Tuning of the primary vertex reconstruction algorithm in the BM@N experiment

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Abstract. The BM@N (Baryonic Matter at the Nuclotron) is a working experiment at the NICA (Nuclotron-based Ion Collider Facility) complex. The first physics runs with beams of argon and krypton (BM@N setup) as well as with beams of carbon (SRC setup - extension of the BM@N physics program) were carried in 2018. One of the prerequisites for physics analysis of experimental data is the existence of the primary vertex position estimation. Current report describes the proposed algorithm to reconstruct the primary vertex using the virtual planes method. The results of this algorithm for different targets, beams and trigger conditions are presented. The sensitivity of presented method to its parameters is considered.

1. Introduction

The BM@N [1] is the first working experiment performed on the NICA accelerating complex [2]. It is a fixed target experiment. To this moment there have been seven runs of the experiment, most of which were technical. In 2018 the first run of the experimental facility with physics data collection took place. One of the most important condition for the physics analysis of experimental data is determination of the primary vertex. Knowing the coordinates of the primary vertex makes it possible to better estimate the path of neutral decayed particles like \( \Lambda \)-hyperons, otherwise the precise reconstruction of these particles is impossible.

Figure 1. View of the BM@N (a) and SRC (b) experimental setups [3].
2. Vertex finder

The geometry of the BM@N experimental setup (see figure 1) is typical for fixed target experiments: right behind the target area there are a number of detection planes required to reconstruct trajectories of charged particles [3]. At the same time, the material of these detection planes is the source of secondary particles whose trajectories are also reconstructed by the tracking algorithm. Therefore, there may be a number of secondary vertices inside the detector in addition to the primary vertex. So, these secondary vertices must also be reconstructed by developed algorithm.

2.1. Developed algorithm

Proposed algorithm of the vertex reconstruction for the BM@N experiment includes two main stages: (I) Primary vertex finder and (II) Secondary vertex finder (see figure 2). The core of both stages is the virtual plane method, which is described in section 2.2.

![Figure 2. Scheme of proposed algorithm main steps.](image)

Preparation steps are performed before starting the algorithm. The Z-coordinate of the experimental target edge obtained from geodetic measurements is taken as an initial approximation of the primary vertex position ($Z_{v_{init}}$). All reconstructed tracks are extrapolated to $Z_{v_{init}}$. If the track is within the “beam region” it is marked as a primary track, and as a secondary track otherwise.

Main steps of the proposed algorithm are shown below. These steps are repeated until the required accuracy is achieved:

**Stage I. Primary vertex finder**

(i) If there is less then 2 tracks marked as primary, return.

(ii) Reconstruct primary vertex for tracks marked as primary by virtual planes algorithm (see section 2.2).

(iii) If Z position of found vertex is out of range ($r$), mark tracks as secondary and return.

(iv) Extrapolate tracks belonging to this primary vertex to found $Z_{PV}$ and calculate mean for X and Y distributions ($X_{PV}$ and $Y_{PV}$).

**Stage II. Secondary vertex finder**

(i) If there are less than 2 tracks marked as secondary, return.

(ii) Reconstruct vertex for tracks marked as secondary by virtual planes algorithm (see 2.2) in wide range ($±300$ cm).

(iii) Extrapolate tracks belonging to this vertex to found $Z_{SV}$ and calculate mean for X and Y distributions ($X_{SV}$ and $Y_{SV}$).
2.2. Virtual planes method

Virtual planes algorithm description:
(i) Set of $M$ equidistant virtual planes transverse $Z$ axes are created in the $(Z_v^{\text{init}} - r, Z_v^{\text{init}} + r)$ range (see figure 3).
(ii) The charged particle tracks reconstructed in the inner tracker are extrapolated by the Kalman filter [4] to each created virtual plane.
(iii) For each $k$ virtual plane an average distance between a pair of points $(i, j)$ is calculated:
\[
d_k = \frac{1}{N} \sum_{i=0}^{N} \sum_{j=i+1}^{N} \sqrt{(x_k^i - x_k^j)^2 + (y_k^i - y_k^j)^2}
\]
(iv) For the set of $M$ average distances a minimum ($d_{\text{min}}$) is found. The updated value of $Z_v$ corresponding to the virtual plane with $d_{\text{min}}$ is determined.
(v) The search range is narrowed by factor $s$: $r = r/s$.

Figure 3. Explanation of virtual planes algorithm.

Figure 4. Profile of the reconstructed vertex in Z direction for the BM@N setup.
Typical profile of the reconstructed vertex for the BM@N setup is presented in figure 4. It is clearly seen that the main peak on the distribution corresponds to the primary vertex. Smaller peaks on the right side of the distribution were produced by secondary tracks born on the elements of the experimental setup.

![Figure 5](image-url) Profile of the reconstructed vertex in Z direction for the SRC setup.

In figure 5 profile of the reconstructed primary vertices for the SRC setup are shown. The figures 5(a) and 5(b) show the vertex distribution in case of one and three lead planes as a target. These planes were used during experimental run to calibrate track reconstruction algorithms. The figure 5(c) shows the distribution of the primary vertex for the liquid hydrogen target used as the main target for the physical data collecting. The peaks from the beam interaction with the elements of the liquid hydrogen barrel construction are clearly visible.

3. Tuning of the algorithm

The algorithm described in the article has several free parameters that affect the result of its work and the execution time. These variables are:

- range of vertex search ($r$)
- number of virtual planes ($M$)
- speed of narrowing the range of vertex search ($s$)

![Figure 6](image-url) Dependence of vertex quality on tuning parameters.

In the current work we have analyzed the effect of these parameters on the algorithm’s result. The analysis was carried out at the first stage of the algorithm (primary vertex search). The
peak width of the primary vertex in Z-axis distribution ($\sigma$), the number of vertices reconstructed in $-3 \text{ cm} < Z_{PV} < 3 \text{ cm}$ (Integral) and the execution time of algorithm (time) were selected as control parameters.

In figure 6 the results of the tuning procedure are presented for $s = 1.5$. It’s clearly seen that the integral grows rapidly with increasing search range ($r$) until it reaches a maximum about 100 cm. Working time increases with increasing search range not as much as with increasing the number of virtual planes, this is due to frequent call of Kalman filter procedures. The peak width of the primary vertex depends weakly on the parameters, all values lie within the range of about 100 micrometers.

![Figure 7](image.png)

**Figure 7.** Comparison of the default vertex finder algorithm (a) and tuned one (b).

The figure 7 shows Z-coordinate distributions of the reconstructed primary vertex for two sets of input parameters: default parameters (a); a set of parameters for which the width of the distribution is as narrow as possible and the integral is as large as possible (b). The distributions differ very little, which suggests that the default parameters have been selected quite well. However, the selected optimal parameters improve the result of the algorithm, which is the result of fine-tuning procedure.

### 4. Conclusion
The algorithm of primary and secondary vertices reconstruction was developed for the BM@N experiment and its extension SRC and was implemented in the BmnRoot [5] software package. Input parameters and control parameters were selected for the algorithm tuning. Scanning by input parameters allowed to select combinations leading to the best values of control parameters. On the next step of the current research selection of the optimal parameters for different types of events (trigger-target pairs) is going to be investigated.

### Acknowledgments
This work is supported by Russian Foundation for Basic Research grants 18-02-40104 mega and 18-02-40046 mega.
We are also grateful to the Physics Educational Center of the Research Park of the Saint-Petersburg State University for support of educational projects related to the subject of the present study.

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