LAYOUT OF THE STORAGE RING COMPLEX OF THE INTERNATIONAL ACCELERATOR FACILITY FOR RESEARCH WITH IONS AND ANTIPROTONS AT GSI

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Abstract

The storage ring complex at the Facility for Antiproton and Ion Research (FAIR) at GSI consists of the Collector Ring CR, the accumulator/decelerator ring RESR and the New Experimental Storage Ring NESR. An additional High Energy Storage Ring HESR serves experiments with high energy antiprotons.

The CR serves for fast stochastic precooling of antiproton and rare isotope (RI) beams. Additionally it will be used for isochronous mass measurement of very short-lived radioactive nuclei.

For experiments with RI beams, the RESR serves as a decelerator ring. For the physics program with antiprotons the RESR is used to accumulate high intensity antiproton beams.

The NESR will be one of the main instruments for nuclear and atomic physics. In the case of antiproton operation, the NESR could be used to decelerate injected beams for experiments with low energy antiprotons.

This contribution presents the layout of the storage ring complex and operation schemes of the rings for the different research fields.

THE STORAGE RING COMPLEX

The storage ring complex at the Facility for Antiproton and Ion Research (FAIR) at GSI [1, 2] is vitally important for antiproton physics, nuclear physics with rare isotope beams and atomic physics. It consists of several storage rings: the Collector Ring CR, the accumulator/decelerator ring RESR, the New Experimental Storage Ring NESR and the High Energy Storage Ring HESR. The HESR is designed by a consortium led by FZ Jülich. Recent HESR lattice design studies are described in [3].

Due to the different requirements of each research field, operation schemes are different for rare isotope, antiproton and atomic physics experiments. Antiprotons are produced by an intense 29 GeV proton beam delivered by the SIS100. Up to 2.8×10^{28} protons per cycle produce 1×10^{8} antiprotons at a special production target. The antiprotons are then precooled at 3 GeV in the CR by a stochastic cooling system. Afterwards the antiprotons are transferred to the RESR. The accumulation of 7×10^{10} antiprotons per hour is foreseen. The antiprotons are either reinjected to the SIS100 and accelerated for experiments with high energy antiprotons in the HESR or directly transferred to the NESR. The NESR could then be used to decelerate the beam to 30 MeV for experiments with low energy antiprotons.

Rare isotopes are produced by intense beams of heavy ions delivered by the SIS100. The typical scenario foresees a single 50 ns bunch of up to1×10^{12} U^{28+}-ions at 1.5 GeV/u which is focused to the production target. The rare isotopes are separated in the SuperFRS and then injected into the CR at fixed energy of 740 MeV/u. After precooling in the CR the beam is transferred to the RESR. For experiments with RI beams the RESR serves as a decelerator ring. The RESR is capable of decelerating rare isotopes to variable energies down to 100 MeV/u within approximately 1 s. The NESR will be the final storage ring in the accelerator chain. Besides experiments using an internal target, the NESR offers the possibility to collide circulating bunches of ions with electron bunches counter-propagating in a small 500 MeV electron storage ring [4].

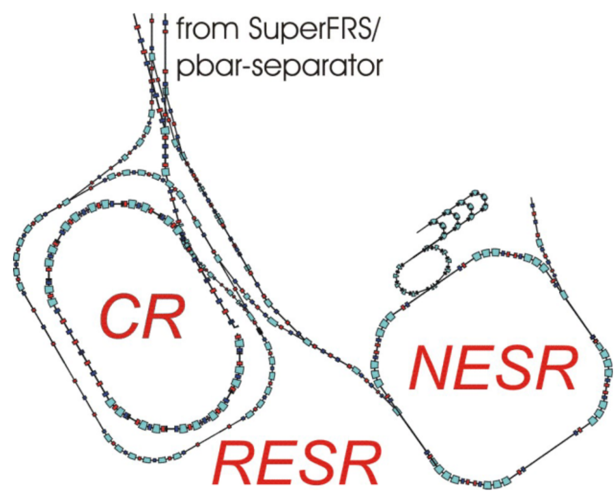

Figure 1: The low energy storage rings at the Facility for Antiproton and Ion Research (FAIR) at GSI.

THE COLLECTOR RING CR

The Collector Ring CR has a circumference of 213.45 m. The ring is designed for three different tasks [5]:

- Fast cooling of rare isotope beams (RIB)
- Fast cooling of antiprotons (pbar)
- Isochronous mass measurements

Each of the three tasks requires a completely different setting of the ring optics with different beta- and dispersion functions. This leads to a variation of the acceptance of the CR. The main parameters for each mode are listed in Table 1.

Earlier lattice layouts favored a so-called split ring design. Although this design has advantages with respect to cooling efficiency, the present layout foresees two identical arcs. The recent layout offers a larger dynamic aperture and enables much simpler injection and extraction schemes.

