HEAVY ION INJECTOR FOR NICA/MPD PROJECT

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Abstract

General goal of the NICA/MPD project under realization at JINR is to start in the coming 5÷7 years an experimental study of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions. The Nuclotron-based Ion Collider fAcility (NICA) and the Multi Purpose Detector (MPD) are proposed for these purposes. The NICA collider is aimed to provide experiment with heavy ions like Au, Pb or U at energy up to 3.5 x 3.5 GeV/u with average luminosity of 10^{27} $cm^{-2}\cdot s^{-1}$ and to provide collisions of light ions in the total energy range available with the Nuclotron. New injector designed for efficient operation of the NICA facility is based on Electron String Ion Source providing short (< 10 μs) and intensive (up to 10 mA) pulses of U^{32+} ions, one section of RFQ and four sections of RFQ Drift Tube Linac accelerating the ions at $Z/A \geq 0.12$ up to 6.2 MeV/u of the kinetic energy. General parameters of the injector are discussed.

INTRODUCTION

General challenge of the NICA facility is to achieve a high luminosity level of heavy ion collisions in a wide energy range starting with about 1 GeV/u. To reach this goal the NICA injection chain has to deliver a single bunch of fully stripped heavy ions (U^{92+}, Pb^{82+} or Au^{79+}) at intensity of about $1÷1.5\cdot 10^9$ ions [1]. The existing Nuclotron injection complex consists of HV fore-injector and Alvarez-type linac LU-20. The LU-20 accelerates the protons up to the energy of 20 MeV and ions at $Z/A \geq 0.33$ up to the energy of 5 MeV/u [2]. Because of the limitation in charge to mass ration the LU-20 can not be used effectively for operation as a part of the NICA facility. Additionally, an effective stripping of the ions before injection into the Nuclotron requires their preliminary acceleration to an energy of a few hundreds of MeV/u. Therefore, realization of the NICA project presumes design and construction a heavy ion injector and intermediate booster synchrotron as new elements of the NICA collider injection chain. The injection chain optimization was started from the choice of an ion source and formulation of requirements to the linear accelerator.

ION SOURSE AND REQUIREMENTS FOR LINAC

We have considered a few types of the heavy ion sources – namely the Laser Ion Source (LIS), the Electron Beam Ion Source (EBIS), the Electron String Ion Source (ESIS) and the Electron Cyclotron Resonance (ECR) ion source.

The LIS has limitations in the kind of ions that can be produced. Additional obstacles, such as large beam emittance due to a large energy spread, target erosion and coating of mirrors, state of the art laser requirements, and very large pulse-to-pulse fluctuations of the beam current, set one thinking seriously about development of this type of the ion source presently.

The EBIS ion source chosen as the base of the new RHIC injector [3] has parameters close to the required ones and expected for the ESIS. General disadvantage of the EBIS is very high DC power of the electron beam. So, the EBIS proposed for the new RHIC injector requires of about 300 kW DC power for the operation and maximum charge state is limited because of the electron energy limitations. At the same time, the maximum DC power of the electron beam in the ESIS is about 200 W. By contrast to the EBIS, the ESIS source can provide heavy ions in very high charge states, like Au^{51+} or U^{64+} at practically same intensity as Au^{30+} or U^{32+}. The repetition frequency of ESIS operation in this mode is at the level of 1 Hz.

In view of the facts described above the decision to use the development of the ESIS as the baseline for the NICA project has been taken.

The possibility to work with ECR ion source as reserve option for the NICA facility operation is considered as well. To realize it the linac has to accelerate long heavy ions pulse generated in an ECR source for multiturn injection into the booster.

To provide optimization of the heavy ion injection chain and cover the polarized program of the NICA facility the injector-linac has to provide the following options of the operation:

- acceleration of the heavy ions at the charge state of 30+ ÷ 32+ at the intensity of $(2÷4)\cdot 10^9$ ions and the pulse duration of 7 μs (the ion revolution period in the booster);
- acceleration of the heavy ions like Au^{51+} and U^{64+} at the intensity of $(2÷4)\cdot 10^9$ and the pulse duration of 7 μs;
- acceleration of the heavy ions at the charge state of about 30+ ÷ 32+ at the current of 0.1 ÷ 0.2 mA and pulse duration up to 100 μs (operation with ECR source);
- acceleration of the polarized D^- ions at the current up to 1 mA and the pulse duration of about 1 ms.

The first option is chosen as the baseline for realization of U-U collision experiment. The pulse of $4\cdot 10^9$ U^{32+} ions at 7 μs duration corresponds to the peak current of about

3 mA. Maximum ion current corresponds to the second option and it is about 6 mA. To provide required technical reserve the linac has to have good efficiency of the heavy ion acceleration at the current up to 10 – 15 mA.

