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LONGITUDINAL PARTICLE DYNAMICS IN NICA COLLIDER

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Abstract

A specific feature of the NICA acceleration complex is high luminosity of colliding beams. Three types of RF stations will be used in the NICA Collider to reach the necessary beam parameters. The first one is for accumulation of particles in the longitudinal phase space with the moving burrier buckets under action of stochastic and/or electron cooling systems. The second and third RF stations are for formation of the final bunch size in the colliding regime. This report presents numerical simulations of longitudinal beam dynamics which taken into account the longitudinal space charge effect during the accumulation and bunching procedures. Influence of space effects leads to some decrease in the accumulation efficiency and requires special manipulation with the 2nd and 3rd RF stations during the adiabatic capture and bunching procedures.

INTRODUCTION

The goal of the NICA facility [1] in the heavy ion collision mode is to reach the luminosity level of 10^{27} cm^{-2}s^{-1} in the energy range from 1 GeV/n to 4.5 GeV/n.

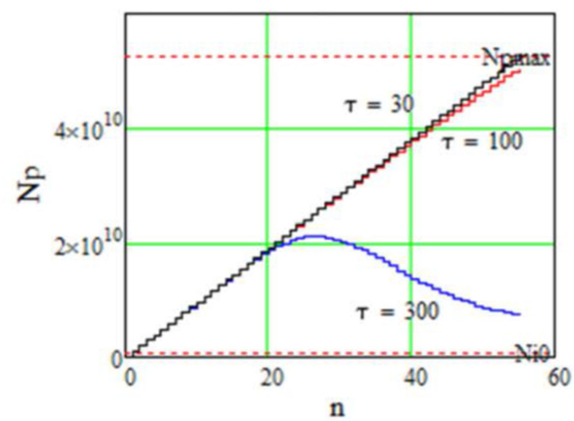
Collider RF systems [1,2] have to provide accumulation of required numbers of ions in the energy range 1-3.9 GeV/n, accumulation at some optimum energy and acceleration to the energy of the experiment in the range of 1-4.5 GeV/n, formation of 22 ion bunches, and achievement of the required bunch parameters.

This can be done with the help of three RF systems [1], one of the broad-band type and two narrow-bands ones. The first one accumulates particles in longitudinal phase space with application of RF barrier bucket technique. The maximal voltage of the barrier is 5 kV, it has rectangular shape with phase length $\pi/12$. By applying additional voltage of 300 V, one can also use the meander between the barriers for inductive acceleration. The second RF system works on the 22th harmonic of the revolution frequency and is used for formation of the proper number of bunches. The maximal RF2 voltage corresponds to 100 kV. The RF2 can also be used for beam acceleration or deceleration. The third RF system works on the 66th harmonic and is used for the final bunch formation and maintenance of the bunch parameters during the collision mode. The maximal RF3 voltage is 1 MV. The RF3 system is also used for ion beam acceleration or deceleration.

All stages of the bunch formation as well as the collision mode are accompanied by a cooling process, either stochastic or electron.

ACCUMULATION OF IONS BY RF BARRIER BUCKETS

Application of the RF barrier bucket technique provides independent optimization of the bunch intensity. The Collider rings receive a bunch from the Nuclotron every four seconds. A bunch contains (0.2-2)$\cdot 10^9$ particles. The dependences of the number of stored ^{197}Au^{79+} ions and the momentum spread on the number of injections in the Collider ring at ion energy 3 GeV/n are shown in Fig. 1.



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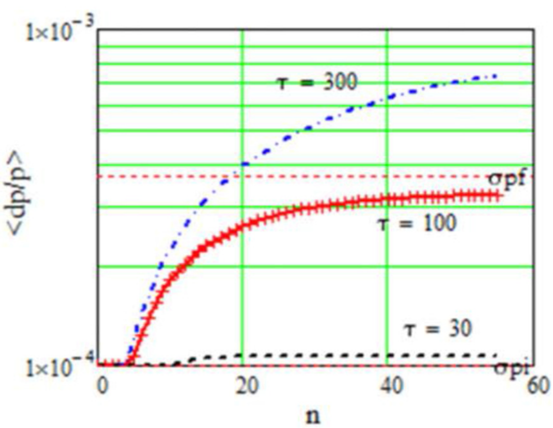

b)

Figure 1: Dependence of the number of stored ions (a) and the momentum spread (b) on the number of injection cycles at different cooling times.

The momentum spread of the stored ions is determined by the equilibrium between intrabeam scattering and cooling. When the cooling time is 30-100 s (Fig. 1 b), the momentum spread is small and the number of stored ions linearly increases with the number of injection cycles. At the

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cooling time of 300 s the momentum spread is larger than the critical value of the momentum spread (red dashed line in Fig. 1 b) determined by ion stack space charge effects. The number of accumulated ions has a maximum at an optimal number of injection cycles.

