CHROMATIC AND NONLINEAR DYNAMICS OF ANTIPROTONS INJECTED TO COLLECTOR RING AT FAIR*

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Abstract

Collector Ring (CR) is the storage ring for capturing and stochastic cooling of secondary beams of antiprotons or secondary ions. It is a part of a FAIR project being presently at the early start of a construction phase. Due to the proposed large acceptance in both transverse and longitudinal phase spaces, the chromatic aberrations and their correction with sextupoles are very important for capture efficiency. Calculations results for beam transfer from Pbar target to the ring are presented.

INTRODUCTION

The concept for the production of antiproton ($\bar{p}$, pbar) beams at FAIR is determined by the luminosity requirements for experiments with cooled $\bar{p}$ beams colliding with an internal H_2-target in the kinetic energy range from 0.8 GeV to 15 GeV at the High Energy Storage Ring (HESR) with $\bar{\text{P}}$ANDA [1].

Antiprotons are produced in inelastic collisions of high-energy protons with nucleons of a target. In the present accelerator layout for FAIR (see Fig.1) the SIS100 synchrotron accelerates protons to a kinetic energy of 29 GeV. Every 10 seconds the target will be hit with 2×10^{13} protons in a bunch of about 50 ns duration. The maximum yield (production and collection with reasonable emittance and momentum spread) is achieved for $\bar{p}$ kinetic energy of around 3 GeV that corresponds to 13 Tm of magnetic rigidity.

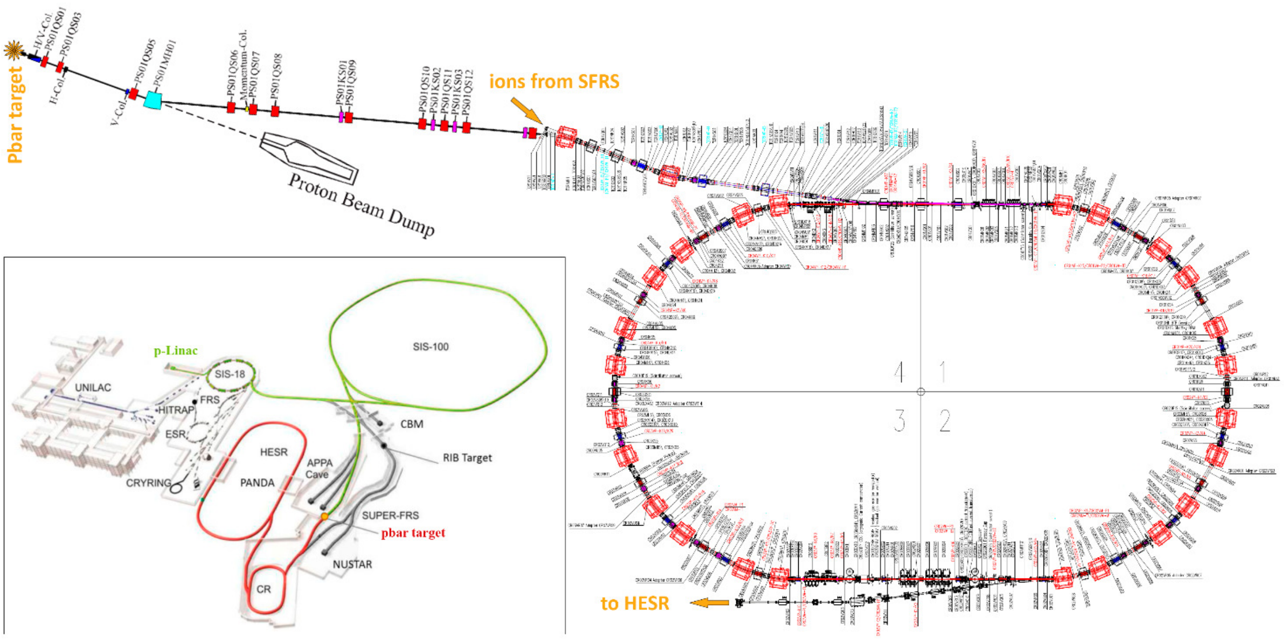

Figure 1: The overall antiproton program scheme at FAIR (left-down), and layout of AS-TCR1 beamline and Collector Ring.