LINAC AND INJECTION CHAIN

The RFQ section was chosen as the initial part of the injector linear accelerator. At low ion velocity RFQ permits a continuous acceleration and perfect adiabatic conditions to produce a very good bunching efficiency (~ 100%). For the main part of the injector linac we considered four versions:

1) Alvarez-type accelerator,
2) an accelerator with the Alternative Phase Focusing (APF) [4],
2) hybrid type of the focusing proposed at GSI [5],
3) RFQ DTL developed in IHEP (Protvino) [6].

1st version assumes installation of an RFQ accelerator instead of the existing HV fore-injector and replacement of the drift tubes system of the LU-20 by a new one. However, in the ion energy range of a few MeV/u the peak RF power required for the Alvarez structure is about three times larger than for the structures based on H-cavities. Furthermore, the drift tube length in E-cavity structure has to be long enough to place a quadrupole lens inside it. This leads to low acceleration rate in the initial part of the structure and to decrease of the accelerator efficiency.

2nd version. The APF accelerator provides high acceleration rate and is simple in operation. However, its maximum ion current is below 1 mA.

3rd version. In the GSI type structure the strength of the transverse focusing of the APF is sufficiently increased by using quadrupole triplets located in a few large drift tubes. Such structure is used for lead ion acceleration in CERN and is planned as the main part of the new RHIC injector [3]. However, up to now such accelerators were used with ECR ion sources and their application to acceleration of a high current ion beam has been never demonstrated yet experimentally.

The 4rd version - the RFQ DTL, in contrast to the APF structures utilizes focusing by quadrupole components of the RF field and provides a strong focusing in both longitudinal and transverse planes. As result, the maximum ion beam current can reach of about 100 mA. The IHEP group (founded by one of the inventors of the RFQ accelerator Vladimir Teplyakov) has more than 30 years experience in design and construction of such structures.

Finally, *the 4d version* - RFQ DTL has been chosen as the basis for the main part of the new linac design and construction. On the basis of conceptual design of the RFQ and the RFQ DTL prepared by the IHEP group the optimization of the NICA injection chain (Fig. 1) was done. The booster maximum energy is limited by available room in the existing building and maximum magnetic field of its bending magnets. The injection chain satisfies to the requirements of the heavy ion program and provides technical reserve for the facility development.

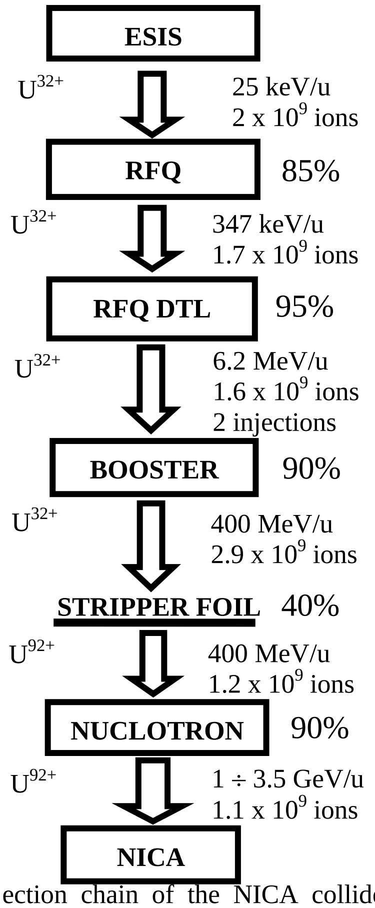

Fig. 1. Injection chain of the NICA collider based on ESIS source and RFQ linac.

STRUCTURE AND PARAMETERS OF THE INJECTOR

The injector delivers ions in wide atomic number range – from polarized deuterons to $^{238}U^{32+}$ at the energy of 6.2 MeV/u. Its total length is of 30 m. The injector will be constructed in the existing so called UFTI building (a very preliminary design is shown in the Fig. 2) in order to provide its assembly and commissioning without interruption of the Nuclotron operation.

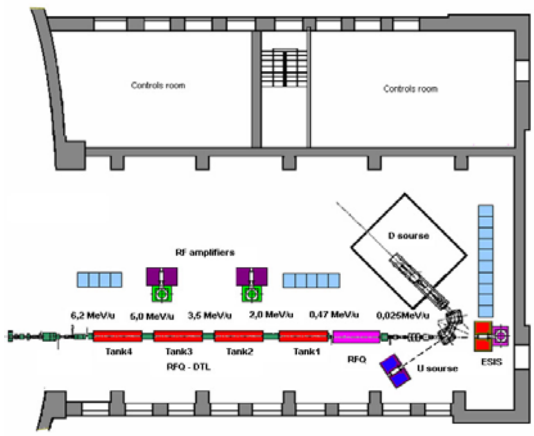

Fig. 2. Injector location in the existing building.

