AN UPDATE OF THE USR LATTICE: TOWARDS A TRUE MULTI-USER EXPERIMENTAL FACILITY

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Abstract

In the future Facility for Low-energy Antiproton and Ion Research (FLAIR) at GSI, the Ultra-low energy electrostatic Storage Ring (USR) will provide cooled beams of antiprotons and possibly also highly charged ions down to energies of 20 keV/A. A large variety of the envisaged experiments demands a very flexible ring lattice to provide a beam with variable cross section, shape and time structure, ranging from ultra-short pulses to coasting beams. The preliminary design of the USR worked out in 2005 was not optimized in this respect and had to be reconsidered.

In this contribution we present the final layout of the USR with a focus on its “split-achromat” geometry, the combined fast/slow extraction, and show the different modes of operation required for electron cooling, internal experiments, or beam extraction. We finally give a summary of the machine parameters and the layout of the optical elements.

INTRODUCTION

The Facility for Antiproton and Ion Research (FAIR) at GSI (Darmstadt, Germany) will include a dedicated facility for research with low energy antiprotons in the keV regime or even at rest, named FLAIR [1]. The deceleration of antiprotons to a final energy of 20 keV (and even down to 1 keV) will be realized in a dedicated electrostatic Ultra low energy Storage Ring (USR). The use of electrostatic elements has the significant advantage that, as compared to their magnetic counterparts, a high field homogeneity in combination with a fast ramping of the fields over a wide range is possible. In addition, remanence and hysteresis effects do not occur in electrostatic elements. As the ring aims to be a multi-user facility, a high luminosity, low emittance and low momentum spread of the beam together with a flexible beam shape are required. External experiments for precision studies, like e.g. trap experiments, will form an integral part of FLAIR and the USR will provide fast as well as slow extraction, for the first time in an electrostatic storage ring.

An interesting option is to decelerate also exotic highly charged ions down to $E=20*Q/A$ *keV/A* in the USR. In this case, a cryogenic vacuum system would be required putting substantially more demanding requirements on the vacuum system. Light ions could be stored even in the room temperature version of the storage ring.

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In order to match the requirements from the envisaged experiments, different modes of operation have to be included in the USR: deceleration and e-cooling, fast/slow extraction [2], in-ring experiments with ultra-short bunches [3,4], and optimization of the beam shape, size, and dispersion with respect to the respective experiment.

SPLIT-ACHROMAT LATTICE

The modified layout of the USR Lattice is based on a split–achromat geometry which gives the necessary flexibility to satisfy the before-mentioned boundary conditions, Fig.1. show the new layout of the storage ring which now has a circumference of 42.6 m, i.e. almost unaltered geometrical dimensions. Four 4 m long straight sections are used to accommodate the so-called Reaction Microscope (ReMi), the different rf systems for the short bunch operation mode [5], the electron cooler, the decelerating drift tube, and the elements for fast/slow extraction [2]. One of the straight sections is kept free for a possible inclusion of a merged positron ring, see [1]. Five electrostatic quadrupoles, two 8^o and two 37^o electrostatic deflectors form an achromatic 90^o bend. A drift space of 1 m between the 8^o and the 37^o deflectors is left to allow for the detection of neutral particles leaving the ring after the ReMi under an opening angle of $\Omega=\pm 0.7^o$.

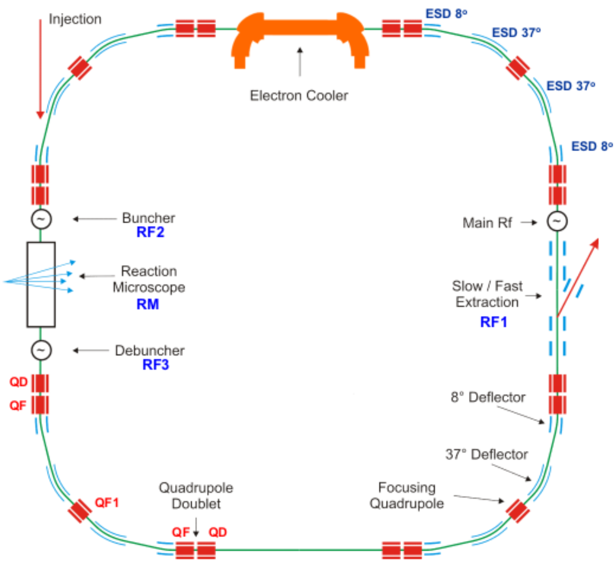

Figure 1: New layout of the USR.

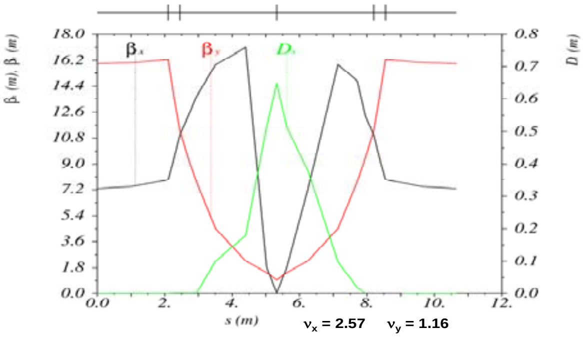

Figure 2. Beta-functions and dispersion of one ring quarter. A dispersion-free mode is used during short pulse operation. MAD-X simulation.