TRANSPORT CHANNEL

The antiproton beam coming from target is focused by magnetic horn and passed through Antiproton Separator (AS) beamline with 4 consecutive collimators [2]. The calculated distribution of $\bar{p}$ in transverse phase space is shown in Fig.2 [3]. Only particles within aperture of first H/V collimator are shown.

The beamline following junction with path of ion beam from SFRS is called TCR1. The aim of the whole transfer line is to separate and to pass antiprotons with transverse emittance of $\varepsilon_{x,y}$ = 240 mm·mrad and momentum spread of $\Delta p/p = \pm 3\%$ that corresponds to CR acceptance.

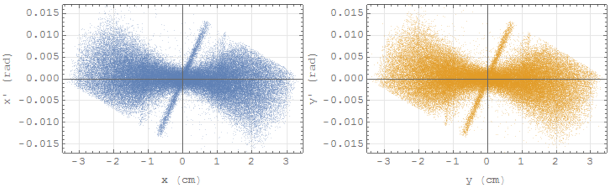

Figure 2: Transverse phase space after horn.

The lattice functions of whole transfer channel including straight section of CR ending with kickers are presented in

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Fig.3. The transverse beam sizes along the channel can be found in the same figure.

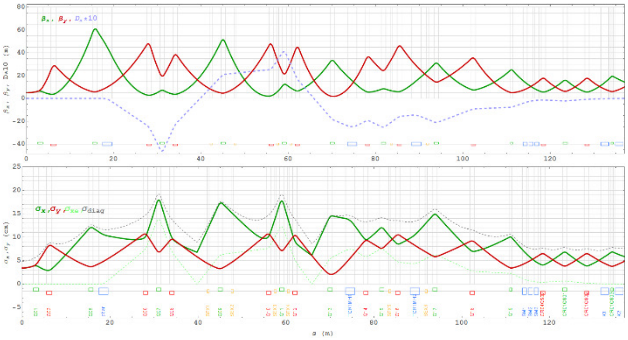


Figure 3: Lattice functions (above) and beam sizes (below) along the transverse channel.

Due to large momentum spread the second-order chromatic effects of the focusing structure are important. In Fig.4 the variation of lattice functions with momentum deviation in the range of ±3% is shown together with second-order dispersion function D_1. Both these effects leads to beam size increase and to mismatch of the lattice functions with CR ones for particles with momentum deviation. To suppress chromatic effects, shown with orange in Fig.3 6 sextupoles are foreseen.

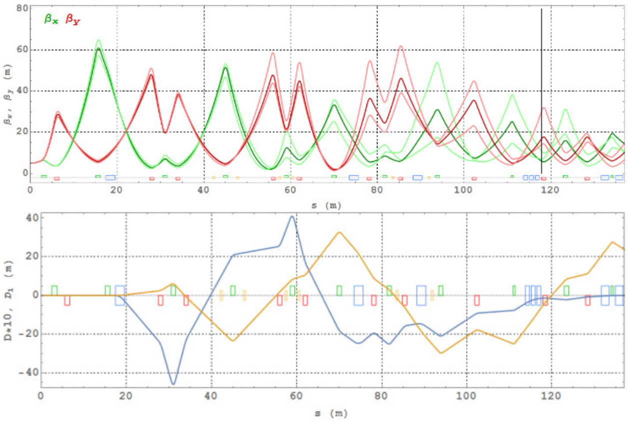


Figure 4: Beta-functions variation for $\Delta p/p = \pm 3\%$ (above) and first- and second-order dispersion-functions (below).

The careful tracking of antiprotons from magnetic horn to CR with realistic aperture limitations and collimation to given emittance and momentum spread was done with full 6D SAD code [4]. The sample of 10000 particles' tracks is shown in Fig.5.