Table 1: CR main parameters

	RIB	pbar	isochron.
Horizontal tune	3.36	4.62	2.19
Vertical tune	2.88	4.19	3.46
Transition energy	2.7	4.48	1.75
Hor. acc. [mm mrad]	200	240	70
Vert. acc. [mm mrad]	200	240	50
Momentum acc. [%]	±1.75	±3	±0.7

Fast cooling of rare isotopes and antiprotons is accomplished via bunch rotation, adiabatic debunching and stochastic cooling. Rare isotopes are injected at a fixed energy of 740 MeV/u while antiprotons have an energy of 3 GeV. This requires a stochastic cooling system, which can be adjusted to two different energies [6]. Minimum cooling time constants of 0.1 s for rare isotopes and 1 s for antiprotons are envisaged. For isochronous mass measurements of very short-lived radioactive nuclei the CR is equipped with a time-of-flight detector.

Due to the required large aperture and its static operation, superconducting magnets are favorable for the CR. The dipole magnets are superferric type magnets with superconducting coils and warm iron, while the quadrupole magnets are cos(2Θ) superconducting magnets. Sextupole components are included into the quadrupoles by additional cos(3Θ) superconducting coils.

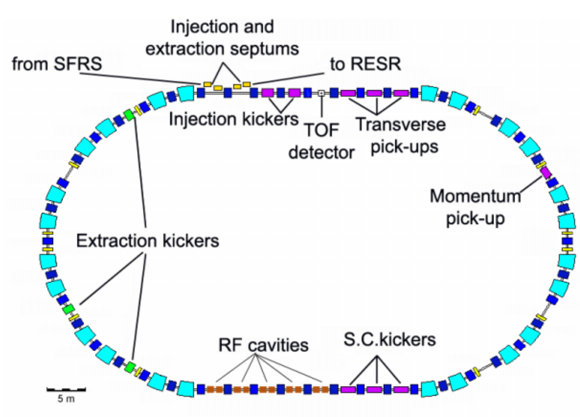

Figure 2: Layout of the Collector Ring CR. The CR is dedicated to fast stochastic cooling of RI beams and antiprotons.

Crucial issues of the CR-design are the rf-cavities, which are used for the bunch rotation process. A total amount of 400 kV rf-voltage is necessary for the bunch rotation process in the case of rare isotopes. In the case of antiprotons the rf-voltage can be reduced to 150 kV.

THE ACCUMULATOR AND DECELERATOR RING RESR

The RESR has a circumference of 245.5 m. The tasks of the RESR should originally have been taken over by the NESR. But the implementation of a stochastic cooling system into the NESR, which is necessary for antiproton accumulation, without strong interference with the other functions, was not possible. To keep the additional costs of the RESR low, it is foreseen to recycle as many parts as possible from the existing Experimental Storage Ring ESR [7]. Some main components that are reused are the quadrupole magnets and beam diagnosis elements. In order to minimize the design effort, the RESR uses the same type of superferric dipole magnets as the NESR.

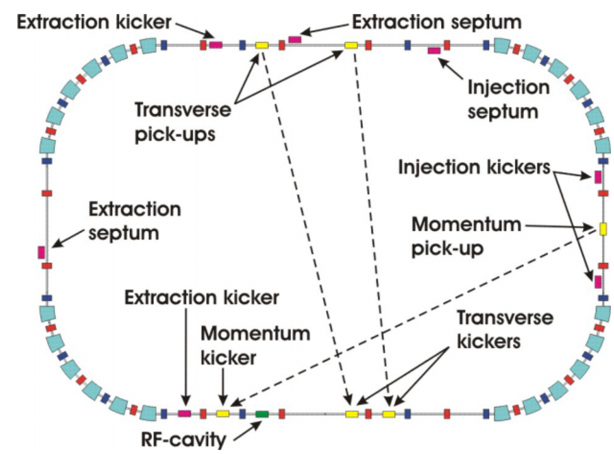

Figure 3: Layout of the RESR. The main task of the RESR is the accumulation of intense antiproton beams.

The primary task of the RESR will be the efficient accumulation of antiprotons. Accumulation of up to 1×10^{11} antiprotons within 0.5 – 2 hours is foreseen. This is accomplished by accumulating batches of 1×10^{8} antiprotons every 5 seconds at 3 GeV. The accumulation scheme foresees longitudinal stacking in combination with stochastic cooling. This could be either momentum stacking or a system using barrier buckets. Hence the RESR will be equipped with two transverse cooling systems and up to three momentum cooling systems. The RESR lattice has to fulfill the requirements of the stochastic cooling system with regard to transition energy, beta functions, phase advance between pick-ups and kickers and dispersion to enable fast cooling and accumulation of the antiproton batches. The main RESR-parameters are listed in Table 2.

