JOINT INSTITUTE FOR NUCLEAR RESEARCH
Flerov Laboratory of Nuclear Reactions

FINAL REPORT ON THE SUMMER STUDENT PROGRAM

Upgrade of Ionization Beam Profile Monitor (IBPM) with a new set of Micro Channel Plates (MCP)

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Participation period:
July 22 – September 15

Dubna, 2018

Abstract

Main goal of this project was to improve efficiency of collecting charge and resolution of Ionization Beam Profile Monitor (IBPM). During many tests and modifications of experimental and test setups, some damage of detector occurred. It was decided to upgrade the IBPM by a new set of Micro Channel Plates (MCP).

The design and the performance of the Ionization Beam Profile Monitor operating on the residual gas ionization principle are described. The main advantage of the constructed device is the non-contact measuring method. Operating under hard environmental conditions it delivers the information about the primary beam position, profile and intensity in “on-line” regime. It was tested in advanced under high gamma and neutron radiation conditions and changing vacuum using a range of low and intermediate energy beams at the beam current of a few nA to 15 μA. The diagnostic box was located in the vicinity of the accelerator, where the neutron flux was over 106 n/cm2s. It was found out that the device is capable to operate in vacuum in the range of 10^{-6}÷10-3 mbar without the loss of the resolution power at the beam current as low as a few nA. The IBPM is prospective for beam profile monitoring due to long time. Emergency situations do not lead to decrease of its operability.

Chapter I.
Introduction

In the last two decades a variety of beam diagnostic techniques and devices has been developed [1 - 15]. At the same time the beam intensity available at the present-day facilities has increased many times. The increasing beam intensity leads to a rise of neutrons and γ flux, accompanying the beam. Therefore, the problem of reliability of beam diagnostics devices operating under hard radiation conditions occurs, especially if the beam is to be monitored in the area close to the driver accelerator. Main factors influencing the reliability of the diagnostic device are due to an adverse impact of the beam on the diagnostics tools and vice versa. In emergency situations, the endurance of diagnostics tools to vacuum deterioration also becomes important.

The goal of this research was to build a reliable device which is able to determine the position and profile of the ion beam operating in a wide range of the beam intensities and resistant to adverse environmental conditions. A device satisfying these requirements seems to be the Ionization Beam Profile Monitor (IBPM) [1 - 8]. The minimum interaction with the ion beam is provided when no material is introduced into the beam. The ionization profilometer is a position-sensitive ionization chamber operating in a current mode. The residual gas is used as a buffer (working) gas.
The residual gas pressure in the beam line is approximately 10^{-6} mbar, so the current density of collected ions is 10^{-13} - 10^{-11} A/mm2. Usually, before collecting, the ionization current is amplified using microchannel plates (MCP). With the MCP as an in-situ ion current amplifier, a spatial resolution of 1mm rms and temporal resolution of 1 ms have been achieved [2]. Using a microprocessor-based scanning ADC a sequence of ten profiles can be acquired in 100 ms.

Chapter II

Ion Beam Profile Monitor

The physical view of the IBPM and schematic layout are presented in Figs. 1, 2 and 3, respectively[1]. The IBPM consists of three main parts: the extractor, the scanner and the analyzer. Each of the parts operates like a couple of parallel conductive plates with high voltage applied between them. This results in the homogeneous electric field E perpendicular to the beam direction. The beam passes through the space between the electrodes of the extractor. Due to the collisions of the beam particles with the residual gas molecules, the latter get ionized. The operation principle of the IBPM is based on the collection of the ions with positive charge. Positive ions are accelerated in the direction of the electric field, gaining kinetic energy proportional to the distance passed in the extractor. Further they pass through the grid electrode at the bottom of the extractor and reach the scanner.

