PROJECT OF THE NUCLOTRON-BASED ION COLLIDER FACILITY (NICA) AT JINR

G. Trubnikov, N. Agapov, V. Alexandrov, A. Butenko, E. Donets, A. Eliseev, V.V.Fimushkin, Yu. Filatov, A.Govorov, V.Karpinsky, T. Katayama, V. Kekelidze, H. Khodzhibagiyan, V. Kobets, S.Kostromin, A. Kovalenko, O. Kozlov, A. Kuznetsov, I. Meshkov, V. Mikhaylov, V. Monchinsky, V. Shevtsov, A. Sidorin, A. Sissakian, A. Smirnov, A. Sorin, V. Toneev, V. Volkov, V. Zhabitsky, O. Brovko, JINR, Dubna, Russia

Abstract

The Nuclotron-based Ion Collider fAcility (NICA) is the new accelerator complex being constructed at JINR aimed to provide collider experiments with heavy ions up to uranium at the center of mass energy from 4 to 11 GeV/amu. It includes 6 MeV/amu heavy ion linac, 600 MeV/amu booster, upgraded Super Conducting (SC) synchrotron Nuclotron and collider consisting of two SC rings, which provide average luminosity of the level of $10^{27}cm^{-2}s^{-1}$.

INTRODUCTION

The goal of the NICA project is construction at JINR of the new accelerator facility that consists of (see Fig.1)

- cryogenic heavy ion source of Electron String type (ESIS),
- source of polarized protons and deuterons,
- the existing linac LU-20,
- a new heavy ion linear accelerator (HILAc) [1],
- a new SC Booster-synchrotron (that will be placed inside the decommissioned Synchrophasotron yoke),
- the existing proton and heavy ion synchrotron Nuclotron (located in the basement of the Synchrophasatron building) [2],
- two new SC storage rings of the collider,
- a new system of beam transfer channels.

The facility will have to provide ion-ion (1÷4.5 GeV/amu of the ion kinetic energy), ion-proton collisions and polarized proton-proton (5÷12.6 GeV) and deuteron-deuteron (2÷5.8 GeV/amu) beams collisions.

As a result of the project realization, the potential of the Nuclotron accelerator complex will be sufficiently increased in all the fields of its current physics program. The fixed target experiments with slow extracted Nuclotron beams are presumed the experiments with internal target as well. The Booster will be equipped with a slow extraction system to perform radio-biological and applied researches using heavy ion beams.

The collider will have two interaction points. The Multi Purpose Detector (MPD), aimed for 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, is located in one of them. The second one is used for the Spin Physics Detector (SPD).

Main goal of the NICA facility construction is to provide collider experiment with heavy ions like Au, Pb or U at luminosity above $1\cdot10^{27}$ $cm^{-2}\cdot s^{-1}$ at the energy of 3.5 GeV/amu. It was decided to choose the Gold nuclei $^{197}Au^{79+}$ as the reference particles for the heavy ion collider mode. In the collisions of polarized beams the luminosity above $1\cdot10^{31}$ $cm^{-2}\cdot s^{-1}$ is planned to be achieved in the total energy range.

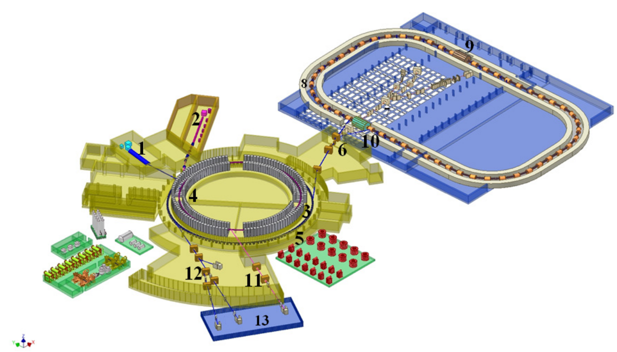

Figure 1: Scheme of NICA facility: 1 – light and polarized ion sources and "old" Alvarez-type linac; 2 – ESIS source and new RFQ linac; 3 – Synchrophasotron yoke; 4 – Booster; 5 – Nuclotron; 6 – beam transfer line; 7 – Nuclotron beam lines and fixed target experiments (to be dismantled); 8 – Collider; 9 – MPD; 10 – SPD; 11, 12 – transfer lines; 13 – new research.

