluctuations caused by close proximity nucleon pairs in a carbon nucleus. Figure 1 shows the experimental setup used for the first measurement of SRC at BM@N in 2018. The experimental setup consists of a liquid hydrogen target and the following detectors. The scintillator counters were used to define the start time (T0), measure the total charge per event (BC1–4), and were a part of the trigger system. The detectors for determining particle trajectories upstream of the magnet are MultiWire Proportional Chambers (MWPC) [5] and Silicon Detectors (SiDet) [6], downstream of the magnet — two Drift Chambers (DCH). The two-arm spectrometer contained trigger scintillator counters (X1, 2, Y1, 2), Gas Electron Multipliers (Gem) providing track coordinates, and the Time of Flight (ToF) system helping to separate signal protons from background pions.

As shown in Fig. 1, between the target and the magnet there was a system of coordinate detectors, consisting of two MWPCs (Pair1) and three SiDets (the first two detectors are inside the same box). Two MWPCs comprising Pair0 were positioned upstream of the target.

Pair0 was used to determine the beam vector impinging on the target. The coordinate of the primary point of interaction was calculated using the input beam track from Pair0 and the reconstructed proton tracks in the two-arm spectrometer. The MWPCs and SiDets downstream of the target and DCHs

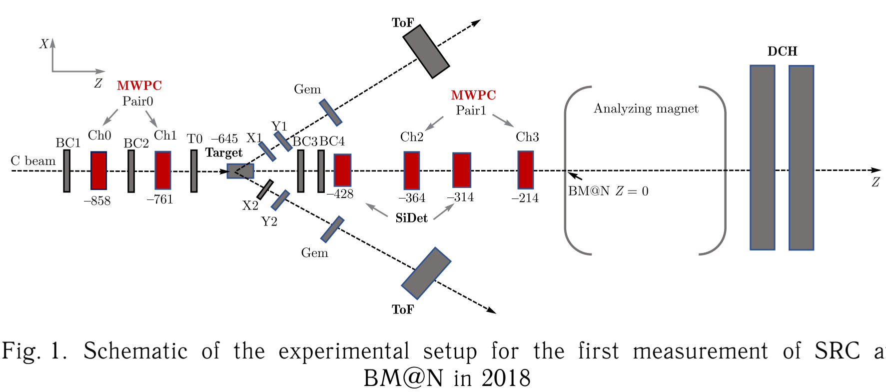

Fig. 1. Schematic of the experimental setup for the first measurement of SRC at BM@N in 2018

provide straight trajectories of the residual nuclei upstream and downstream of the analyzing magnet, which, together with the charge information from the BC counters (BC3, 4), were used for the fragment identification. The results of the physics analysis can be found in [7]. More details about the reconstruction of SiDets and MWPCs can be found in [8].

1. RECONSTRUCTION EFFICIENCY FOR THE DETECTORS UPSTREAM OF THE MAGNET

The MWPC consists of six wire planes located at a distance of 1 cm relative to each other along the Z axis. Each plane consists of 96 anode wires with a pitch of 2.5 mm. The SiDet consists of modules that have straight strips on one side and sloped strips on the other side. Each module has 640 straight and 640 sloped strips with steps of 95 and 103 μm, respectively. For

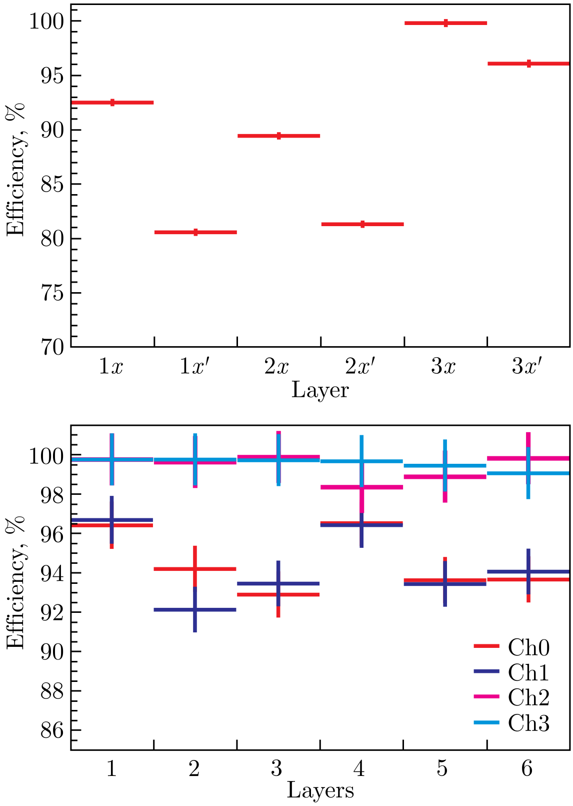

Fig. 2. The layer efficiency of the three SiDet stations (1, 2, 3 label three SiDet stations, x and x' correspond to the straight and sloped strips, respectively) (top) and for the MWPCs (bottom); Run 3430 (empty target data)