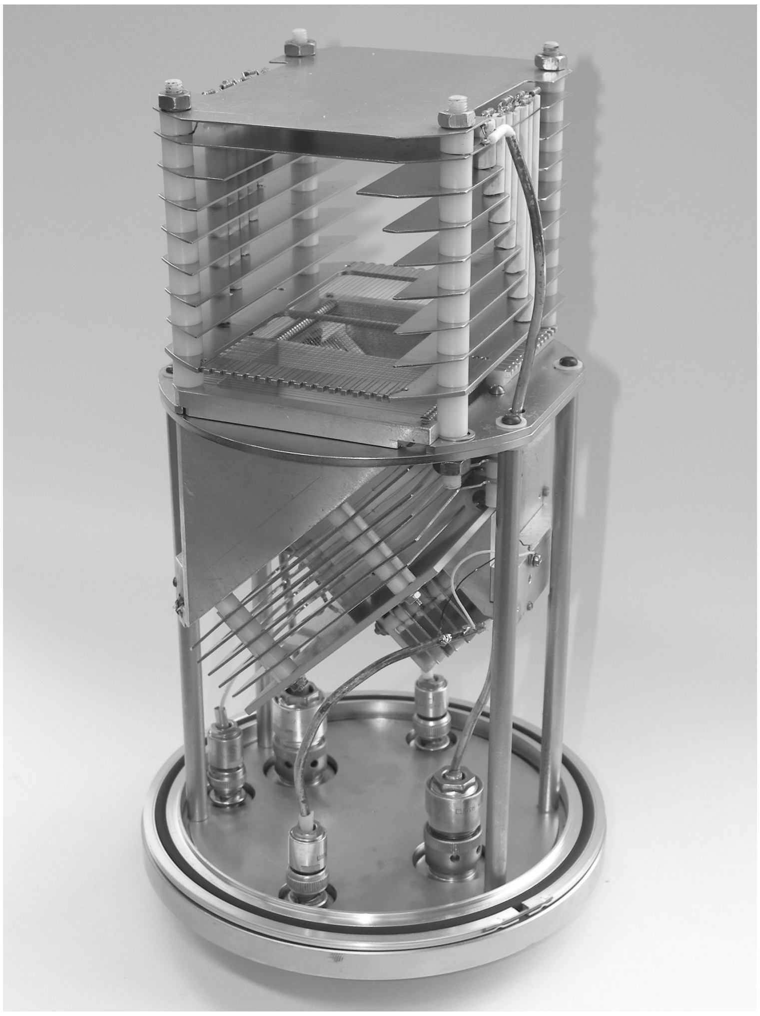

Fig. 1. - The physical configuration of the IBPMs. The IBPM is adopted for mounting via ISO DN100 vacuum port.

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[1] Yu. G. Teterev, G. Kaminski, Phi Thanh Huong, E. Kozik *Ionization Beam Profile Monitor For Operation Under Hard Environmental Conditions.*

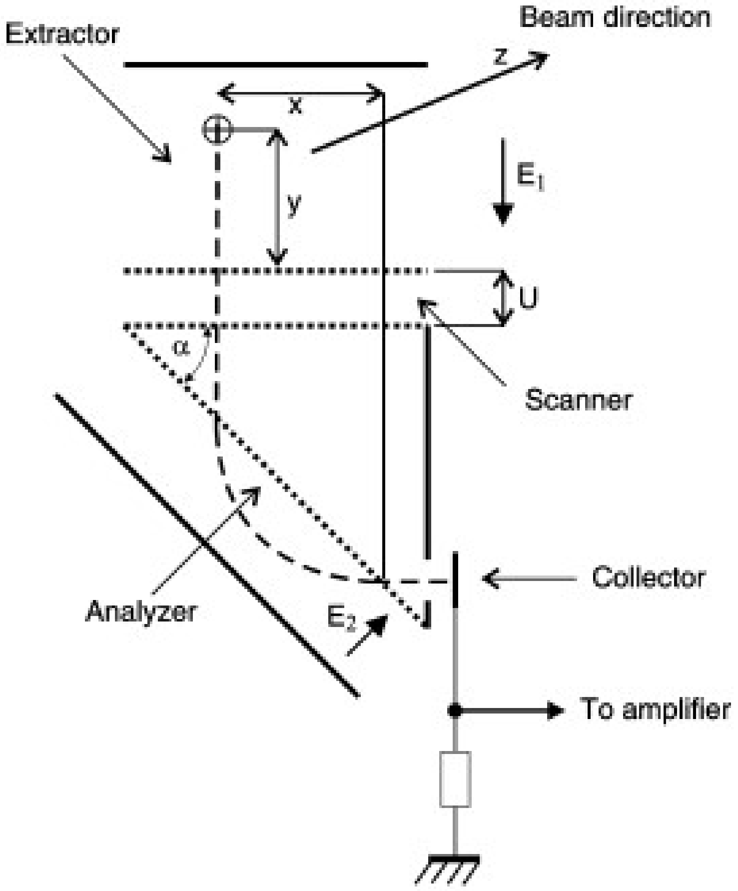


Fig. 2. Schematic view of the detector for on-line beam monitoring: E_1, E_2 are the electric fields in the extractor and analyzer; U is the potential difference applied to the scanner; (π – α) is the angle between the E_1 and E_2 vectors; and x,y are the coordinates of the location of electron-ion pair production.

