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NEW EXPERIMENTAL CHANNALS AT NUCLOTRON

M.M. Kats*, T.V. Kulevoy,
"Kurchatov Institute" – ITEP, Moscow

Abstract

In framework of NICA project two new experimental channels are under development. At first channel the biological experiments under ion beam irradiation are planned. At second one the radiation resistance of electronics and its' components under heavy ion irradiation will be tested. The structure of channels includes several dipoles, focusing quadrupoles and active scanning systems. The results of the channel simulation providing lossless transportation for different ions (from C to Au) with energy per nucleon from 0.25 GeV to 0.8 GeV are presented and discussed.

INTRODUCTION

Significant project NICA in JINR (Dubna) is devoted mainly to problems of experimental physics of high energy. It consist of ion sources, linacs, buster, Nuclotron and collider with its experimental equipments. In addition a few experiments on extracted beams with fixed targets both in physics, and for testing influence of different ion beams on biological and electronics objects are planned. For those aims extracted from Nuclotron beam must be transported to two new targets. According to requirements for biological experiments the beam with sizes less 10x10 cm^2 and with minimal background are needed. Meanwhile to test elements of new electronics, the beam with sizes from 2x2 cm^2 up to 20x20 cm^2 is needed. Experimental targets must be irradiated with uniformity better than ±10%.

The place for new channels location is shown on Fig.1. The dimension of stands with additional place for beam collimators and supported devices are about 3m*3m in plan. For stands service the comfortable pass with 1 m width must be provided.

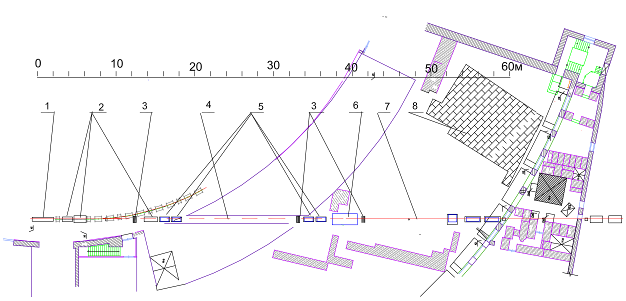

Figure 1: The place for new channels location . 1 – septum magnet, 2 – magnets for bend extracted ion beam in vertical plane to the top, 3 – devices of JNIR PIK for measurement shape of the beam, 4 –beamline with angle 0.105 to the top, 5 – exsisting quadrupoles, 6 – magnet SP12, 7 – beamlines in horizontal direction, 8 – concrete walls.

*markmkats@gmail.com

Behind each stand the beam stop with dimension in plan of 4m*4m must be placed at distance at least 3m. The maximal magnetic field for new magnets must be limited by B < 1.6 T.

After extraction from Nuclotron ion beam is bended up by 3 dipoles in vertical plane with angle near 0.105 rad. At the ground flow another dipole SP12 putthe beam horizontally. Four existing quadruples in front of the last dipole provide the beam focusing.

The beam properties depend on the mode of Nuclotron and extraction system operation as well as on the experiment request. The beam extraction time can be from 0.1 to 10 sec. Stability of extracted beam intensity can be near ±5%.

At the exit of Nuclotron the extracted beams can be different both by ions (from C to Au) and by ions energy (0.25 < t < 0.8 GeV, t kinetic energy per nuclon) and by phase volumes in both planes and by its impulses spread dP/P [%]. Intensity of extracted beams can be from 10^4 to 10^9 per sec. The P(max)/z и P(min)/z for extracted ions can be calculated using equations:

$$P/z = (T^2+2TM)^{0.5}$$
$$T=A*t,$$
$$M=A*0.936\ \text{GeV}$$

where T is a total kinetic energy of ion, A – an atomic mass, t – kinetic energy per nuclon, 0.936 is a mass of one nuclon, z is charge of ion. As result t(max)=0.8 GeV, t(min)=0.25 GeV.

For output channel development we have used

$$P(max)/z\ (Au^{+79})=3.6\ \text{GeV/c}.$$

Parameters of extracted beams were received from Nuclotron team (see Fig.2):

X*X'=3mm*mrad, Y*Y'=8mm*mrad, dP/P=0.1%.

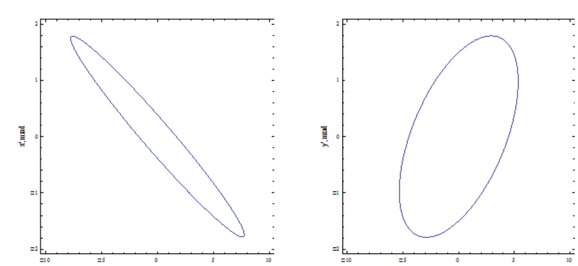

Figure 2: Phase volumes of extracted beams at level 2*sigma.