Table 2: RESR main parameters

Horizontal tune	3.8
Vertical tune	3.3
Transition energy	3.62
Horizontal acceptance [mm mrad]	80
Vertical acceptance [mm mrad]	35
Momentum acceptance [%]	±1
Maximum dispersion [m]	8

The second task of the RESR will be the fast deceleration of rare isotopes to energies between 100 MeV/u and 500 MeV/u within 1 s. Therefore, a ramp rate of 1 T/s is required. The optical mode of the RESR remains unchanged during deceleration.

THE NEW EXPERIMENTAL STORAGE RING NESR

The New Experimental Storage Ring NESR has a circumference of 218.75 m. The NESR is one main instrument for nuclear and atomic physics with stable and radioactive heavy ions [8]. It also serves an area for experiments with decelerated antiproton and RI beams. To provide high quality beams for experiments the NESR is equipped with an 450 kV electron cooler.

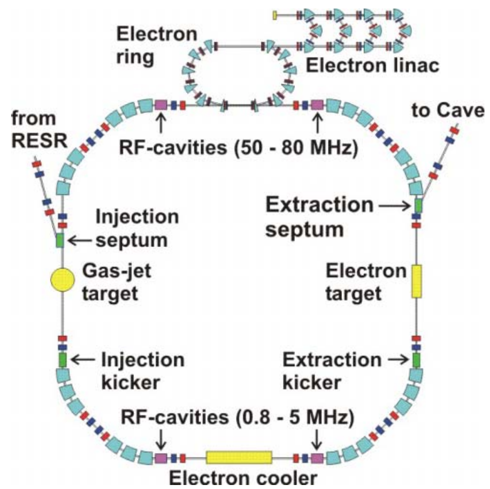

Figure 4: Layout of the NESR. The NESR is one main instrument for atomic and nuclear physics.

Main experimental installations of the NESR are the internal target, an electron target and an electron-nucleus scattering facility employing a 500 MeV electron storage ring. The electron-nucleus scattering facility enables the determination of charge radii and charge distributions of radioactive nuclei circulating in the NESR. In order to achieve luminosities up to 1×10^{28} cm^{-2} s^{-1}, the circulating ion beam has to be bunched at a higher harmonic of the revolution frequency to form short bunches, which are matched to the bunch length in the electron ring. Therefore the NESR will be equipped with an rf-system for frequencies between 40 MHz and 80 MHz. The internal target could either be a gas jet target as in the ESR [9] or a pellet target. It is used for atomic as well as for nuclear physics experiments. The installation of an additional electron target, which will be an electron cooler-like device, makes it possible to do experiments with arbitrary relative velocities between ions and electrons.

Table 3: NESR main parameters.

Horizontal tune	3.4
Vertical tune	3.2
Transition energy	5.74
Horizontal acceptance [mm mrad[]	160
Vertical acceptance [mm mrad]	50
Momentum acceptance [%]	±1.5

Various experiments will use the arcs of the NESR as a kind of spectrometer either for scattered ions or for reaction products. To obtain a high resolution, the lattice has to provide small beta functions and a large dispersion in the arcs. In the NESR arcs the horizontal beta function is below 7 m and the dispersion is 7.24 m. The resulting momentum resolution amounts to 2×10^{-4} for a horizontal emittance of 0.1 mm mrad. This value is sufficient for most nuclear and atomic physics experiments.

To increase the intensity of short-lived rare isotope beams, the NESR allows the accumulation of RI beams. This is accomplished by the use of a barrier bucket accumulation system in combination with electron cooling.

Atomic and antiproton physics require fast and slow extraction of decelerated stored beams. The minimum energy for antiprotons will be 30 MeV while the minimum energy for ions will be 4 MeV/u. The NESR will enable two different kinds of slow extraction. Charge exchange extraction can be used for highly charged heavy ions. The extraction rate is adjusted either by the variation of the electron current of the electron cooler or the thickness of the internal target. Resonant extraction can be used for antiprotons as well as for heavy ions. In this case the extraction rate is controlled by the sextupole magnets or noise excitation. Charge exchange and resonant methods will use the same extraction elements.

OUTLOOK

The general layout of the storage ring facility presently fulfills the requirements of the different physics experiments. Much work is left to be done. The layouts of the three rings are still not frozen. The final layout of the CR depends much on the results of the R & D work on the stochastic cooling system, while the RESR layout will be strongly influenced by the accumulation scheme which will be chosen. The layout of the NESR strongly depends on the final requirements of the different in-ring experiments. For instance, it is still not clear if additional focusing elements in the straight sections are necessary. In addition to the work on ring design, further beam dynamics and equilibrium beam parameter calculations have to be carried out.

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