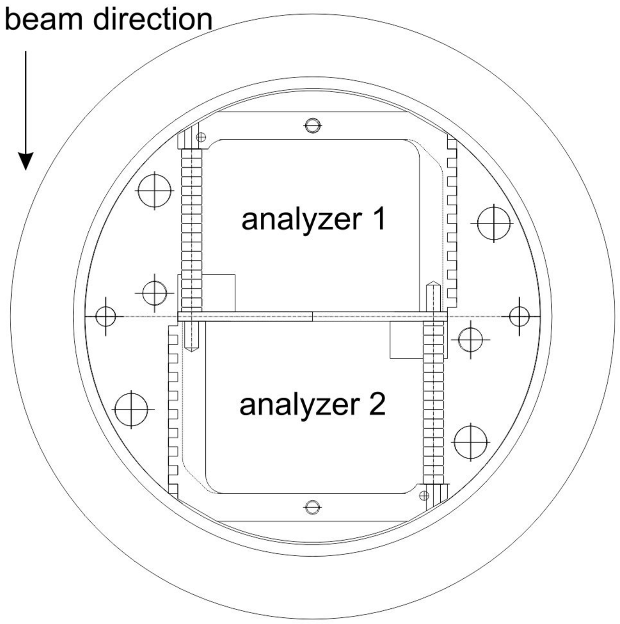


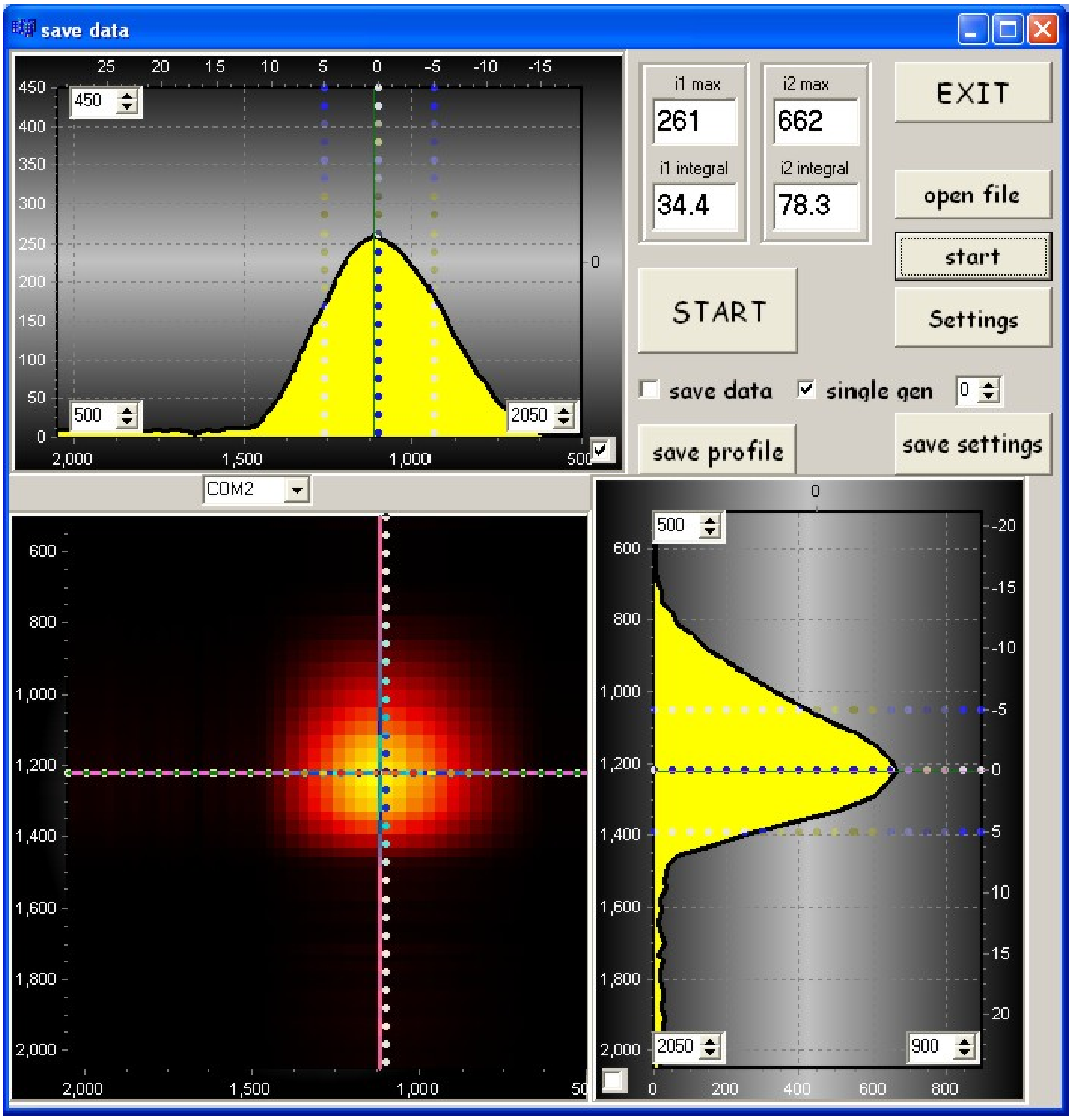
Fig. 3. Auto cad view of the bottom part of the IBPM. The layout window is set from the vacuum port projected along the beam axis. The location of two analyzer sections is visible. The function of each analyzer is to collect the ions deflected into two parallel directions; **x** *and* **– x***, perpendicular to the beam axis.*

Passing the scanner, they gain an additional portion of energy, the same for all the ions, and leave it through the other grid electrode into the analyzer, where they are deflected by the constant electric field applied. The electrodes in the analyzer are rotated by α angle in relation to the electrodes in the scanner. The resolution of the IBPM is determined by the narrow slit installed in front of the collector. Only the ions that pass through the slit are collected. The resolution of the IBPM of determines the size of slit. In our case the slit of 1mm was installed. More detailed description of the operation principle of the IBPM is given in Refs. [9, 10].

The analyzer part is used for collection of the ionization products along one selected direction. Obviously, to get the information about the beam current distribution in horizontal and vertical directions two independent analyzers are required. Therefore the IBPM is equipped with two analyzers fixed successively along the beam path. The second analyzer is turned by 180° in respect to the first analyzer as well the exit slit in the second analyzer is on the opposite side in relation to the slit in the first one. The schematic location of the analyzers along the beam path is presented in Fig. 3. The function of each analyzer is to assure scanning along x and y coordinates axes.

DC current amplifiers U5-11 are used to measure the ion current on the collectors. The electric fields inside the extractor and the analyzers are 200 V/cm and 282 V/cm, respectively, provided by DC high voltage power suppliers. The high voltage generator is used to generate saw-shaped scanning potential. The current module of high voltage generator provides us with the scanning voltage signal with a period of 2, 6 or 18 s. Within one scanning period, the analyzed volume in the extractor is scanned twice; on a rise and on a fall of a saw-shaped scanning pulses. The two ionization current signals and saw-shaped scanning voltage analog signals are digitalized by ADC and transferred to PC via the parallel port. Then all signals are processed and displayed on-line. Current amplifiers and DC high voltage suppliers have to be located in a distance more than 0.5 meter from the diagnostic box depending on the radiation background. If the radiation background is on a high level, the electronic modules are located behind the radiation shield, or in a place more distantly located. The reason is the necessity to avoid the influence of high neutron and γ flux on them, resulting in their shortest life span.