GENERAL APPROACH

The most restriction of the project is the requirements of homogeneous irradiation for targets with different dimensions. The increase of total beam spot at the target to provide the required homogeneity leads to loss of the high part of beam intensity. The "active scanning" as it

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used in proton therapy has been suggested. For use of this method:

a) Beam spot at the target must be at least ten times less then target sizes. Optic of channels must provide the beam focusing with variable diameter at the target surface,

b) Linear dispersion of ion beam at the target must be decreased as much as possible in both planes for both channels,

c) Suitable place for scanning magnets is behind last focusing quadruples installed in each channel. Magnetic rigidity of scanning magnets (maximal field*length) together with distances L between scanning magnets and targets must be enough for scanning of ion beams with P(max)/z at targets with maximal sizes (200mm*200mm).

SOFT FOR OPTICAL SOLUTION

For optical development, the TRANSPORT code [1] (at 2 order) was used. The beam cross-sections at any channel point have been simulated by MC REVMOC code [2] after TRANSPORT calculation.

NEW ADDITIONAL MAGNETS

For beam lines development the following requirements for magnets are used:

a) 2 or 3 new bending magnets (depend on layout solution) must be C-shapes, with gaps like 80mm*300mm*1600mm, with max field 1.6 T (constant in time, without laminated iron). They are placed behind SP12.

b) The beam focus should be formed by now existing system after SP12 and in front of the new bend magnets.

c) To refocus the beam from that point to the targets, two triplets of quadruples are used. Quadruples in triplets have a gap of 100 mm in diameter and 800 mm (central one) and 400 mm (lateral ones) length with max field on iron less than 1 Tl.

d) two scanning magnets for each channel are placed just after triplets. Their gaps dimension are 100mm*100mm*400mm with max field 0.5 T and frequancy less than 100 Hz.

It is supposed that the maximal currents for all new magnetic elements are less than 600 A.

Steps of changing currents and its stability for magnets is 10^{-3} and $5{\bullet}10^{-3}$ for quadruples (all magnets and quadruples which took place in transport extracted ion beam from Nuclotron have to satisfy similar requirement).

PRELIMINARY LAYOUT OF NEW CHANNELS

According to requirement one beam must be guided to old existing beam stop. Therefore the bend angle of a first new magnet must be near 12 degree. For unification it is possible to use the additional same angle 12^0 (with one additional similar magnet) for second line. However the place between two stands would be uncomfortable for experiments preparation (see Fig. 3).

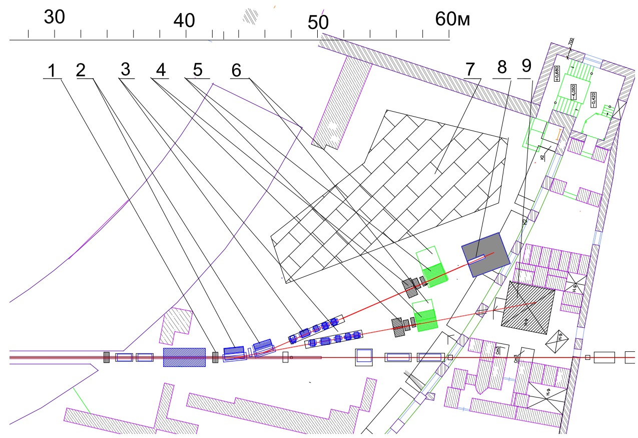

Figure 3: Layout of channels at two bends on 12 degrees. 1 – PIK4, 2 – magnets, 3 – triplets and scanning magnets on commom supports, 4 – devices and collimations, 5 – stends, 6 – entrance for montages, 7 – entrance for rooms, 8 – beam stop 2, 9 – old beam stop.

As an variant the total bend of about 30^0 to second stand was suggested. It can be realized by increasing of either the second magnet length or both magnets or by using 3 magnets with decreasing length (see Fig. 4). The final choice of the solution has small influence on beam focusing, but the such bending angle provides the more comfort conditions for experiments.

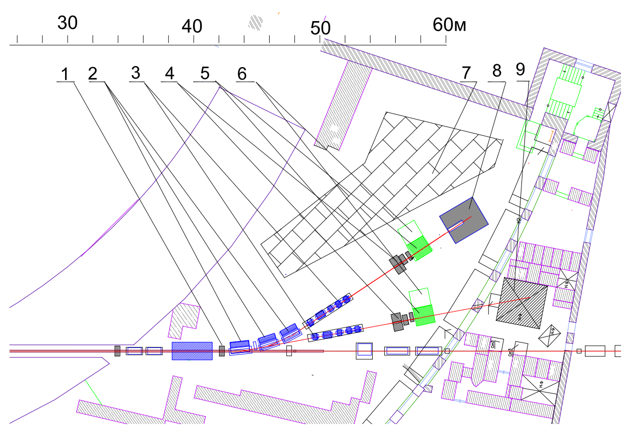

Figure 4: Layout of channels at three bends on 12 degrees. 1 – PIC4, 2 – magnets, 3 – triplets and scanning magnets on commom supports, 4 – devises and collimations, 5 – stends, 6 – entrance for montages, 7 – entrance for rooms, 8 – beam stop 2, 9 – old beam stop.