evaluation of the detector efficiency, each one of the six planes in an MWPC is called a layer, and one side of a module with strips in a SiDet is called a layer. A cluster in the MWPC is a combination of several neighboring fired wires. A cluster in a silicon detector is a group of neighboring strips containing signals above the threshold of 150 ADC. The center of the cluster in either case is called a hit. The efficiency per layer in the SiDet system and in the MWPCs is calculated as a fraction, where the numerator is incremented if there was a hit belonging to the track in the given layer of the detector, and the denominator reflects the total number of tracks.

The layer efficiency for three SiDets and four MWPCs is shown in Fig. 2. The average layer efficiency for the SiDet system was 90%. The average layer efficiency for MWPC upstream of the target was 94% and for chambers downstream of the target was 98%, respectively.

The track reconstruction efficiency of MWPCs upstream of the target was calculated relative to the identified carbon ion in the scintillation counters BC1 and BC2 as a ratio between the number of events containing at least one track through Pair0 and number of events with a registered charge of 6 by BC1 and BC2. The reconstruction efficiency of Pair0 as a function of the run number is shown in Fig. 3. The average reconstruction efficiency of the Pair0 for particles with a charge of 6 is $(92.2 \pm 0.1)\%$. The fluctuations of the reconstruction efficiency do not affect the quality of the data analysis.

The track reconstruction efficiency for MWPCs downstream of the target (Pair1) was calculated as a ratio of the number of events containing at least one track in Pair1 and one track in Pair0 to the number of events where the carbon ion was identified in BC1, BC2, BC3, and BC4 and exactly one track was reconstructed in Pair0. The track reconstruction efficiency for MWPC (Pair1) for experimental data shown in Fig. 4 is $(90.4 \pm 0.3)\%$ for carbon ions

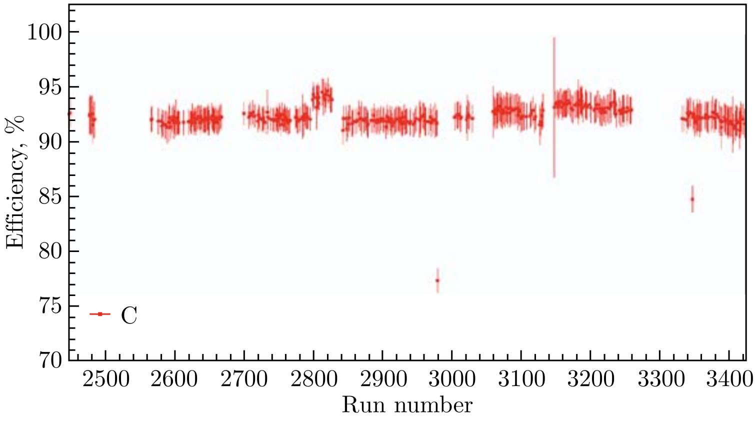

Fig. 3. Reconstruction efficiency of MWPCs in Pair0 based on experimental data. The average efficiency for carbon ions is $(92.2 \pm 0.1)\%$

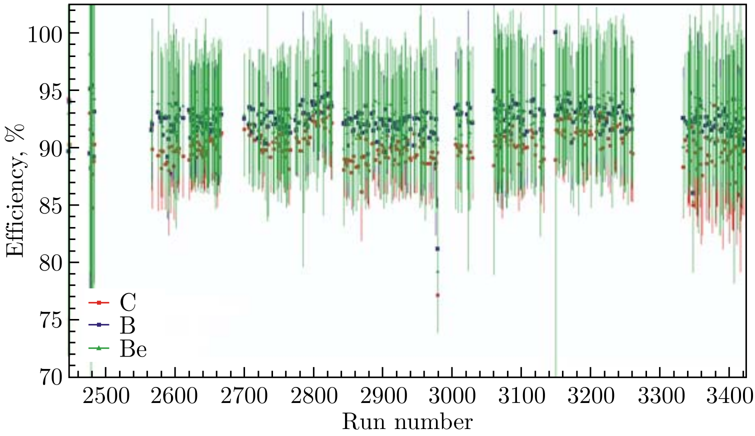

Fig. 4. Reconstruction efficiency of MWPC (Pair1) for experimental data for different charge values measured in BC3 and BC4

with $Z = 6$, $(92.3 \pm 0.4)\%$ for boron ions with $Z = 5$, and $(92.6 \pm 0.5)\%$ for beryllium ions with $Z = 4$.