In Fig. 4 an example of one and two dimensional beam profiles are presented. On the main panel of the data acquisition software, there are three sub panels; two, top-left and bottom-right displaying the beam current distribution along horizontal (top-left panel) and vertical (bottom-right) directions and the central panel displaying a two dimensional beam profile. In two first panels the dependence of ionization current as a function of scanning voltage is plotted.



i1 max 261

i2 max 662

i1 integral 34.4

i2 integral 78.3

☐ save data ☑ single gen 0

COM2

Fig. 4. An example of the 11B beam profile is displayed by the data acquisition software. The beam energy was 33 AMeV, beam intensity was 1 μA, measured under the pressure of 2 × 10-5 mbar. In the top-left and the bottom-right panels the dependences of I1(U1) and I2(U1) are displayed, respectively. In the bottom-left (central) panel 2D beam profile is shown.

The x axis of all the panels relates to the beam coordinates inside the extractor. The two-dimensional beam profile is generated by the projection of one dimensional distribution into two dimensional matrix. The refresh time depends on the half-period of the scanning voltage. During the half-period of 1 s more than 60 values of ion current are measured. The number of measurements increases with the increase of scanning voltage period. After one half-period time, the value of start/stop signal changes and the stored data stream is displayed. As soon as the beam profile is generated, a new measurement cycle starts from the last stored data.

Although the scanning method along two mutually perpendicular directions does not offer a detailed beam profile image, monitoring of the dynamical evolution of the artificially generated profile is sufficient to focus the primary ion beam to the optimum size and to tune up the beam spot in/at the center of the target.

Chapter III
Micro Channel Plate

Micro channel plate is a device for increasing the amount of electrons by multiplying them by secondary emission. Its task is to increase the number of electrons to facilitate their detection or use to create an image.

MCP is a development of the electron multiplier construction. The device is a plate with a typically thickness of 0.75 to 2.00 mm made of glass with regular holes or slits. Holes, otherwise known as channels, have diameters from few to tens of micrometers, and the distance between them is in order of 10 μm. The ducts are set at an angle of 2° to 8° to the normal to the plane of the tile. The microchannel plate is metallized on both sides, and the glass layer is an insulator.

External metallized surfaces are polarized with a voltage from 100 to 500V. A non-parallel channel arrangement causes the electron entering the channel to hit the wall. After impact, it strikes from 2 to 4 secondary electrons. Depending on the length of the channel and its inclination, there may be between 3 and 8 reflections of the electron on the thickness of the plate.

Set of two MCP used in IBPM are shown on Fig. 5.

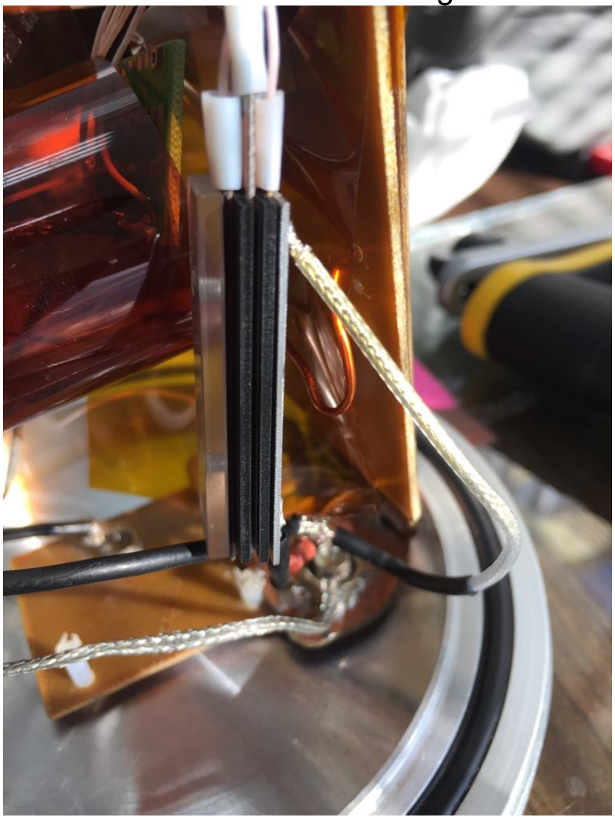


Fig. 5. Set of two MCP used in IBPM

Chapter IV

Upgrade of IBPM

The first tests of the IBPM on the PETtrace cyclotron proton beam at HIL, UW in Warsaw has showed that the sensitivity of its basic construction is to low and is out of range of the operation at the experimental conditions at HIL. To amplify the ion signal on the collector we propose in installation of a set of Micro Channel Plates detectors (MCP) in front of the collector plate (Fig. 6.). This would increase of the sensitivity of the IBPM at least by factor of $10^3 - 10^4$ and solve the problem with of too low sensitivity of the device at operation on small *Z* ion beams. Implementation of the MCP to the construction of the IBPM needs a modification of its construction - additional HV connector to supply voltage to the MCP, and installation of two voltage dividers are needed.

