ALIGNMENT OF THE TOF-400 DETECTOR AT THE BM@N EXPERIMENT

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Abstract - For correct processing of experimental data from the BM@N experiment, it is necessary to know exactly the positions in the space of the detectors of the experimental setup. Misalignment of the detector elements can worsen the accuracy reconstructed data. The alignment procedure corrects those initial position values. The goal of the work is to perform the alignment procedure for TOF-400 detector planes after the first physics run, using the collected experimental data. Three methods were applied, the results are presented and discussed.

INTRODUCTION

The BM@N (Baryonic Matter at the Nuclotron) is the first experiment at the accelerator complex of NICA-Nuclotron. Its main purpose is to investigate properties of nuclear matter under extreme density and temperature [1]. The experiment combines high precision track measurements with time-of-flight information for particle identification and calorimetry for the analysis of the collision’s centrality. Its schematic view is presented on the Fig. 1.

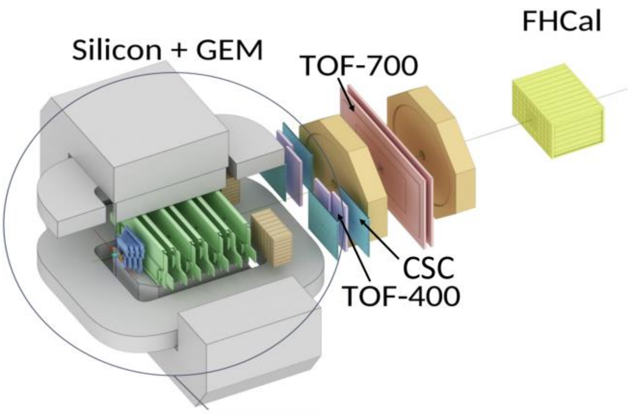

Fig. 1. Schematic view of the BM@N experimental setup.

The charged particle momentum and multiplicity are measured with the inner Forward Silicon Detector+Gaseous Electron Multiplayers located inside the analyzing magnet [2]. The outer tracking system consists of five planes of cathode strip chambers (CSC). FHCal is designed to determine the centrality of the collision and the orientation of the reaction plane for the study of collective flows.

The design parameters of the time-of-flight detectors based on a multigap resistive plate chamber (mRPC) technology with a strip read-out allows one to perform separation between hadrons (π, K, p) as well as light nuclei with the momentum up to few GeV/c [3].

The TOF-400 wall consists of two part (left and right) that are placed symmetrical to the beam. Each part consists of two gas boxes (modules) with each consisting of 5 mRPCs of size $300 * 600\,\mathrm{mm}^2$. In the work mRPCs are referred to as planes, numbering from 1 to 20. Planes are counted from top to bottom as follow: the first module includes planes 1 to 5, the second module – planes 6 to 10, the third one – planes 11-15, the fourth – planes 16-20.

PROBLEM STATEMENT AND METHODS

The particles produced in the collision go through the FSD+GEM tracking system placed in a magnetic field and then hit the TOF-400 detector. A passing particle leaves a signal called hit in one of the planes it goes through. In addition to the hit reconstruction algorithms extrapolate track of the particle from the tracking system to the TOF-400 plane. The intersection point of the extrapolated track with the plane is characterized by the x coordinate of the hit and the angle α of the track, at which it intersects the plane of the TOF-400 detector. Thus, there are two points to consider for a given particle: the actual hit and the extrapolated track intersection point. The track-to-hit distance is referred to as residual. In the first approximation, the position of all the planes is known from the results of measurements of the module surfaces position after the assembly of the detector, but it is not possible to determine the planes position more precisely when they are sealed inside the modules. The purpose of the alignment procedure is to reduce the error due to the uncertainty of the plane positions. This is achieved by calculating position corrections for each plane in the system. Geodesic measurements showed there are no rotations of the modules, thus the full alignment procedure requires calculating corrections for possible translation shifts along the three axes. The calculated corrections are added to the geometry description used by the reconstruction algorithms. In this work we were focusing on calculating corrections along the z axis only, which is notated in the paper as dz .