Dependence of the maximal number of stored ions on their momentum spread is given in Fig. 2. The maximal number of the stack ions is determined by the equilibrium between the new injection portion and the stack ion losses due to the kicker action at the injection on the to stack tails placed outside of the RF barriers. The growth of the stack ion momentum spread leads to an increase in the kicker ion losses. The ion space charge restricts the number of stored ions at a small momentum spread. The maximum number of stored ions is also restricted by the ion beam instability. Dependence of the maximum number of stored ions on the momentum spread is shown in Fig. 2 (the black dashed line) in accordance with the Keil-Schnell criterion.

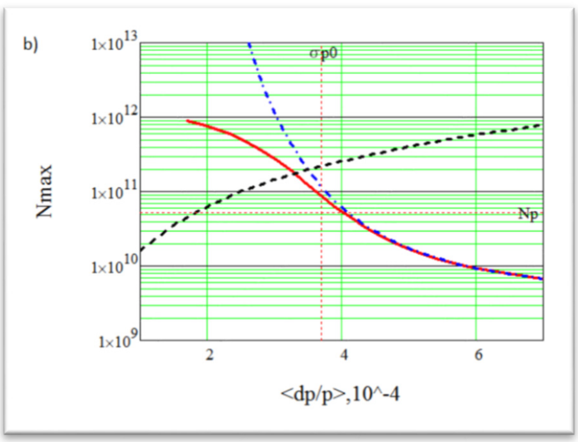

Figure 2: Dependence of the number of stored ions on the momentum spread at the ion energy of 3 GeV/n. Read line: with ion space charge effects, blue line: without ion space charge effects.

BUNCHING OF ION BEAMS IN COLLIDER RINGS

Preparation of beams for ion-ion collision occurs in two stages. Firstly 22 bunches are produced using adiabatic capture technique at slowly increasing RF voltage. Under cooling, the bunch shrinks not only in length but also in emittance (Fig. 3 - Fig. 4).

When RF2 voltage reaches the maximum of 100 kV, the voltage of the RF3 system working on the 66th harmonic starts adiabatically increasing from 21.8 kV (Fig. 5). When the bunch length becomes short enough due to cooling and adiabatic RF2 voltage increases, the bunch is intercepted into the RF3 system.

The maximal RF2 voltage together with cooling should provide conditions when the final longitudinal bunch length at interception must be equal to the length completely fitting into the bucket of the RF3 system. However, a small number of ions at interception can be captured in the parasitic side separatrix of 66th harmonic. This leads to parasitic-collisions in the Collider. The ratio of the number of captured ions in the side parasitic separatrix to the total number of bunch ions (Fig. 6) strongly depends on the rms bunch length after the RF2 bunching and cooling (Fig. 4).

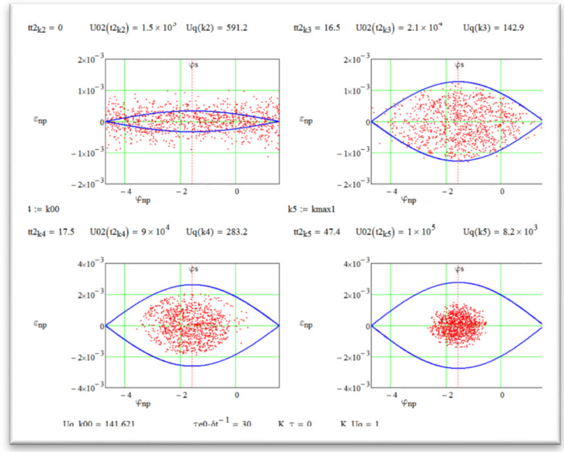

Figure 3: Bunching of the ion beam by the RF2 system at the $^{197}Au^{79+}$ ion energy of 3 GeV/n (initial RF2 voltage 1.5 kV, final voltage 100 kV, RF2 frequency variation 10 half bends/s, and cooling time 100 s).

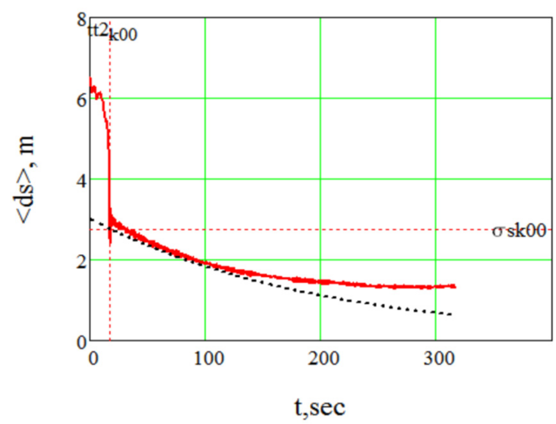

Figure 4: Dependence of the rms bunch length on time at the ion energy of 3 GeV/n (cooling time 100 s).

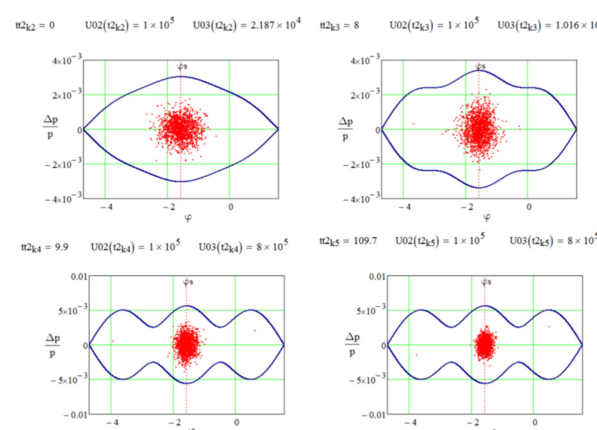

Figure 5: Dependence of the rms bunch length on time at the ion energy of 3 GeV/n (cooling time 100 s).