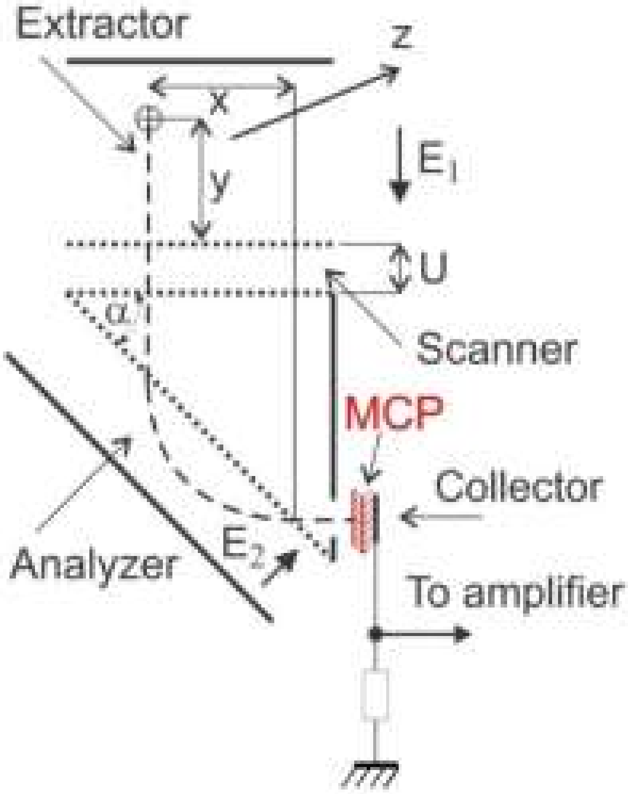


Fig. 6. Scheme of upgraded IBPM.

Inside IBPM are two sets of double MCP. During installation, one of MCP set get damaged. MCP are very fragile and fits very precisely into device, even 0.5 mm difference in with of plates can cause a damage. That's why cutting of plates must be done very carefully. Broken MCP is shown on Fig. 7. Using new MCP (Fig. 8.) new set was prepared. Additionally, new voltage divider (Fig. 9.) were made. For test, a simple setup was created. To simulate beam of small Z charge particles, alpha source were used. Test setup and alpha source are shown on Fig. 10. and Fig. 11.