The injector includes the following elements:

- Electron String Ion Source (ESIS);
- External uranium ion source;
- Source of polarized D^- ions (POLARIS or CIPIOS);
- Low Energy Beam Transport (LEBT) to match the beam with the entrance of the linear accelerator;
- Linear accelerator consisting of the RFQ section and four sections of the RFQ DTL;
- High Energy Beam Transport (HEBT) from the exit of the linac to the injection point of the booster. This line includes also a debuncher system.

ESIS

Electron beam ion sources (EBIS) invented at JINR [8] are used widely in many accelerator centers for production of highly charged ions. In the reflex mode of the EBIS operation the electrons do not reach electron collector after one pass through the drift space of the source. Instead they are reflected back towards the electron gun, where are reflected again near the gun cathode, travel one more to the reflector, and so on. Thus, the electrons are bouncing between the cathode and the reflector of the source and can be used for generation of highly charged ions much as a direct electron beam does.

It was found that in certain conditions the "cloud" consisting of the multiply reflected electrons confined in a strong solenoid magnetic field exhibits properties similar to a phase transition. It leads to a stepwise increase of the confined electron plasma density in a new steady state called "the electron string". Various highly charged ion beams have been produced with the ESIS "KRION-2" constructed at JINR (Fig. 3) and used in two Nuclotron runs during recent years [9].

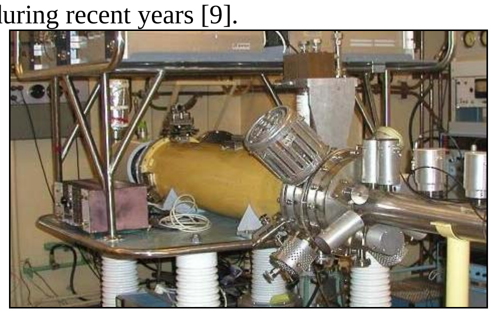

Fig. 3. ESIS "KRION-2" operated at JINR.

New stand ESIS "KRION-6T" aimed to achieve parameters required for NICA (Table 1) is under construction now.

Table 1. Main parameters of the ESIS sources

	"KRION-2" achieved to date	"KRION-6T" expected
Magnetic field, T	≤ 3	≤ 6
Electron energy, keV	≤ 8	≤ 25
Ions	Au^{30+}	Au^{32+} (U^{32+})
Ionization time, s	$2{\cdot}10^{-2}$	0.015
Work frequency, Hz	40	50
Number of ions per pulse (at given charge state)	$5{\cdot}10^{8}$	$2{\cdot}10^{9}$
Extraction time, μs	8	6 - 8

RFQ AND RFQ DTL

The RF in both accelerators - the RFQ and the RFQ DTL - is equal to 75 MHz. The accelerator is designed to accelerate the beam of initial normalized rms emittance of 0.1 π·mm·mrad and the emittance growth during acceleration does not exceed two times. To avoid electron load of the cavity (cold emission) the maximum electric field at the electrode surface is chosen to be limited by the value about 350 kV/cm for RFQ DTL and about 220 kV/cm for RFQ . The accelerator consists of the RFQ section (of the length of about 7 m) and four RFQ DTL sections (of the length of about 4.5 m, Fig. 4). The section number and length are determined by technological reasons. The RF, water cooling, vacuum systems and the beam diagnostics along the accelerator will be designed and constructed on the basis of the IHEP long experience in the design, construction and exploitation of RFQ structures. All the elements of the linear accelerator can be fabricated in Protvino at the IHEP workshop.

Fig. 4. RFQ DTL proton linac in IHEP.

REFERENCES

[1] NICA Conceptual Design Report, JINR, January 2008. http://www.jinr.ru/

[2] Govorov A.N., Kovalenko A.D., Monchinsky V.A. et al., Linac LU-20 as injector of NUCLOTRON, Proc. of LINAC-96, 394 – 396.

[3] Electron beam ion source pre-injector project (EBIS), Conceptual Design Report, under edition by J. Alessi, BNL-73700-2005-IR.

[4] M.L.Good, Phase-reversal in linear accelerators, Phys. Rev., v.92, N 2, p. 538 (1953), Fainberg I.B., Alternating Phase Focusing, In: Proc. Symp. on High Energy Accelerators and Pion Physics, V. 1. Geneva, CERN, 1956, p. 91-100.

[5] http://www.gsi.de/portrait/Broschueren/Therapie/index_e.html

[6] O.K. Belyaev A.P. Maltsev,, V.B. Stepanov, et. al., RFQ Drift-Tube proton linacs in IHEP, Proceedings of LINAC 2004, Lübeck, Germany

[8] E.D.Donets, in "Physics and Technology of Ion Sources", Ed. by I.G. Brown, Wiley &Sons, NY, 1989, p. 245.

[9] E.D. Donets et al., Electron string source of highly charged ions: Studies and the first test on a synchrotron, in Proc. of EPAC-2002, Paris, June 3-7, 2002 p.1700-1702.