**Comparison of figure-8 and racetrack designs in the MEIC Ion Complex**

The baseline scheme for beam polarization control in the MEIC ion complex using figure-8 ring configuration was presented at IPAC2015 [1] (see also [2]). The possibility of making the booster a racetrack has been reported at the DSPIN 2015 conference [3] (see also [4]).

Let us compare figure-8 and racetrack ring configuration options for the MEIC ion complex [5].

**1. Siberian Snakes in Racetrack**

Siberian snakes must be used when working with polarized protons in racetrack rings (see Table 1).

**Table 1**. Siberian snakes for proton beam in racetrack rings.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ring | snake type | number | *BL*, T⋅m | *L*snake, m |
| Booster | solenoidal | 1 | 30 | 10 |
| Collider MEIC | helical | 2 | 2×25 | 2×10 |

Snakes allow one to preserve the polarization during proton acceleration in a racetrack, since they eliminate crossing of spin resonances. Besides, identical snakes in a racetrack collider create a “spin transparency” mode that allows one to use the advantages of figure 8 for polarization control.

**2. Arc dipoles**

With the same lengths of the main straights, a racetrack ring requires a shorter arc length than a figure-8 one. Table 2 shows the total field integrals of the arc dipoles (*BL*) and their total length *L*dip for racetrack and figure-8 boosters with a maximum dipole field of 3 T.

**Table 2**. Arc dipoles in racetrack and figure-8 boosters.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| ring | p, GeV/c | Racetrack | Figure-8 | Difference |
| *BL*, T⋅m | *L*dip, m | *BL*, T⋅m | *L*dip, m | Δ(*BL*), T⋅m | Δ(*L*dip), m |
| Booster | 8 | 167 | 56 | 237 | 79 | 70 | 23 |
| Collider MEIC | 100 | 2094 | 698 | 3045 | 1015 | 951 | 317 |

Thus, the length occupied by arc dipoles is about 20 m shorter for a racetrack booster and about 300 m shorter for a collider. The lengths occupied by the snakes in the racetracks are about 10 m for the booster and 20 m for the collider.

**2. Racetrack vs figure-8 booster**

*2.1 Preservation of ion polarization in the booster*

In a figure-8 booster, preserving the polarization during acceleration of ***any ion species*** requires introduction of a single weak solenoid with a field integral of ~0.6 Tm. Let us emphasize the ***universality of this polarization preservation scheme***, which does not depend on the field ramp rate of the dipole magnets.

In a racetrack booster, polarization preservation techniques are conceptually different for protons and deuterons. Protons require a solenoidal snake with a maximum field integral of 30 Tm.

A solenoidal snake can be used for deuterons as well but this requires a maximum field integral of ~100 Tm. The snake then occupies ~35 m.

For deuterons, it would be more adequate to use acceleration of a vertically polarized beam with consequent crossing of spin resonances. This has to do with the fact that the resonance grid for deuterons is very sparse. A proper choice of the magnetic lattice can eliminate strong linear intrinsic spin resonances owing to correlation of the spin and betatron motions. As a result, in the booster momentum range, there will only be linear resonances related to imperfections of the magnetic lattice and higher-order resonances. Polarization loss will depend on the field ramp rate of the utilized magnets.

Magnets with a fast ramp rate of ~1 T/s practically guarantee fast crossing of linear resonances as well as of high-order ones. Superconducting magnets with such a field ramp rate are used in Dubna’s Nuclotron [6].

When using magnets with a field ramp rate of ~1 T/min (conventional super-ferric magnets), the linear resonances are crossed at an intermediate rate. Thus, one has to use fast quadrupoles to produce a betatron tune jump at the moment of resonance crossing. Fast crossing of a linear resonance still does not guarantee preservation of the polarization in the whole booster momentum range. Higher-order resonances must be analyzed. One also has to carefully optimize the booster lattice and account for more subtle effects such as those related to synchrotron energy oscillations, which lead to splitting of a resonance into a series of synchrotron side-band resonances.

The betatron tune jump technique was used for protons at ZGS and AGS [7,8].

*2.2 Orbital characteristics*

The orbital characteristics of a racetrack booster change depending on the ion species. Moreover, when using magnets with a field ramp rate of ~1 T/min, the orbital characteristics change in the process of a betatron tune jump.

The orbital characteristics of a figure-8 booster do not change when using a weak solenoid. An advantage of figure-8 is that there is ***no change in the orbital characteristics when running with polarized and unpolarized ion beams.***

**3. Racetrack vs figure-8 collider**

*3.1 Preservation of ion polarization in the collider*

The above discussion about acceleration of polarized ions in a figure-8 booster applies to the collider case as well. A weak solenoid with a field integral of ~8 Tm is sufficient to preserve the polarization in the whole momentum range of the collider.

When running with protons, a racetrack collider is setup in the “spin transparency” mode using two identical helical snakes. Therefore, proton polarization control itself is not conceptually different from the polarization control in a figure-8 collider.

In the collider momentum range, there are strong resonances for deuterons: ~7 integer resonances and ~12 intrinsic resonances. While the series of the integer resonances can be crossed by introducing a partial solenoidal snake, crossing of the 12 intrinsic resonances by betatron tune jumps causes a problem even when using magnets with field ramp rate of ~1 T/s. One has to keep in mind that many higher-order resonances will most likely also have to be crossed with the betatron tune jump technique that will unavoidably lead to a significant polarization loss. Even if polarization is preserved during acceleration, there is ***no guarantee of sufficient polarization lifetime***; in fact, it will most likely be short.

We conclude that ***running with polarized deuterons in a racetrack collider is not practical***.

*3.2 Orbital characteristics*

When accelerating protons in a racetrack collider, helical snakes introduce a betatron tune shift proportional to 1/γ2 and change β-functions. Thus, it will require optical correction of changes in the collider’s orbital characteristics, especially at low energies.

In a figure-8 collider, optical characteristics do not change during acceleration of ions and during manipulation of particle spins.

**Conclusions**

Summing up the above discussion, one can draw the following conclusions:

* a racetrack booster does not give conceptual advantages over a figure-8 booster,
* a racetrack collider for protons allows one to shorten the collider’s circumference by about 15% but then excludes the possibility of experiments with polarized deuterons,
* a figure-8 collider allows one to run with any light ion beams.

**References**

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