Fig. 7. Broken MCP

Fig. 8. The material for preparation of a new MCPs strips

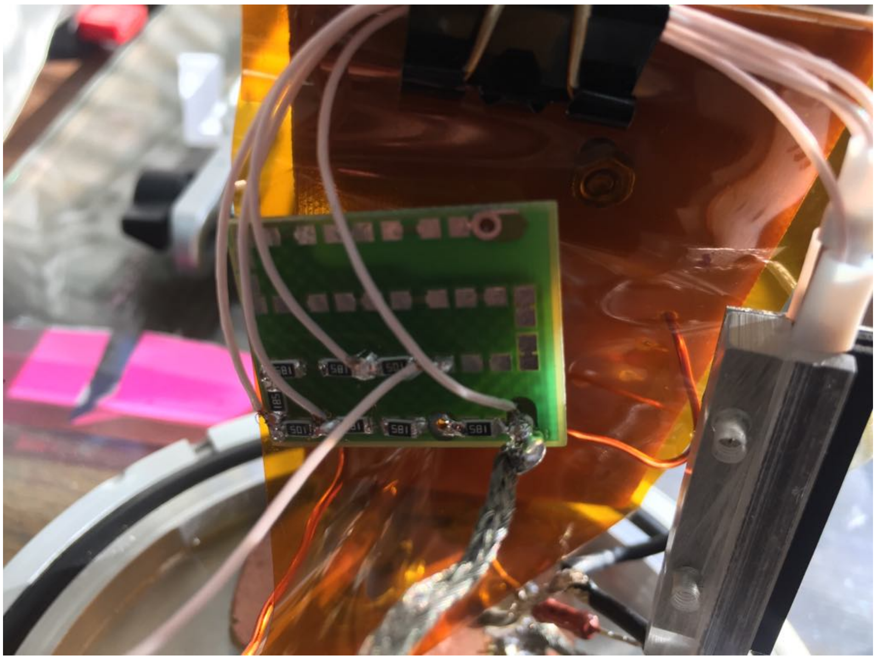


Fig. 9. New voltage divider

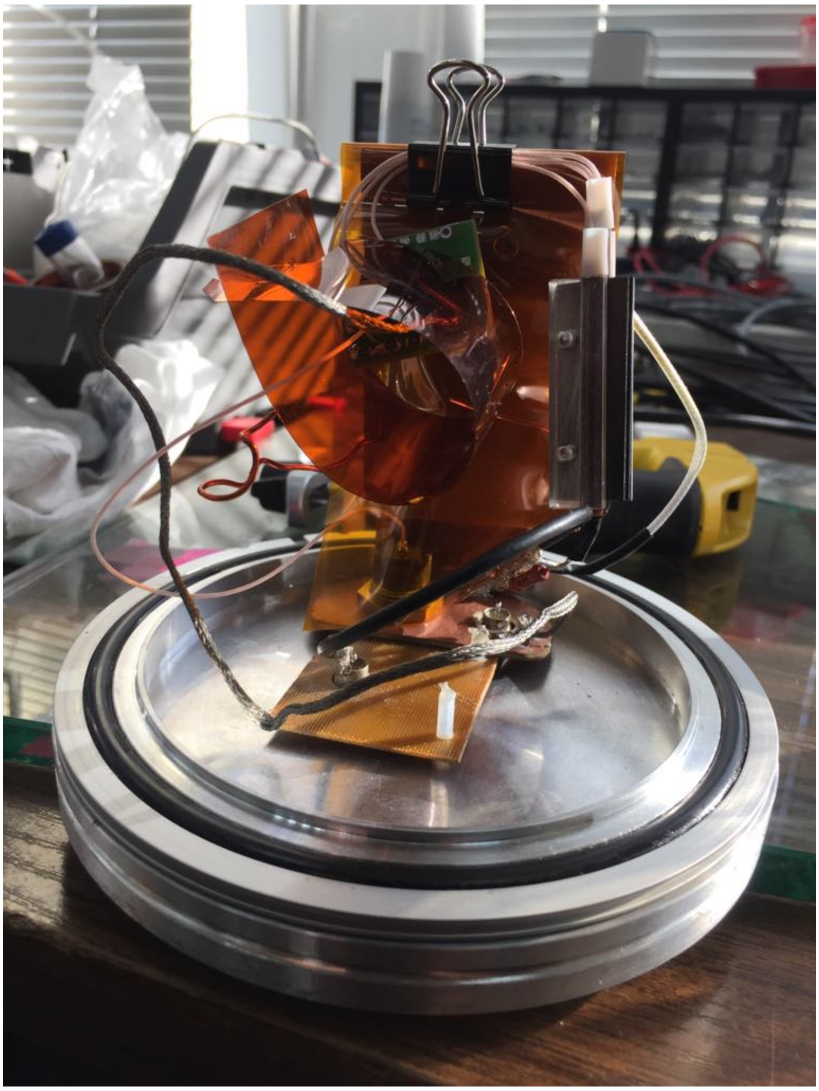


Fig. 10. Test setup

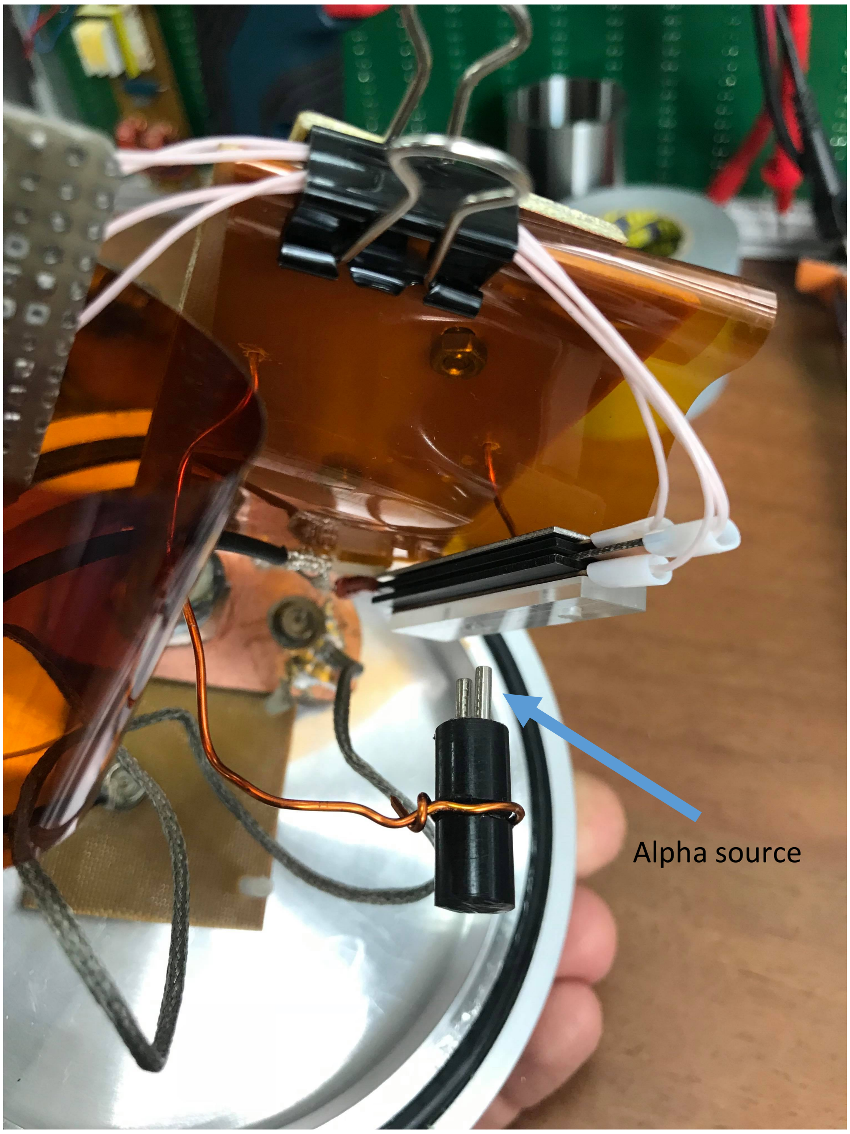


Fig. 11. Alpha source in test setup (two small dots near end of the rods)

To create low pressure environment, special setup was constructed. Setup include turbo molecular pump, vacuum chamber and several valves. To apply high voltage was used HV power supply. Signal was increased by amplifier and readout by oscilloscope. Whole setup is presented on Fig. 12.