The reconstruction efficiency for SiDet was evaluated relative to BC counters. In particular, the ratio of the number of events containing at least one SiDet and MWPC (Pair0) track to the number of events where the carbon ion was identified in BC1, BC2 and exactly one track was reconstructed in Pair0 was calculated. The track reconstruction efficiency for SiDet for experimental data is shown in Fig. 5 and on average it is $(81.5 \pm 0.7)\%$ for ions with $Z = 6$ and $(82.6 \pm 0.7)\%$ for ions with $Z = 5$.

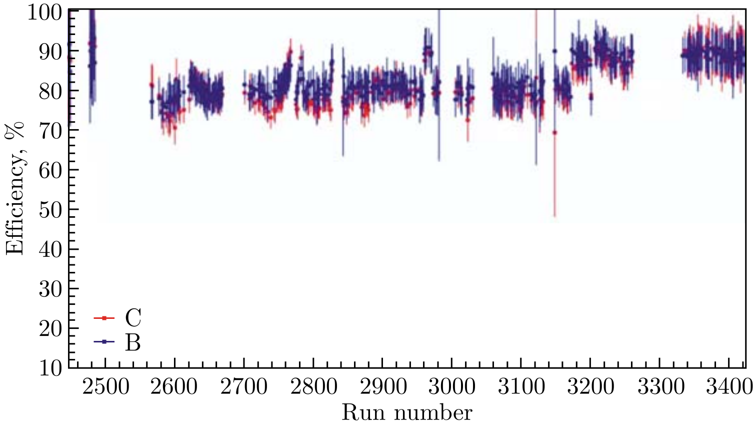

Fig. 5. SiDet efficiency for experimental data with different restrictions on the ion leaving the target

The combined tracks (Upstream track) [8] after the target were reconstructed using information from MWPC (Pair1) and tracks from SiDet. The upstream track efficiency was evaluated relative to BC counters. The upstream track efficiency was calculated as a fraction, where the numerator was incremented if charge i was registered by BC3 and BC4 and any track was found between the target and the magnet: it could be a track in MWPC (Pair1) or in SiDet, or an Upstream track, and the denominator was incremented if there was a track upstream of the target in Pair0 and charge i was registered in BC1 and BC2. The Upstream-track reconstruction efficiency values can be found in [8].

2. SIMULATION PROCEDURE

The first step in modeling the response of the detectors is to trace the particle trajectories from the target through the detectors and materials of the setup, taking into account the magnetic field and all physical effects by using Geant4-based BmnRoot [9]. An ion generator was used to test the algorithm under ideal conditions. The DCM-SMM [10] model representing the topology of physics events was used to study the realistic detector response.

The particles traced through the chambers generate MC points in each of the six layers of the chamber, which are then translated into the numbers of the nearest wires. The wire numbers obtained in this way are then input to the reconstruction algorithm [8], which makes a track-segment within one

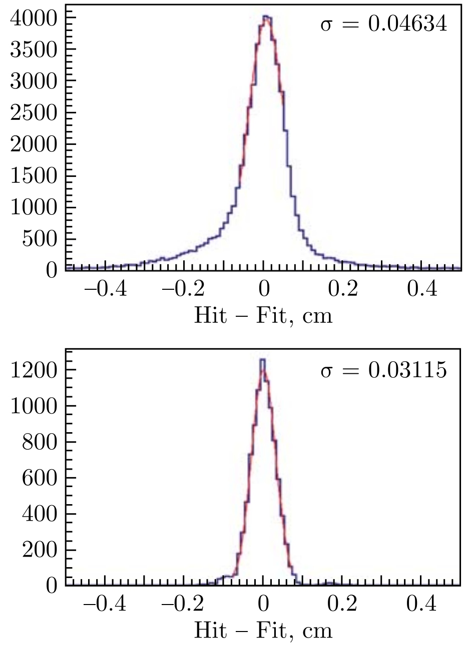

Fig. 6. The difference between measurement and track coordinate (top); the difference between the coordinate of the MC point and the track coordinate (bottom) on the MWPC (Ch2)

MWPC chamber using the least squares method, and then a track through two chambers in the same way as for the experimental data.

