Analysis of two proposals for a polarized program of NICA

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Currently, two proposals are being considered for the implementation of a polarized program at NICA:

A. **Yu. Shatunov et al., Polarized colliding beams in a NICA in accumulating mode**
B. **A. Kondratenko et al., Polarized ions in the NICA complex**

In analyzing these proposals, we proceeded from the reliability of the numerical estimates and calculations which have been done by authors in the proposals. The main tasks of the magnetic optics of the accelerator complex "Nuclotron + NICA" are to preserve ion polarization during beam acceleration at each stage, to control the direction of polarization at the meeting point in the collider and also to match the direction of polarization between the stages.

Proposal A

The authors of the proposal (A) consider a single mode of operation, when the Nuclotron in the entire energy range accelerates the polarized beam to the required energy and then injects the beam into the collider NICA operated in the accumulating and colliding mode. In accordance with this scheme, the task falls into two: preservation of polarization in the Nuclotron and control of polarization direction in the NICA collider.

In the first part of the proposal, the authors make a thorough analysis of the spin resonances of protons in the Nuclotron in the whole range of energies up to 14 GeV. The analysis made by the authors showed that the most dangerous of spin-betatron resonances are 16-Qz and 8 + Qz, for the crossing of which special measures are required. The authors propose to use one of the already tested methods on other accelerators. In particular, it is recommended to keep the field rate at a level of 1.2 T / sec. Then the authors analyze the spin tune integer resonances arising due to the distortion of the closed orbit. Here it is proposed to introduce a solenoid with a length of 1 m and a field of 200 G in one of the straight sections for the implementation of an adiabatic flipping with a small degree of depolarization.

As a result of this consideration, **the authors conclude that the problem of preserving the polarization of protons in the Nuclotron can be solved using standard methods in the whole range of energies**. Regarding deuterons, analysis has shown **that the acceleration of polarized deuterons is not a problem as well** and in fact has been used for a long time at the Nuclotron. Assuming that the beam will be injected into the collider at any necessary energy, the authors nevertheless made estimates of the resonance forces in the collider in the whole range of energies from 2 to 14 GeV.

In the second part, the authors of proposal (A) consider the polarization control in the NICA collider at the spin tune integer resonances (ν_s = k) for protons and deuterons. First, they consider as an example the transformation of a vertically polarized proton beam with a slight initial detuning from resonance ν_s = k-ε into a beam with longitudinal polarization for the frequency ν_s = 12 and ν_s = 26 by slow switching on weak solenoids 0.5-1 T · m (partial Siberian snake) and reduce detuning ε to zero. At the same time, the authors suggest apparently comparing with the “spin transparence” method working at the frequency ν_s = 0, discussed in the proposal (B), where the required field in two Siberian snakes is 45 T · m. But this is not quite a correct comparison, since in this case the zero tune ν_s = 0 is realized in the whole range of energies, and the controll of the polarization direction can be performed with an arbitrary energy value, which is very important for physical experiments such as Drell-Yan, J/Psi, exotic states, where requires smooth energy regulation with step 0.3-1000 MeV, rather than fixed values. Then, the authors of proposal (A) show that for deuterons the control of the polarization direction on the integer resonances is even more efficient.

The authors then make an assessment of the use of Siberian snakes to control the direction of polarization of deuterons. If for protons the magnitudes of the magnetic fields can be realistic ~ 45 T · m, then for deuterons the value BL = 165 T · m looks unrealistic.

In conclusion, the authors estimate the parameters of the RF flipper, which can be used to control the direction of polarization. The frequency of the RF flipper must be tunable depending on the energy. The estimates of the polarization lifetime are very optimistic, about 10^5 seconds. The authors recommend exploring this option.

Proposal B

The authors of the proposal (B) from the very beginning orient us to “spin transparence mode” (ST), comparing it with the “preferred spin mode” (PS) mode using strong spin-rotators. This method is based on work in the vicinity of the integer spin tune resonance ν_s = k using weak magnetic fields that determine the direction of polarization. At the same time, the required magnetic fields are estimated at the level of 1 T · m. In this part (A) and (B) the sentences are similar to each other. Comparing ST mode with PS mode, where 20-30 Tm fields are required, ST shows a clear advantage over PS mode.

In fact, these two weak magnetic fields determine the spin-flipping system (SF). The authors of the proposal (B) show how and what the spin-flipping system consists of, determine its location on the collider ring.

The authors of proposal (B) consider two modes of operation of the accelerator complex:

- the NICA collider operates in the accumulating mode with an arbitrary fixed energy, and the Nuclotron injects a polarized beam with the required energy;

- the NICA itself accelerates the polarized beam to the required energy, and the injection energy from the Nuclotron is fixed.

In the first version, all the problems of polarization conservation lie on the Nuclotron, and the functions controlling the direction of polarization are in the collider. In this case, the set of integer spin resonances (25) for the proton beam can be used to control the direction of polarization in the energy range from 108 MeV with a step of 523 MeV. For deuterons, there is a single point of 5.63 GeV / u (pc = 13 GeV).

The SF scheme allows to get any spin direction in the yz plane. This scheme is successfully tied to the existing collider optics. For this option, the authors made an assessment of the forces of polarization resonances in the Nuclotron. The problems of polarization preservation in the Nuclotron, which can be solved by standard methods, are considered. This conclusion coincides with the conclusions of A proposal.

In the second option, the authors propose a variant of spin transparency in the whole range of energies due to the introduction of solenoid snakes with a symmetric arrangement relative to the detector to each straight section. This idea echoes the proposal with their co-authorship in the LEIC collider with the orbit of the form 8. Solenoid snakes make it possible to obtain a zero spin tune in the entire energy range. This approach solves two problems:

- control of the direction of polarization in the vicinity of integer resonance;

- preservation of polarization at long time.

With this approach, a polarized beam is injected from the Nuclotron at a relatively low energy, and the collider accelerates the beam up to any energy with any discreteness. In this case, the problems of polarization conservation in the Nuclotron are practically reduced to zero.

Unfortunately, this is given non-free and the required fields in solenoids for overlapping the entire range of proton and deuteron energy are 25 Tm and 80 Tm, respectively. This requires free space for protons of 4.2 m and 13.3 m for deuterons, but from our point of view these figures are realistic for existing lattice.

Conclusion

Both proposals show the positive possibilities of the polarization program at the accelerator complex with the NICA collider. From the point of view of which method is most preferable, one can speak about two potential solutions: “spin transparence” mode and with RF flipper driving the polarization direction. In addition to the proposed methods, it is necessary to decide on the choice of injection energy from the Nuclotron to the NICA collider, and it is also recommended to “spin transparancy “ mode to carry out full-scale tracking for the case of non-ideal structure.