DESIGN OF THE NICA COLLIDER RINGS

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Abstract

The Nuclotron-based Ion Collider fAcility (NICA) [1] is a new accelerator complex being constructed at JINR. It is aimed to collider experiments with ions and protons and has to provide the ion-ion (Au^{+79}) and ion-proton collision in the energy range of 1÷4.5 GeV/amu and also polarized proton-proton (5÷12.6 GeV) and deuteron-deuteron (2÷5.8 GeV/amu) collisions. Two collider rings are designed to achieve the required luminosity at two interaction points (IP). Each ring has a racetrack shape with to bending arcs and two long straight sections. The optics concept supposes the constant γ_{tr} and also its slight variation. The two beams are separated in vertical plane and come into collisions in IPs optimized for β^*=0.35 m. The long straight sections are matched to the arcs and have the possibility of betatron tuning.

INTRODUCTION

The goal of the NICA project is construction at JINR of the new accelerator facility that consist of [1]: cryogenic heavy ion source of Electron String type (ESIS), source of polarized protons and deuterons, the existing linac LU-20 of Alvaretz type, a new heavy ion linear accelerators RFQ-DTL, a new superconducting Booster-synchrotron placed inside the decommissioned Synchrophasotron yoke, the existing proton and heavy ion synchrotron Nuclotron, the new system of beam transfer channels, and two new superconducting storage rings of the collider. NICA collider lattice development has overcome many iterations [2] taking into account many necessary aspects of the design. The collider should operate in the energy range for Au-ions of 1÷4.5 GeV/amu, with the peak luminosity up to $5\cdot10^{27}$ cm^{-2} s^{-1} at 4.5 GeV/amu. The ring should work with the different particle species (Au^{+79}, protons and deuterons). Collider must fit into JINR infrastructure and has circumference limitation of about 500 m. The collider lattice is based on the technology of super-ferric magnets developed in VBLHE, JINR [3]. The dipole magnet with up to 2 T bending field operates with hollow composite NbTi cable at 4.5 K. The collider optical structure choice is following the physical effects which set the certain limits on the lattice parameters:

- Beam (luminosity) lifetime limitation by intrabeam scattering in a bunch (IBS);
- Space charge effects: - threshold of microwave instability development (Keil-Schnell criterion); - incoherent (Laslett) tune shift; - beam-beam tune shift;
- Slippage factor optimization for efficient stochastic cooling;
- RF voltage amplitude dependence on transition energy.

Together with the physical effects the another technical constraints were taken into account in lattices comparison: ring circumference, number of the dipole magnets in arc, convenience of the beam injection into the ring. At the final stage two option of the ring lattice have been considered in simulation: Triplet structure with 8 cells per arc, FODO structure with 12 cells per arc. The choice was done in a favor of FODO optics. FODO-12 has a larger efficiency of stochastic cooling at 4.5 GeV/amu. But the luminosity of 10^{27} cm^{-2} s^{-1} could be reached in the wide energy range. Besides FODO-12 arc has a more simple structure, the convenient injection scheme through the dipole-empty cell, relatively simple matching to the long straight section then the moderate γ_{tr} tuning needed.

Table 1: General ring parameters

Maximum energy (for Au^{+79})	4.5 GeV/amu
Ring circumference	503.04 m
Gamma-transition, γ_{tr}	7.091
Betatron tunes, Q_x/Q_y	9.44/9.44
Particles per bunch	$6.1\cdot10^9$
Number of bunches	23
Ring acceptance	40π mm mrad
Longitudinal acceptance, $\Delta p/p$	±0.010
RMS momentum spread, σ_p	0.0018
RMS emittance, $\varepsilon_x/\varepsilon_y$	$1.2/0.9\pi$mm mrad
Minimum beta function at IP, β^*	0.35 m
RMS bunch length, σ_s	0.60 m
IBS growth time	940 s
Luminosity (for Au^{+79} beam)	$6.7\cdot10^{27}$ cm^{-2} s^{-1}

FODO-12 LATTICE STRUCTURE

FODO-cell geometry is set up with the fixed lengths of magnetic elements and spaces. In Fig. 1 the scheme of 11.96 m cell is shown. There are four rectangular dipole magnets per cell (80 magnets per ring), two quadrupoles, multipole correctors and BPMs. Their general parameters are [3]: Dipole, L_{eff}=1.94 m, B_{max}=1.8 T, sagitta=±9.41 mm; Quadrupole, L_{eff}=0.4 m, G_{max}=27 T/m, R_{pole}=47.5 mm; Corrector, L_{eff}=0.3 m, B_{dip}=0.14 T, G_{quad}=1.8 T/m, $G_{quad,skew}$=0.01 T/m, G_{sext}=150 T/m^2, R_{pole}=80 mm. Dipole/quadrupole magnet has 2 apertures (320 mm between beam axes) that fits beam pipe size 120mm∗70mm.