Investigations into the machine lattice were done using the computer codes MAD-X [6] and TRACE3D [7], see Fig. 2-5 and table 1. It should be pointed out that the quadrupole Q3 in the middle of each bending section is used to provide a round beam mode as depicted in Fig. 3 as well as the achromatic condition D=D'=0 if required, see Fig. 2. The dispersion function can be modified in a wide range from D≈+60 cm down to values of D≈–50 cm.

By using different polarity settings on the quadrupole electrodes, the machine can be operated in various regimes of the tune diagram. Two examples are illustrated in Fig.6 where the round beam and the zero dispersion mode are depicted along with the working points of the former USR lattice. The machine chromaticity is reasonably small with a negative tune shift that does not exceed Δν≈–0.07 even for particles with a momentum offset of ΔP/P=1%, see table 1.

The geometrical parameters of the electrostatic deflectors (central radius and distance between electrodes) and electrostatic quadrupoles (effective length and inscribed aperture) were defined by taking into account the possibility to extract neutral particles after the ReMi, to operate with a beam with a normalized 4rms emittance as large as 1–2π mm·mrad and an upper voltage limit of ±20 kV on the deflectors and ±10 kV on the quadrupole electrodes.

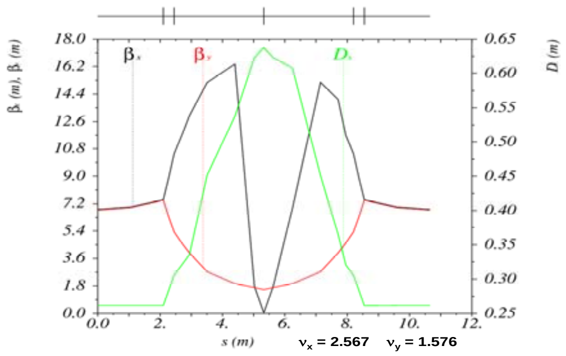

Figure 3. Beta-functions and dispersion in one USR cell for the round beam configuration.

It was shown earlier that fringe fields inside electrostatic elements can have negative effects on the stored beam and even lead to unwanted coupling effects between different optical elements [8] and this grounded shields are foreseen at the entrance and exit regions of the deflectors, the quadrupoles, and between two individual elements of a doublet. The stability of the high voltage power supplies is expected to be better than ±5·10-4 to allow for a safe operation with beam even at lowest possible energies.

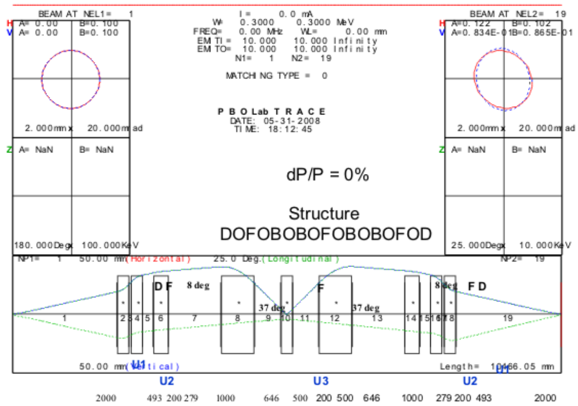

Figure 4. TRACE3D simulation of the 300 keV beam envelope in one quarter of the USR.

The 8° cylinder deflectors have a central bending radius of *r=2 m*, a plate distance of 120mm, and maximum voltages of U=±18 kV. The main 37° deflection is realized by deflector with a central radius of *r=1 m*, a plate distance of 60mm, and again maximum voltages of U=±18 kV.

The aperture radius of the electrostatic quadrupoles is $r_{ap}=100$ *mm* and their effective length *l=200mm*. The voltage that are required to focus a 300 keV antiproton beam are $U_1=-6.1$ *kV*, $U_2=+4.4$ *kV*, and $U_3=+6.35$ *kV*.

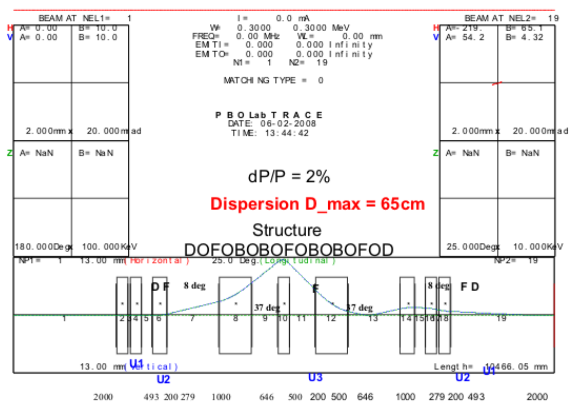

Figure 5. TRACE3D simulation of the central ray of the 300 keV pbar beam in one quarter of the USR.