The realistic efficiency for a particle to create a signal in the detector was modeled using a random number generator [11] with a uniform distribution and efficiency of 90%. The difference between the coordinate of the MC point on the MWPC plane and the track coordinate is shown in Fig. 6. As can be seen from the figure, the standard deviations (σ) of the distribution for MC (bottom) and experimental data (top) are consistent and are 464 and 311 μm, respectively, for the MWPC (Ch2). The difference between the simulation and data can be explained, on the one hand, by the efficiency of the detectors (efficiencies were determined on the real data) and, on the other hand, by a large multiplicity of false noises, while the MC events are cleaner and give better accuracy for any reconstructed object and estimated parameter.

The generated track passing through the detector volume leaves MC points belonging to this track in each SiDet layer. The point in the SiDet detector is smeared by a Gaussian function with $\sigma = 30$ μm for straight and 35 μm for sloped strips. MC points are transformed into numbers of fired straight and sloping strips, which are input to the reconstruction software package as if it were real data.

In the SiDet system a straight track is drawn using the least squares method. The MC points are used in exactly the same way as experimental data [8]. The probability for the SiDet strip to produce a signal is 90% as estimated above.

3. EVALUATION OF RECONSTRUCTION ALGORITHMS EFFICIENCY

Performance evaluation of reconstruction algorithms is very important for data analysis; for this purpose the possibility of operation with simulated data was added. Algorithm efficiency can be estimated as a ratio where the denominator is the number of generated tracks passed through the detector system, and the numerator is the number of tracks reconstructed by the algorithm. The algorithm efficiency for various detector systems and for two generators are shown in the table. The lower algorithm efficiency for the DCM-SMM generator is due to the complex topology of the generated physics events.

Figure 7 shows the number of generated and reconstructed tracks per event using the DCM-SMM generator. The track reconstruction efficiency for

Reconstruction efficiency for simulated data using an ion generator and DCM-SMM

Generator	Ch2	Ch3	MWPC (Pair1)	SiDet	Upstream track
Ion [^{12}C]	99.9%	99.9%	99.2%	99.9%	99.0%
DCM-SMM	97.4%	98.3%	96.4%	97.0%	96.0%

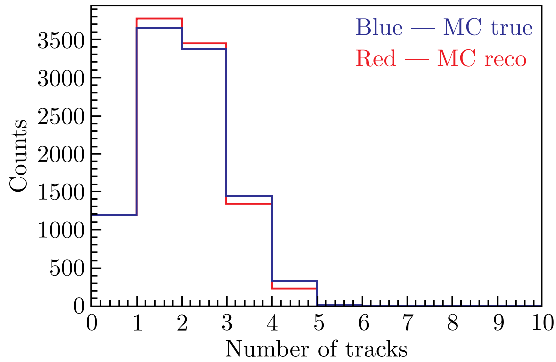

Fig. 7. Number of Upstream tracks using DCM-SMM generator: reconstructed tracks are shown in red; MC tracks, in blue

upstream tracks is 96%. Not all tracks are reconstructed in the multi-track events, which is not so critical for reconstruction of real data.

In the physics events it is important to distinguish between two closely passing tracks. As a result of carbon-12 fragmentation one of the 4 particles: p, ^{2}He, ^{3}He, ^{4}He, can pass near the ^{7}Be ion trajectory in the range less than 2 degrees. A similar picture is present for lithium or helium ions: $^7\mathrm{Li} + {}^3\mathrm{He}/{}^4\mathrm{He}$, $^6\mathrm{Li} + {}^3\mathrm{He}/{}^4\mathrm{He}$, $^4\mathrm{He} + {}^4\mathrm{He}$.

The scalar angle between two close tracks in the detector systems upstream of the magnet was defined in simulation. Figure 8 shows the scalar angle between two close tracks for the simulated (blue) and reconstructed (red) tracks. The shape of the distribution is similar for both cases.