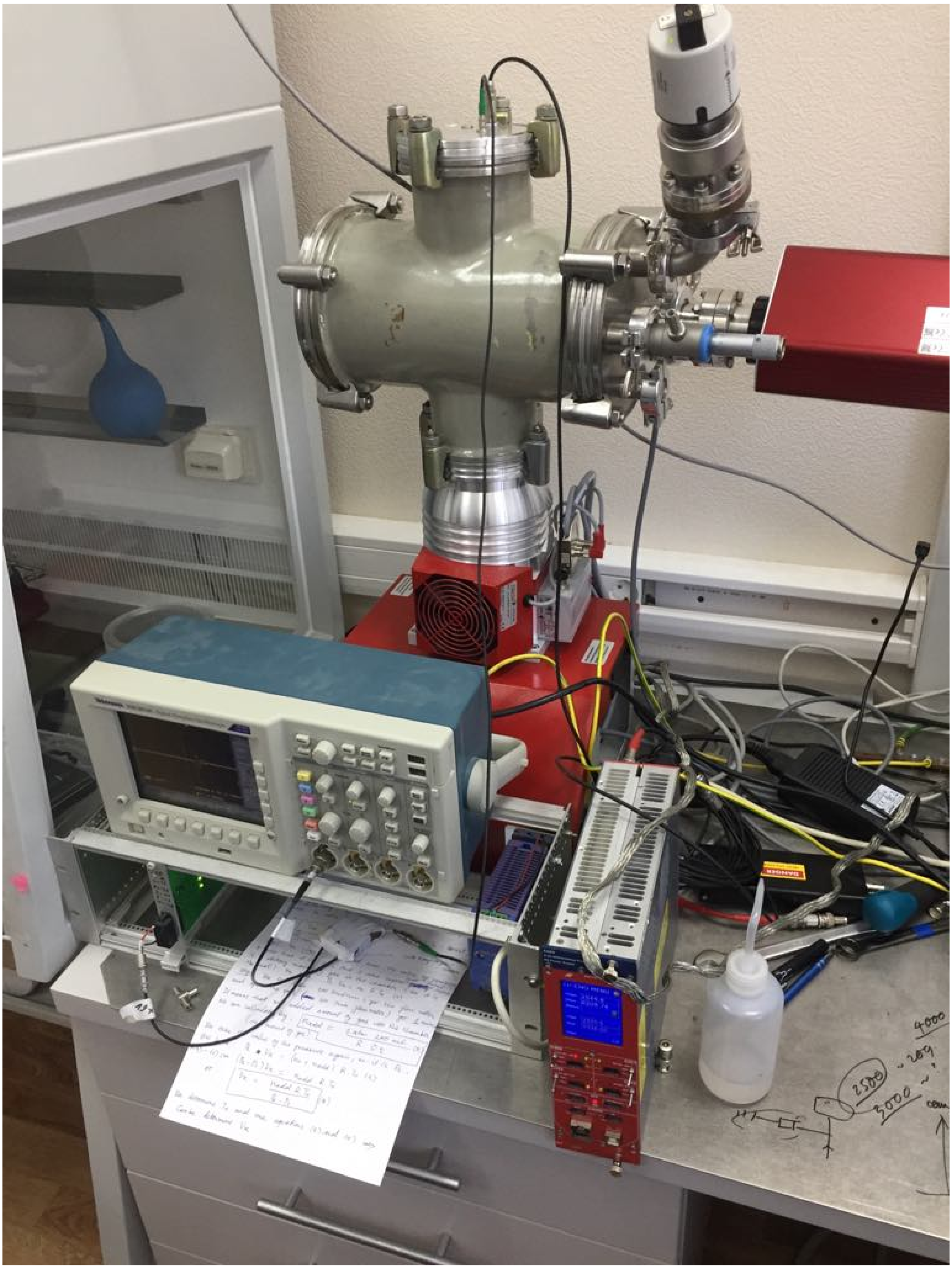


Fig. 12. Vacuum chamber with readout electronics

Chapter V

Results and summary

Tested setup start working after applying 2300V. At 2400V amplitude of the signal is about 0.4 V (Fig. 13.)