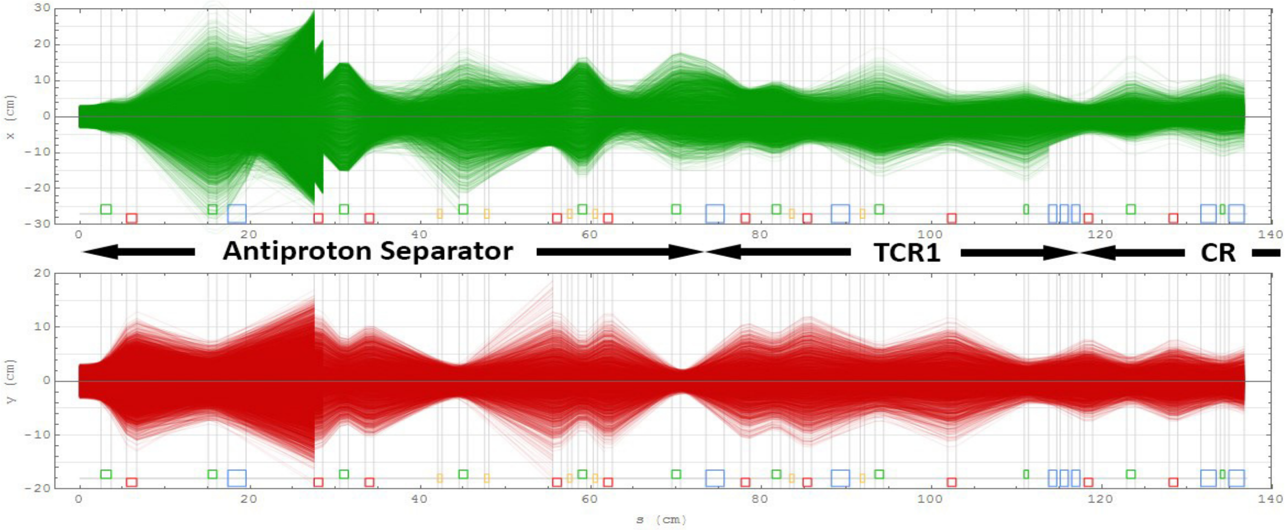


Figure 5: Horizontal (above) and vertical (below) projection of antiprotons tracks.

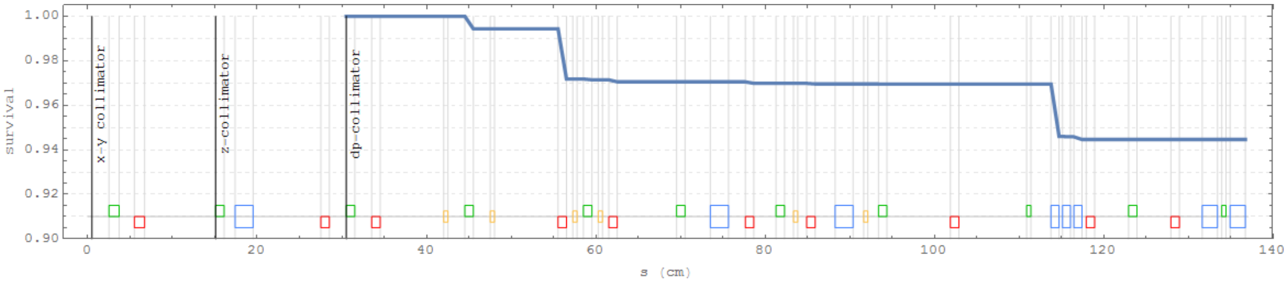


Figure 6: Beam losses along transfer channel.

The corresponding beam losses are presented in Fig.6. Here the number of particles is normalized on number of $\overline{p}$ after last collimation.

In Fig.7 the cross-section of the simulated beam is shown at the entrance of Septum Magnet (SM) [5]. With pink ellipse, the beam cross-section in linear approximation is shown. One can see, that number of particles with large momentum deviation does not fit to the SM vacuum chamber (shown with black circles), being shifted to the left. This is the result of uncompensated chromatic aberrations. The work on optimization of nonlinear correction in channel is still in progress. The momentum spread of pbars injected to CR is shown in Fig.8.