The essential features of the project permitting to minimize its cost, the construction period and to realize a wide experimental program are the following:

- No construction of new buildings, very limited development of the infrastructure;
- Collider facility does allow independent carrying out the fixed target experiments;
- The facility can be used for collider experiments with light and middle weight ions including polarized deuterons;
- The required modifications of the Nuclotron ring including development of the ion sources are realizing within the project of the Nuclotron upgrade, which will be completed in 2010 [3];
- Choice of optimal Booster design based on a few possible versions made before;
- Application of recent world data obtained at BNL, CERN and GSI for achievement of a high collider luminosity;

- Wide co-operation with JINR Member State institutions and active participation of Russian institutions;
- Application of relevant experience available at JINR in superconducting magnets design and fabrication (the magnet cryostating systems of the collider rings and Booster can be made by the institute workshops).

NICA OPERATION

Collider will be operated at a fixed energy without acceleration of an injected beam. Correspondingly the maximum energy of the experiment is determined by the Nuclotron magnetic rigidity that is equal to about 45 T·m at the field value of about 2 T. The collider rings will be placed one above the other one and elements of SC magnetic system are being design as a "twin bore" magnets. For luminosity preservation in the heavy ion collision mode an electron and stochastic cooling systems are planned to be used. To cover the total ion energy range the electron energy of the electron cooling system has to be varied from 0.5 to 2.4 MeV. For optimum operation of the stochastic cooling system the collider optic structure is designed to permit variation of the ring critical energy [4].

To achieve the maximum design energy the Nuclotron has to accelerate fully stripped ions. To provide the ion stripping at high efficiency the ions have to be accelerated to the energy of a few hundreds of MeV/amu. For this goal is used a new synchrotron ring – the Booster. To obtain maximum ion number after single turn injection the Booster has to have a circumference as long as possible. It is realized at the Booster location inside the Synchrophasotron yoke. The yoke will provide also a necessary radiation shielding of the Booster ring .

The heavy ion beam accumulation in the collider rings will be realized with application of RF barrier bucket technique. Intensity of the injected portion influences on the stacking process duration only and could be arbitrary in principle. The required beam emittance is formed during the stacking by the cooling application. The maximum bunch number in the collision mode is limited by requirement to avoid parasitic collisions in the interaction region. The collider will be equipped with Barrier Bucket RF system and two sinusoidal RF systems – one of them is operated at the harmonics number coinciding with the bunch number at the collisions (it is used for the bunching of the stacked beam), another one is operated at significantly larger harmonics number that is necessary to keep a short bunch length at reasonable RF voltage value.

The suggested Project allows one to collide mass asymmetric beams including proton-ion (pA) collisions. Alongside of proper physics meaning, it is quite important as a reference point for comparison with heavy ion data. The experiment will be performed at the same MPD detector therefore the luminosity significantly larger than 10^{27} $cm^{-2}\cdot s^{-1}$ is not necessary. This level is achievable quite easily because of large proton number in the beam comparing with heavy ions.

In this mode the collider injection chain has to be switched fast (during a time of a few seconds) from acceleration of heavy ions to acceleration of protons. Two acceleration and stacking chains of heavy ions and protons (or light polarized ions) are proposed:

- ESIS → HILAc → Booster → Nuclotron → Collider
- Duoplasmatron (polarized ions source) →LU-20 → Nuclotron → Collider

For the proton acceleration the Booster is not necessary. The proton beam generated by duoplasmatron source is accelerated by LU-20 up to energy of 20 MeV. Single-turn injection allows Nuclotron to have more than 10^{11} protons. After adiabatic bunching they are accelerated at the 5-th harmonic of the revolution frequency to the experimental energy and transferred, bunch by bunch, to the collider ring. If necessary the accelerated proton beam can be rebunched in the Nuclotron after the acceleration to form a single bunch of larger intensity.

Another mode of the facility operation will be proton-proton and deuteron-deuteron polarized colliding beams in the energy range 5 ÷ 12.6 GeV for protons and 2 ÷ 5.8 GeV/amu for deuterons. The luminosity above $1\cdot 10^{31}$ $cm^{-2}\cdot s^{-1}$ is required over the total energy range.

For the spin physics program the Booster is not used because it has only four super periods instead of 8 in the Nuclotron. The polarized particles are accelerated with LU-20, single-turn injected into the Nuclotron where accelerated up to the experiment energy.

In the Nuclotron ring the deuteron depolarization resonances are absent in the total achievable energy range. The possibility of acceleration and extraction of polarized deuterons in the Nuclotron has been demonstrated a few years ago. The measurements of polarization degree performed by three independent groups on internal and extracted beams in November 2003 gave the value of 65 % agreed with the expected value.

For acceleration of the polarized proton beam the Nuclotron has to be equipped with insertion devices for the spin tune control to cross the depolarization resonances without loose of the polarization degree. Preliminary design of such devices was prepared and the Nuclotron straight section length is sufficiently long to place them.