To perform the alignment procedure, the data from a physics run session carried out in December 2022 — February 2023 were used. The beam is Xe, the target is CsI. Physical runs with a magnetic field were used, collision energy 3.8 AGeV, 6.7 million events. We performed preliminary particle identification using the $\beta(m, p)$ dependence to separate positively and negatively charged pions and protons.

The first method relies on proton distribution of residuals along the axis against the entry angle tangents along the same axis for every given plane. Thus, this method allows determination of the corrections along *z* axis $- dz$ – via analysis of *dy* against *Ty* and *dx* against *Tx* distribution, where *dy*, *dx* – the residuals along *y*, *x* axes respectively, *Ty*, *Tx* – entry angle tangents of tracks, propagated to the TOF-400, along *y*, *x* axes respectively. We used protons with momenta between 2 and 3 GeV/c.

If we consider a triangle in the *xOz* plane (Fig. 2, a) with the cathet *dx* and the adjacent angle α, then it can be obtained that the discrepancy *dx* is associated with the displacement dz along *z* axis through the tangent of the entry angle. Having fitted the distribution for every plane with a straight line (Fig. 2, b), we obtain *dz* corrections as the 2nd parameter of the fit.

$$\begin{aligned} dx &= dz * Tx \\ dy &= dz * Ty \end{aligned} \tag{1}$$

Thus, since this reasoning for both planes – *xOz* and *yOz* – is the same, either of the two dependencies gives the desired corrections to the position of the *dz* planes, and similar correction values are expected when analyzing both types of distributions. It is also reasonable to expect close correction values for the planes in the same module, i.e. the planes 1-5, 6-10, 11-15, 16-20.

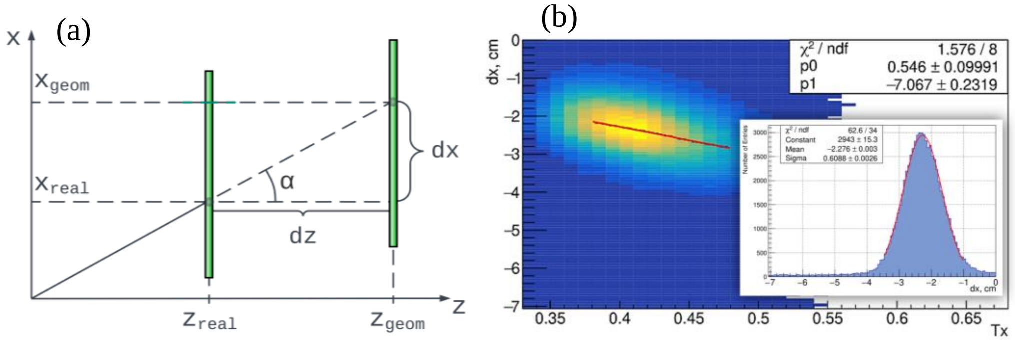

Fig. 2. (a) illustration to formula (1) and (b) to the process of fitting.

The second method involves distribution of residuals according to the coordinates of hits along axes. It differs from the first one in that the fit parameter for each plane is then multiplied at z_{plane} coordinate of the plane, which is known from the geometry.

$$\begin{aligned} dz &= z_{plane} * dx / x_{hit} \\ dz &= z_{plane} * dy / y_{hit} \end{aligned} \tag{2}$$

In both methods obtained corrections for planes are then grouped in five accordingly to the modules planes are placed in and fitted with zero polynomial to get weighted mean.

The third method is based on the residual distribution along axes *dy* against *dx* for negatively and positively charged pions. The key point is that maxima of these distributions do not coincide (Fig. 3, a).

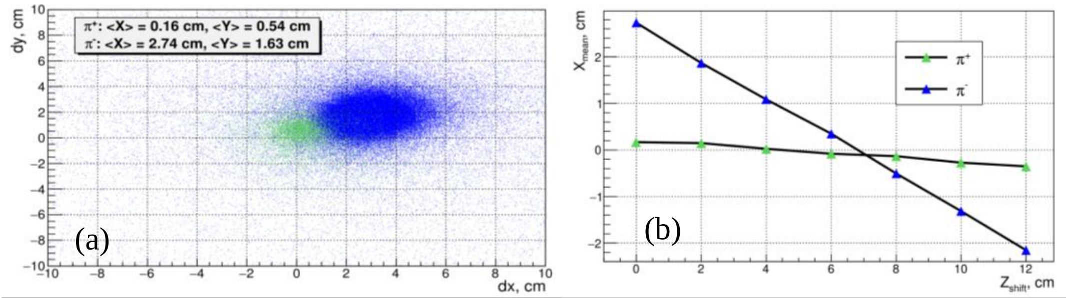

Fig. 3. a) *dy* against *dx* for pions of different charge hitting the same plane, b) illustration of graphs intersection as a result of shifting detector walls.