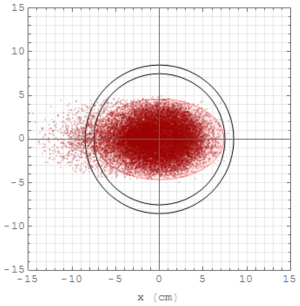


Figure 7: Beam at the entrance to CR septum.

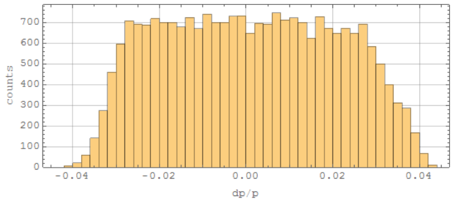
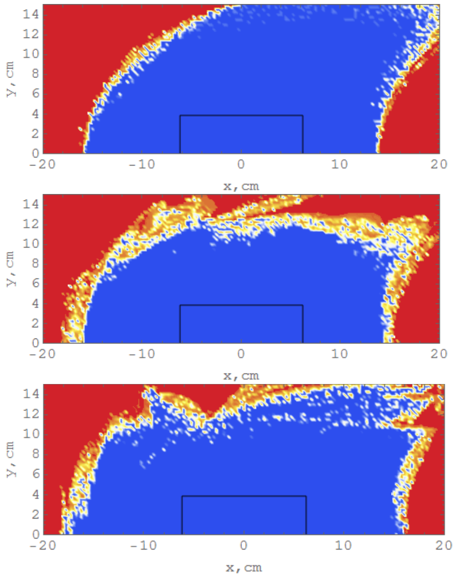


Figure 8: Momentum spread the entrance to CR septum.

COLLECTOR RING

The CR is a large acceptance storage ring designed for capturing and stochastic cooling of hot antiproton or rare isotope beams at FAIR [6, 7]. It will also operate in the isochronous mode to measure masses of short-lived secondary rare isotopes.

In Pbar regime CR should capture the beam with fixed kinetic energy of 3 GeV (γ = 4.20, $B\rho$ = 13 T·m), emittances $\varepsilon_{x,y}$ = 240 mm·mrad and momentum spread of $\Delta p/p = \pm 3$ %.



$\Delta p/p = -3$ %

$\Delta p/p = 0$

$\Delta p/p = +3$ %

Figure 9: Dynamic aperture of CR.

Due to large energy spread it is important to control and tune with help of sextupoles simultaneously betatron tunes chromaticity, second-order chromatic effects, and nonlinear beam dynamics [8]. Six families of sextupoles are foreseen to optimize beam dynamics. The chosen scheme for chromaticity correction provides the sufficient Dynamic Aperture (DA) according to simulations with SAD code [4]. In Fig. 9 the calculated DA is shown. Here the chromatic sextupoles as well as high-order field harmonics of main magnetic elements (dipoles, quadrupoles) are taken into account. Also breaking ring symmetry field errors (±1% for quads, ±10% for sextupoles) and 5÷10 mrad elements rotations were included. The DA is defined as a survival during 1000 turns that corresponds to time of the injected bunch rotation in longitudinal phase space with special RF-debunchers. After rotation the momentum spread decreases significantly and possible DA limitations should be suppressed.

The chromaticity of lattice functions with the same sextupoles' distribution is suppressed to acceptable values (see Fig. 10).

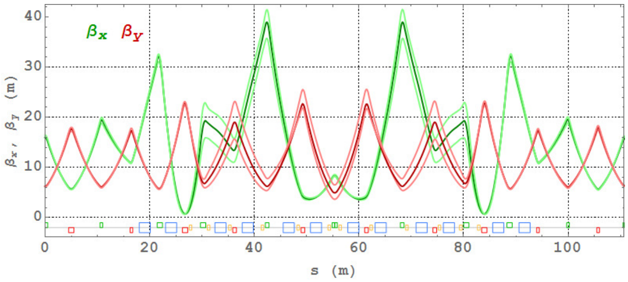


Figure 10: Beam at the entrance to CR septum.

CONCLUSION

Although the further optimization of transfer channel lattice is possible the simulations already show acceptable beam losses in range of several percent with respect to conceptual design parameters.

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