Presently the maximum achieved intensity of polarized beam in the Nuclotron is about $2\cdot 10^{8}$ particles per cycle. The main direction of work aimed at increase of the intensity is connected with the design and construction of a new high current polarized ion source with charge-exchanged plasma ionizer (IPSN) based on the equipment of CIPIOS polarized proton and deuteron source transferred to Dubna from Bloomington (Indiana

University, USA). The work is carried out in collaboration with INR (Troitsk). Some parts of suitable equipment for the new source were presented by DAPHNIA (Saclay). The IPSN will provide the output beam current up to 10 mA of ↑p and ↑d^+ ions. ↑d^+ ion polarization of 90% of the nominal vector mode +/-1 and tensor mode +1,-2 is expected. That will result in increase of the accelerated polarized beam intensity at the Nuclotron up to above 10^{10} particle/cycle.

The collider operational cycle assumes feeding the collider with ions during a few minutes after that the collision experiment will be provided during a few hours at almost constant luminosity without additional injections. At this time the Booster and Nuclotron will be used for independent experimental programs. The Nuclotron with LU-20 as injector will provide light ion beams for internal target experiments and its slow extraction system will be used for fixed target experiments and test of the MPD elements. The Booster will be used as a heavy ion synchrotron. Its designed magnetic rigidity of 25 T·m allows providing the wide range of radio-biological and applied experiments as well as cancer therapy researches with carbon and heavy ions.

PLANS FOR REALISATION

The Nuclotron upgrade program considered as a first stage of the NICA project [5] is in the final stage now. Main goal of the program is to prepare the synchrotron for operation as a part of the NICA collider injection chain. To the moment the upgrade of the Nuclotron vacuum system is completed, deep reconstruction of the liquid helium factory was provided during 2008-2009, modernization of the magnetic system power supply and energy evacuation system will be completed this year. As a result of the works at the Nuclotron run in March 2010 the ions Xe^{42+} were successfully accelerated up to energy of about 1.5 GeV/amu, and the magnetic system was operated at the dipole magnetic field of about 1.8 T (the designed value is 2 T). Development of the new heavy ion source and the polarized ion source is the part of the Nuclotron upgrade as well.

In parallel with the accelerator modernization the technical design of the collider injection chain elements (HILAc, Booster, LU-20 upgrade program) was prepared.

One of the most important problems determining the facility construction period is the possibility of the collider location close to the Nuclotron with minimum civil constructions. To fulfill all these requirements the collider ring circumference has to be about 400 m. To locate such a ring the existing experimental building requires appropriate reconstruction. The project of the building reconstruction is under development by State Specialized Design Institution (Moscow) and we expect it the completion at the end of 2010. As a result the price and the required reconstruction period will be determined.

The structural dipole and quadrupole magnets for the collider, as well as for the Booster, will be based on the design developed during the Nuclotron construction. The Nuclotron superconducting magnets are based on a cold-iron window frame type yoke and low inductance winding made of a hollow composite superconductor. The magnetic field distribution is formed by the iron yoke. The Nuclotron magnet fabrication has brought a great experience to the Institute staff in the field of SC magnet design and manufacturing. Such type of magnets one plans to use for construction of SIS-100 synchrotron of the FAIR project. The collider dipole magnet will be about 2 m long, the distance between apertures is about 30 cm. Construction of the magnet model based on the preliminary design has been started in 2010.

To construct the Booster and collider rings we need to fabricate more than two hundreds of the dipole magnets and lenses during short period of time. The working area for the magnet fabrication and test benches required for the magnet commissioning are under preparation now.

A few elements of the facility (such as electron and stochastic cooling) require R&D works and long term of the construction (HILAc).

Taking into account all these problems the beginning of the facility element commissioning in 2015 looks realistic at the moment. In the optimistic expectations the experiments with circulating beam in the collider rings can be started at the end of 2015. At the first stage of the collider operation the heavy ion collisions will be realized and the design luminosity level can be achieved to 2017. After upgrade of the ring optics in the vicinity of the collision point the heavy ion–proton collisions will be performed. Collisions of light polarized ions are scheduled for the third stage of the collider operation.

REFERENCES

[1] V. Kobets, A.Sidorin et al., Injector Complex of the NICA Facility, These Proceedings.
[2] A. Butenko, V. Mikhaylov et al., Design of the Nuclotron Booster in the NICA Project, These Proceedings.
[3] A. Butenko, G. Trubnikov et al., Status of the Nuclotron. "Nuclotron-M" Project, These Proceedings.
[4] S. Kostromin, O. Kozlov et al., Lattice of the NICA Collider Rings, These Proceedings.
[5] I. Meshkov, A. Sisakian, G. Trubnikov, Heavy Ion Programs for Applications and Fundamental Research at JINR, These Proceedings.