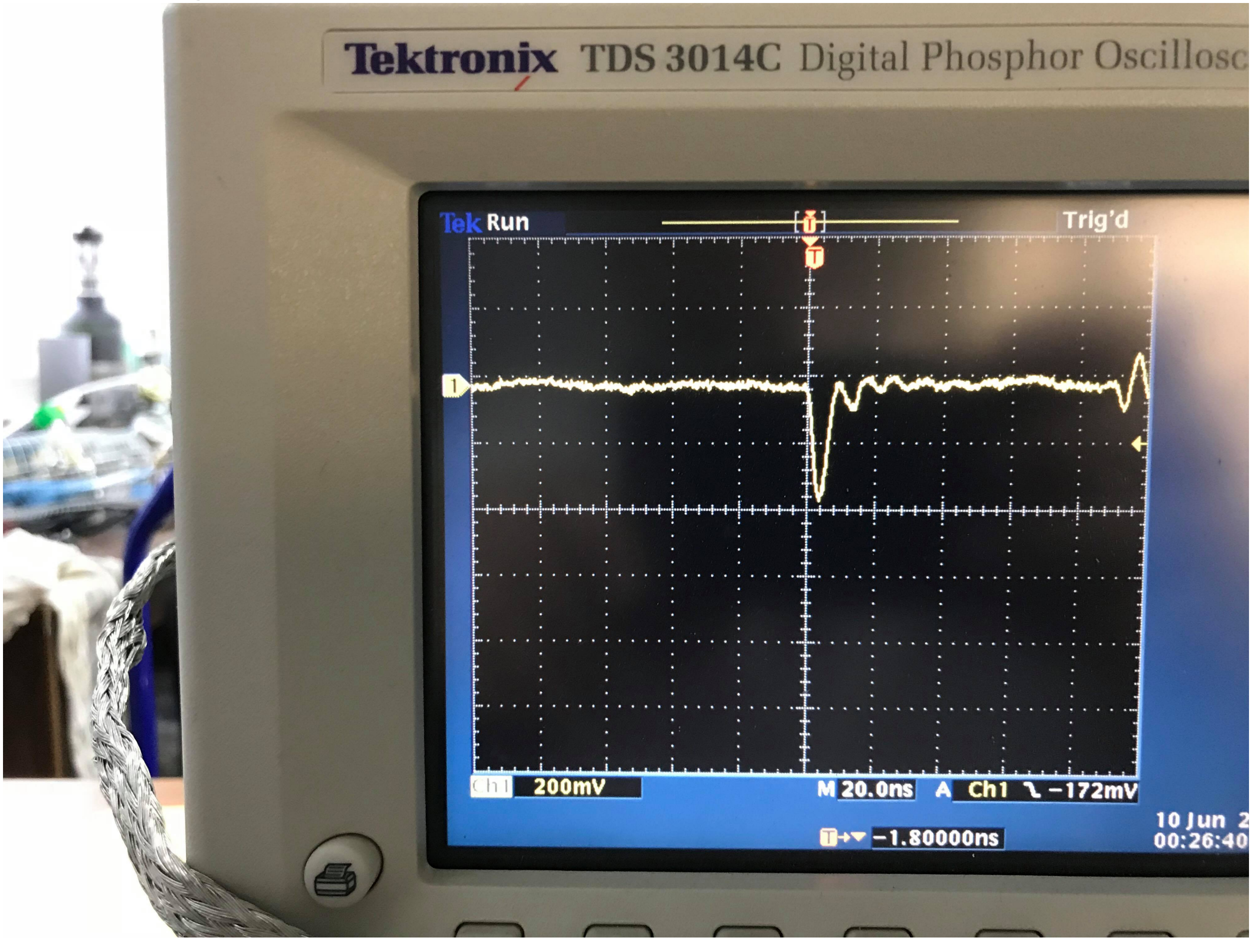


Fig. 13 Signal from IBPM at 2400V.

Used alpha source, compared to typical beam of charged particles is weak. However, using only two MCP in vacuum in order 10^{-6} mbar, tested setup can easily reach signal with amplitude ~1V (Fig. 14.). Applying high voltage up to 2500V, current flowing through detector is about 200 nA (Fig.15.) and it rises linearly.

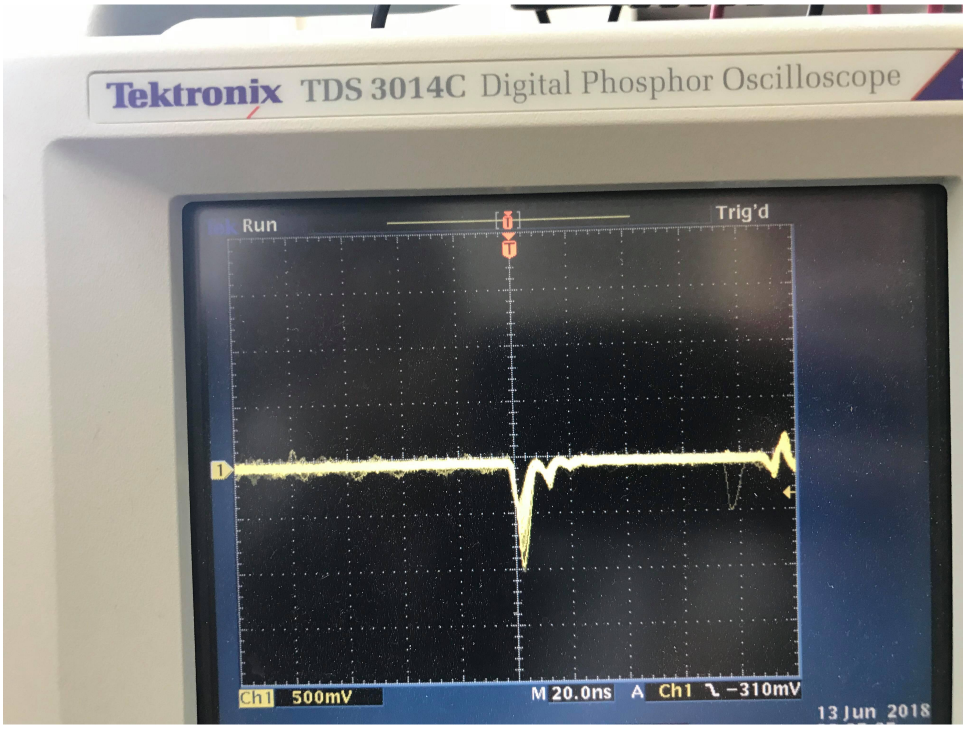


Fig. 14. Signal from IBPM at 2500V.

VMon 2499.9
IMon 0201.95
Status
VSet 2500.0
ISet 0300.00

Fig.15. Value of current at 2500V.

Main goal of this project was to upgrade Ionization beam profile monitor with new set of MCP and replacement of electronic components. During Summer Student Program, all of possible improvements were done including new sets of MCP, new voltage dividers and almost all set of wires. To make those things, a lot of knowledge and skills must be used. To produce vacuum order 10^{-6} mbar, I needed to learn how to build, set and work with vacuum system. Preparation of voltage dividers and wiring requires advanced soldering and manual skills. Constantly assembling and disassembling IBPM requires patience and competence. Cutting of MCP had to be made very precisely which requires concentration and accuracy. To initiate system and obtain signals, I had to acquaint with HV power supplies, amplifiers and oscilloscope. In the end, series of tests and measurements taught me conscientiousness and time organization.

In result, constructed IBPM is fully-working, stable under low pressure and high voltage conditions and have better sensitivity.

Complex setup of IBMP will be further tested under hard environmental conditions with proton beam and this test will fully show precision and scrupulous work done in JINR.

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