The method is aimed to make those maxima equal. To do so, we were iteratively shifting the planes as a whole at 2 cm in a range from 0 cm to 12 cm. Since particle of different charge hit the detector at different angle, misalignment will influence residual values in different ways. Then for the planes we built graphs of dependence x_{mean} on the shift value for negatively and positively charged pions. The intersection point of the two graphs (Fig. 3, b) was then accepted as the *dz* correction for the plane. Such a procedure was carried out for the *y* axis as well. We used planes with the biggest statistics for both types of particles in each, which are 5, 6, 10, 11.

RESULTS AND DISCUSSION

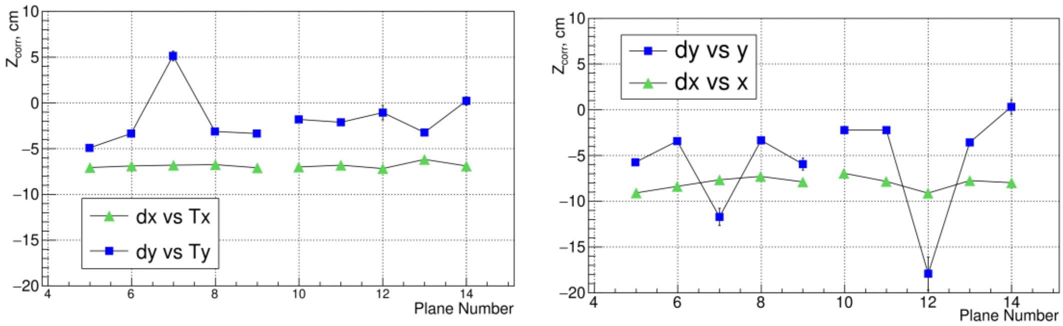

Fig. 4. The two methods comparison for every plane of the 2^{nd} and 3^{rd} modules.

Due to low statistics in the side modules, we were only able to obtain consistent result for planes 5-14 that is given on the Fig.4. Numerical result, i.e. weighted mean values for each module, is shown in Table 1. Two methods along x axis give comparable results for the considered modules. Along y axis values for the two methods are close as well, but we do not observe correspondence between axes within one method. Negative values mean that in our current geometry the z coordinates of the modules are underestimated at those values.

For the third method results are presented in the Table 1 as well, where each value represents the intersection point coordinate of two graphs (see Fig.3, b). From looking at x coordinate column one can see that the z_{corr} is close to 6.5 cm, while from y coordinate it was not possible to determine corrections since graphs did not intersect within the shift range.

Table 1. *dz* corrections from the three methods.

Plane/Module Number	z_{corr}(1^{st} method, along x), cm	z_{corr} (1^{st} method, along y), cm
Module 2	6.74 ± 0.12	3.45 ± 0.04
Module 3	6.92 ± 0.11	2.43 ± 0.07
	z_{corr}(2^{nd} method, along x), cm	z_{corr} (2^{nd} method, along y), cm
Module 2	8.25 ± 0.04	3.87 ± 0.07
Module 3	7.78 ± 0.10	2.55 ± 0.08
	z_{corr}(3^{rd} method, along x), cm	z_{corr} (3^{rd} method, along y), cm
5^{th} plane	6.98 ± 0.07	–
6^{th} plane	6.29 ± 0.05	–
10^{th} plane	7.02 ± 0.02	–
11^{th} plane	6.42 ± 0.02	–

The three methods used gave similar result for modules 2 and 3, located near the beam axis. The result is consistent with the expected 6.5 cm corrections based on geodetic measurements of the position of the detectors of the BM@N installation. Further work will be carried out to understand the deviation from the expected values in the yOz plane.

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