Arc comprises 12 FODO cells (90^0 phase advance per cell). The last 1.5 cells realize the horizontal dispersion suppressor (the effective quadrupole gradient (3 families) tuned by the nearby quadrupole corrector).

Long straight sections are matched to the arcs, contain the insertion devices, produce the betatron tune variation along the beam separation and final focusing in IPs.

Ring general parameters are given in Table 1 a nd assembly for one of t he rings is shown in Fig. 2. Ring circumference 503 m is equal to 2 Nuclotron's ones. The corresponding β and dispersion functions over half of the ring are pictured in Fig. 3 where the symmetry relatively to IP is considered. For the opposite direction beam the final triplet implies the opposite connection and the straight section should be adjusted to the same betatron tunes. For instance, antisymmetric scheme is possible when the uncorrected vertical dispersion approximately cross zero at IP.

A chromaticity correction includes 2 families (focusing and defocusing). Sextupoles in each family are located in 180^0 betatron phase advance for the compensation of their nonlinearity influence on dynamic aperture (DA). The dependence of the collider tune on dp/p is shown in Fig. 4. It is rather nonlinear due to large β^* at IPs that cause the large chromaticity. At the zero corrected chromaticity $\xi_{x,y}$=0 sextupole setting (the maximum sextupole strength

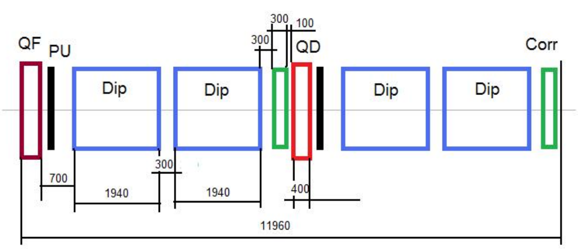

Figure 1: Arc periodic cell.

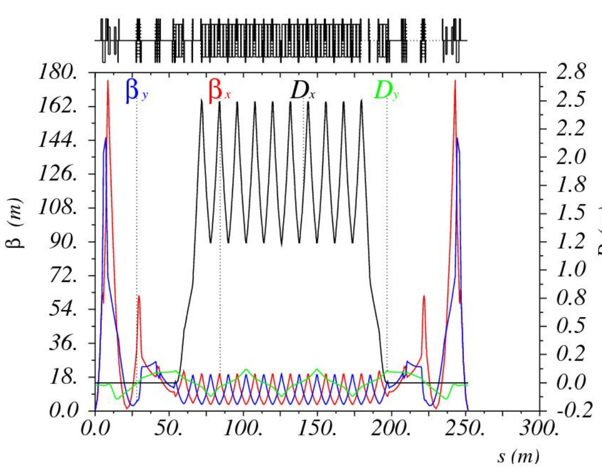

Figure 3: β-functions and dispersions for half a ring.

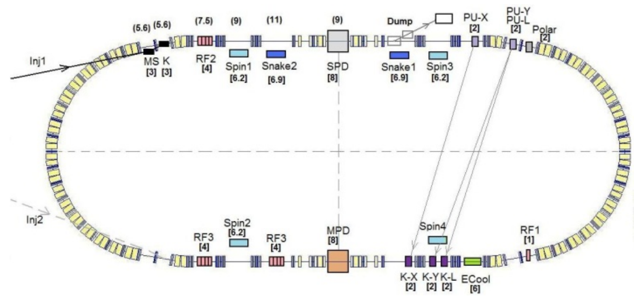

Figure 2: Assembly for one ring.

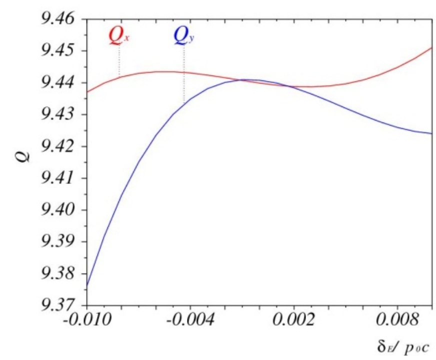

Figure 4: Tune dependence on momentum offset.

is ~70 T/m^2) the corresponding DAs ar e pictured in Fig.5. They are large enough (165π/240π mm mrad) compared to the ring acceptance.

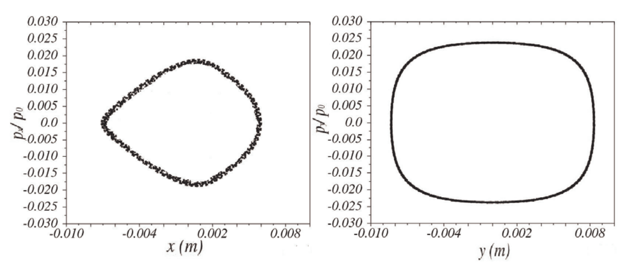

Figure 5: Horizontal and vertical DAs at IP.