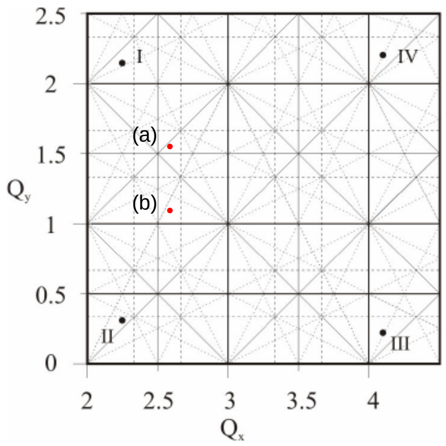

Figure 6. Tune diagram of the USR. (a) Betatron tune of the "round beam" operation mode (ν_x=2.567 and ν_y=1.576), (b) Betatron tune of the achromatic lattice used for short bunch operation mode (ν_x=2.57 and ν_y=1.16). The betatron tunes of the previous USR design based on 90° deflectors are indicated by I to IV.

BEAM EXTRACTION

Computer simulations of the extracted orbit were done using the codes OPERA3D and SIMION. Preliminary results were reported earlier [2] and slightly modified during the optimization process. As can be seen from Fig. 1, the elements for fast and slow extraction are located in one of the straight sections of the ring. Two electrostatic sextupoles and an RF "knock out" cavity which will excite radial beam oscillations are located in another ring section, not shown in Fig. 1. It is foreseen to use four bump electrodes to shift the orbit towards an electrostatic septum which is tilted to the axis by 6°, Fig.7. For fast extraction, the second bump electrode will be switched off quickly in ~200 ns so that the beam can pass directly into the septum electrode. The test setup to analyze all elements of the extraction system is presently being designed.

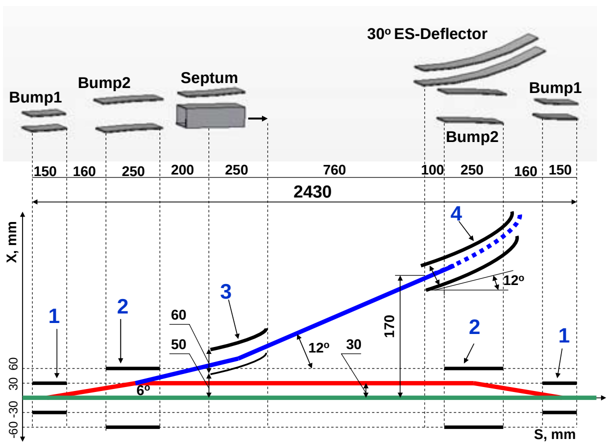

Fig. 7. Position of the USR beam extraction elements.

The extraction system consists of the following elements: two parallel plate deflectors (d_{gap}=60mm, $U \leq \pm 2$ kV), two large parallel plate deflectors (d_{gap}=120mm, $U \leq \pm 3$ kV), the extraction septum, and a cylinder deflector shifted from the beam axis by 50mm. The septum entrance is tilted with respect to the axis by 6° (d_{gap} 60mm, $U \leq +3$ kV, r=2.5 m). A final 30° deflector guides the extracted ions to the external experiments.

Table 1. Overview of the USR parameters.
Beam energy E=20 keV.

Parameter	Achromatic	Round beam	Doublet
γ_{tr} / α	2.87 / 0.12	2.87 / 0.12	2.87 / 0.12
ν_x	2.572	2.567	2.552
ν_y	1.158	1.575	1.67
ξ_y / ξ_x	-8.6 / -3.0	-8.3 / -1.5	-8.4 / -1.3
D_{max} / D_{min} (m)	0.65 / 0	0.64 / 0.26	0.64 / 0.3
β_x^{max} / β_y^{max} (m)	17.2 / 16.3	16.3 / 7.4	16.7 / 6.2
K_{QD} (m^{-2})	-2.415	-2.4	-2.415
k_{QF} (m^{-2})	+1.065	+1.065	+1.065
k_{QF1} (m^{-2})	+6.87	+0.85	0

SUMMARY AND OUTLOOK

In this paper, we present an update of the USR lattice and show how a novel split-achromat geometry can fulfill the requirements from the various user groups interested in carrying out beyond state-of-the-art experiments with low-energy antiprotons at FLAIR. Further detailed studies on the USR's dynamic aperture, correlations between longitudinal and transverse phase space which are especially important for the short bunch operation mode will be realized now by using the 3D computer codes TOSCA and SCALA.

The generous support by the Helmholtz Association of National Research Centers (HGF) under contract number VH-NG-328 and the GSI Helmholtz Centre for Heavy Ion Research GmbH is acknowledged.

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