OPTICAL SOLUTIONS

As result of simulation it was found that the extracted from Nuclotron ion beam can be transport to point between SP12 and the first new magnet (where placed beam profile monitor PIK4) by existing magnets and four quadruples in small cross section. Then it can be refocused by triplet to target with useful diameter. Two

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versions of envelopes for beam transport to the second stand are shown on Fig. 5 (beam diameter at the target 80mm) and Fig. 6 (beam diameter at the target 10mm). Any diameters of the beam spot at the target between 10mm and 80mm are possible by change currents of quadrupoles in triplets. Scanning magnets can move beam in both planes in limits ±100mm.

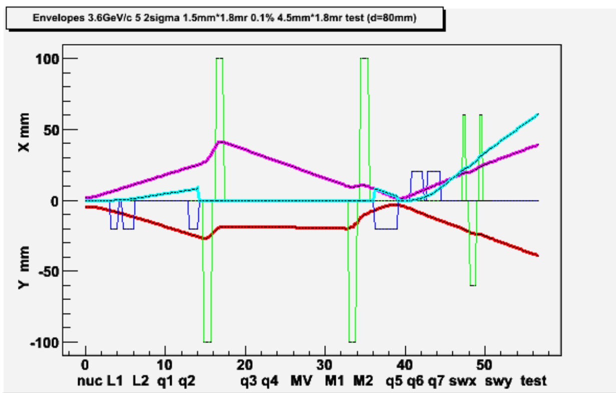

Figure 5: Beam envelopes scheme for bend at 24 degree. X – horizontal plane, Y vertical plane, blue – positions of magnets, green – positions and apertures of quadrupoles.

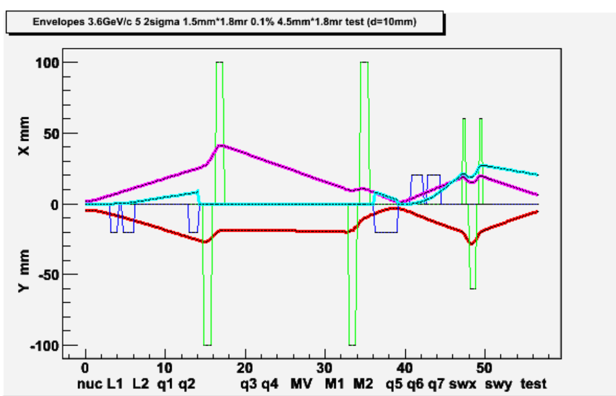

Figure 6: Beam envelopes scheme for bend at 24 degree at beam diameter like 10mm.

The possible cross-sections of the beam were simulated by MC REVMOC. During the one extracted beam pulse (like 10sec) about 50 different position of beam are achievable at the target to provide the homogeneous of dose distribution.

DEVISES FOR BEAM TURNING

To provide the beam tuning it is necessary to provide two different set of devises for different possible beams intensities. Devices must be placed into common vacuum (10^{-3} Torr) with possibility changing its position (in beam and out of beam) with precision like 0.2 mm. Existing devises PIK1 and PIK2 are useful for measurement properties of extracted ion beam. Additional similar devices PIK4 should be placed between SP12 and first new magnet. Additional PIK5 and PIK6 should be placed at input of the channels to the first and the second stands.

Additional devices for experiments must be placed nearby both stands. Signals from all devices will be directed in new control room located in the same hall.

During experiments the magnetic optic tuning can be carried out as following**:**

- Estimation of extracted beam properties by PIK1 and PIK2.
- Tuning the beam at Q3 by PIK2.
- Tuning cross-over in both planes in PIK4(to provid the first focus at proper point).
- Refocus beam to target of stands by its triplets by using PIK 5 or PIK6.
- Test and tune scanning by using devices for accumulation dose distribution in time of one or many cycles of Nuclotron.

CONCLUSION

The preliminary version of transport channels for two experimental stands were developed in framework of NICA project. It was shown the feasibility of two stand installations at the free space between Nuclotron output and existing experimental hall. The beam simulation will be corrected during the development of all new bending magnets, focusing triplets, scanning system as well as the stands design.

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