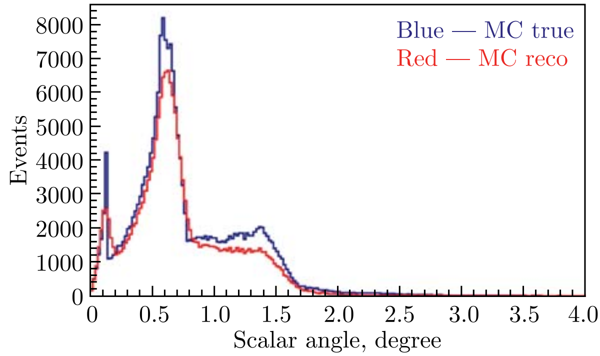

Fig. 8. Scalar angle between two close tracks generated using DCM-SMM model: blue — generated tracks, red — reconstructed tracks

4. REACTIONS WITH THE DCM-SMM MODEL

The DCM-SMM generator represents the expected event topology in the BM@N and SRC at BM@N experiments. The kinetic energy of the carbon beam is 3.17 GeV/nucleon. The statistics used are ~ 50 million events. The tracks generated by the model were passed through the volumes of the detectors of the experimental setup using BmnRoot to study the yields of

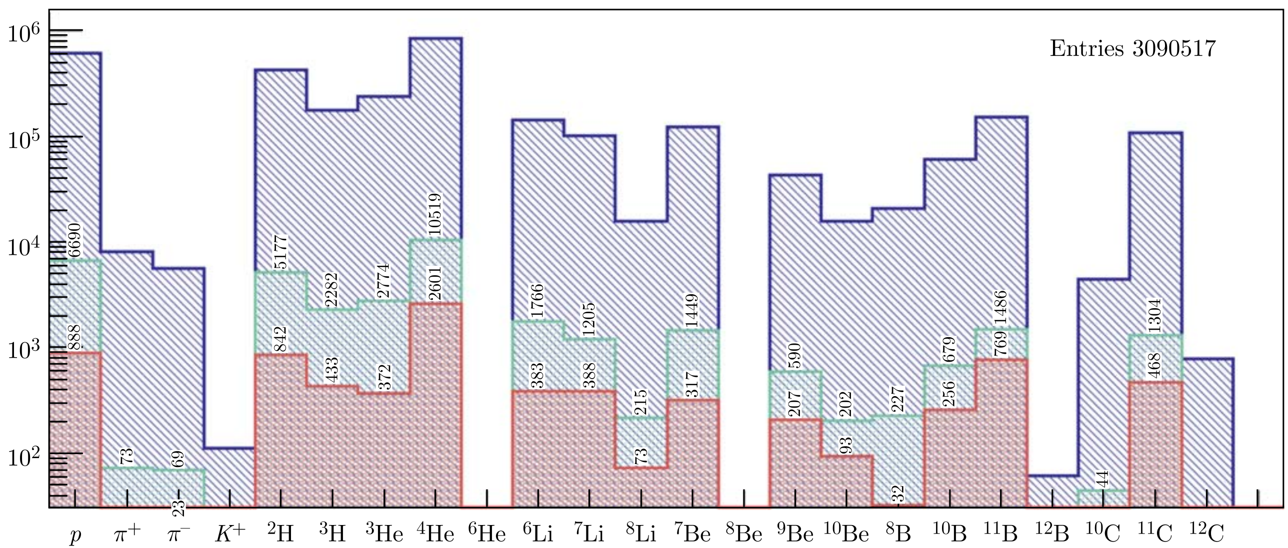

Fig. 9. Simulated yields of X particles in the ^{12}C$(p, 2p)X$ reaction passing through the detectors along the beam with different conditions for protons and $\pi^{\pm}$ in the arm detectors: a charged particle was detected in at least one of the two arms of the spectrometer (blue), charged particles were detected in both arms (green), and protons were detected in both arms (red)

the $^{12}C(p, 2p)X$ reaction. The SRC physics analysis is based on the events with protons detected in the two-arm spectrometer. Figure 9 shows the distributions of charged particles in SiDet and MWPC detectors downstream of the target and registered in the drift chambers in three cases: a charged particle was detected in at least one of the two arms of the spectrometer (blue), charged particles were detected in both arms (green), and protons were detected in both arms (red).

Of great interest is the yield ratio of ^{10}B to ^{11}B. As can be seen from Fig. 8, this ratio on the simulated data is around $256/769 = 33\%$, and the experimental value is $(27.5 \pm 3.0\ (\mathrm{stat.}) \pm 5.3\ (\mathrm{sys.}))\%$ [7].

CONCLUSIONS

The charged particle trajectories reconstruction with simulated and experimental data for the MWPC (upstream and downstream of the target) and SiDet systems was fully developed and implemented in the BM@N experiment software.

The efficiency of track reconstruction upstream of the analyzing magnet is 96% for simulated and 97% for experimental data. The comparison between the reconstruction of simulated and real data shows consistent results. The developed algorithms can be used for further analysis.

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