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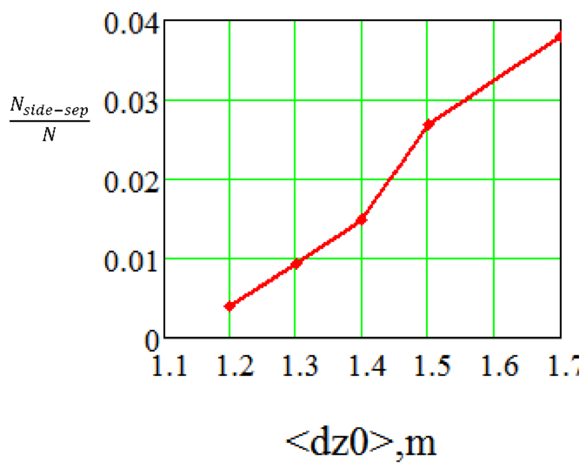
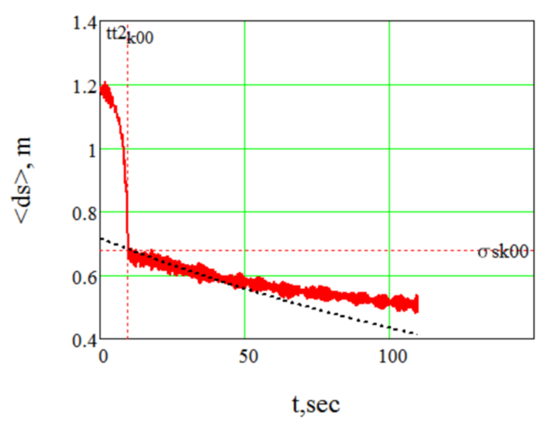


Figure 6: Dependence of the ratio of the number of captured ions in the side parasitic separatrix to the total number of bunch ions on the rms bunch length after the RF2 bunching.

Further adiabatic increase in the RF3 voltage together with cooling provides formation of an ion bunch with the length of 60 cm and momentum spread of 10^{-3} required for colliding experiments (Fig. 7).



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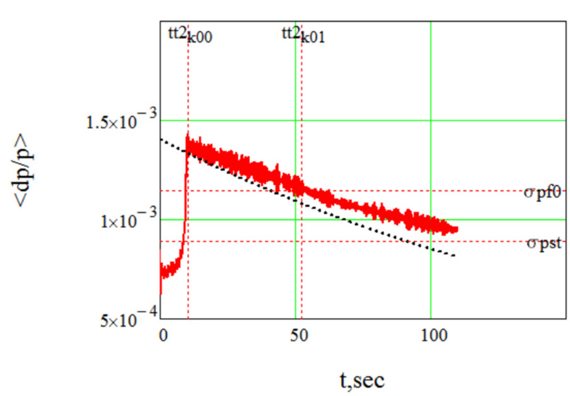

b)

Figure 7: Dependence of the rms bunch length (a) and the momentum spread (b) on the time at the ion energy of 3 GeV/n (cooling time 100 s and bunch length of 1.2 m after RF2 bunching).

Parameters of the ion beam after storage and bunching are given in Table 1 with the use of RF1, RF2 and RF3 systems. The RF2 and RF3 voltages should provide at bunching the ion momentum spread larger than their threshold momentum spread $(dp/p)_{th}$ related to beam instability.

Table 1: Beam Parameters at the Storage and Bunching in the Collider

Energy, GeV /n	1	3	4.5
Number of ions per ring	4.4×10^{9}	5.3×10^{10}	5.1×10^{10}
Rms momentum spread dp/p at ion collisions	6×10^{-4}	1.1×10^{-3}	1.6×10^{-3}
Threshold rms momentum spread $(dp/p)_{th}$ at ion collisions	2×10^{-4}	5.7×10^{-4}	6.5×10^{-4}
Threshold rms momentum spread $(dp/p)_{th}$ for stored coasting beam	5×10^{-5}	1.4×10^{-4}	1.7×10^{-4}
dp/p for separatrix of RF1 barrier	7×10^{-4}	1.1×10^{-3}	1.8×10^{-3}
Emittance at ion collisions, eV·s	28	12	235
Threshold emittance of stored ion beam, eV·s	31	173	300
Emittance of stored beam, eV·s	59	202	470

REFERENCES

[1] Technical Project of NICA Acceleration Complex, Dubna, Russia, 2015.

[2] O. Brovko *et al.*, “Storage, bunching, and parasitic collisions in the NICA Collider”, *Physics of Particles and Nuclei Letters*, vol. 15, no. 7, pp. 792–794, 2018.