INTRA-BEAM SCATTERING AND BUNCH STABILITY

The IBS is one of the main factors limiting the luminosity life-time. For operation below transition that effect is significantly reduced if the three averaged local beam temperatures are equal. The rms horizontal emittance is not exceed 1/6 of the aperture size that determined by final focus triplet acceptance. The rms bunch length is taken to 0.6 m. Then the vertical emmitance and momentum spread are selected to fulfill the condition of the equal emittances growth rates due to IBS [4]. At equilibrium the vertical rms emittance i s lower.

The particles per bunch number defines the total betatron tune shift $\Delta Q_{Las}+2\xi$ (Lasslet and 2 beam-beam) that could not exceed the limit of 0.05 (see Fig. 6). Thus the critical value for the ring is $6.1{\cdot}10^9$ ppb. The number of bunches 23 is getting from the interaction region length of 21.5 m to avoid the parasitic collisions. The corresponding values for the maximum energy are given in Table 1.

The Keil-Schnell criteria for longitudinal microwave instability is met for the single bunch intensity in whole energy range (see Fig. 7).

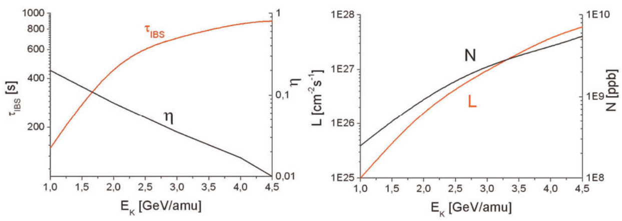

Figure 6: τ_{IBS}, L, N_{ppb} for $\Delta Q_{total}\leq 0.05$.

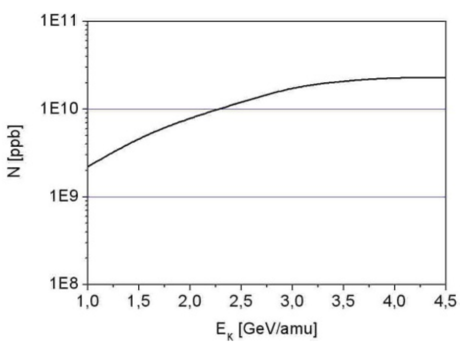

Figure 7: Keil-Schnell threshold for single bunch.

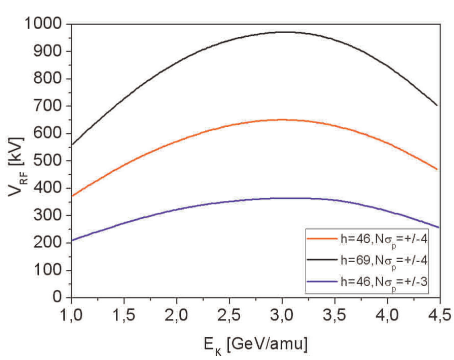

Figure 8: RF voltage vs harmonic number and $n_{\sigma p}$.

STOCHASTIC COOLING

The stochastic cooling (SC) is assumed to be used in the collider to provide the required luminosity at higher energies. The estimations of characteristic cooling times have been carried out for the longitudinal degree of freedom. The stochastic cooling bandwidth is from 3 to 6 GHz (an option of the system with two frequency ranges - 2-4 and 4-8 GHz, is under consideration). Slippage factor η_ω allows to have the efficient cooling at the border of Schottky-band overlap where the cooling rate is maximal. But it is impossible to fulfill the "non-overlapping" condition in a whole energy range 1÷4.5 GeV/amu. In cooling process the proper positions of pickup and kicker have chosen to provide the partial slippage factor from pickup to kicker $\eta_{PK} \ll \eta_{KP}$. In Table 2 the corresponding evaluations for the energy 4.5 GeV/amu and nominal luminosity $1{\cdot}10^{27}$ cm^{-2} s^{-1} are presented. There is some reserve for the cooling time. The SC should be carefully investigated and optimized for intermediate energy in the range 3÷4.5 GeV/amu.

Table 2: SC parameters at energy 4.5 GeV/amu and luminosity $1{\cdot}10^{27}$ cm^{-2} s^{-1}

Particles per bunch	$2.4{\cdot}10^9$
Slippage factor, η_ω	0.010
W	3 GHz
τ_{IBS}	1800 s
τ_{SC}	625 s

CONCLUSION

The collider lattice concept – "2 Nuclotrons" circumference with 12 cell FODO structure in the arcs has been chosen. The optics allows some γ_{tr} variation by changing betatron phase advance per cell around 90^0. SC system suppresses the IBS effects at energies 3÷4.5 GeV/amu. At lower energies electron cooling will provide the project luminosity lifetime. The ring meets the requirements of tunes adjustment in the dispersion free sections, large transversal and momentum acceptances, location of number of the insertions, vertical beam separation in interaction region, maximum total voltage of RF stations (≤1MV) (see Fig. 8).

REFERENCES

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