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ABSTRACT

The improvement of the CERN antiproton source relies on a new large acceptance ring, the antiproton collector, which acts as a buffer between the production target and the accumulator. The lattice is made of strong focusing FODO cells; long zero dispersion straight sections result from the bending magnets distribution around the ring; chromatic properties and large amplitude oscillations are controlled by sextupole fields. The antiprotons are subjected to rf debunching followed by stochastic cooling of the longitudinal and transverse phase spaces. At the end of the process, the beam emittances are compatible with the accumulation requirements. The machine acceptance, the beam momentum spread after debunching and the phase space compression after stochastic cooling are reported and discussed.

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Abstract

The improvement of the CERN antiproton source relies on a new large acceptance ring, the antiproton collector, which acts as a buffer between the production target and the accumulator. The lattice is made of strong focusing FODO cells; long zero dispersion straight sections result from the bending magnets distribution around the ring; chromatic properties and large amplitude oscillations are controlled by sextupole fields. The antiprotons are subjected to rf debunching followed by stochastic cooling of the longitudinal and transverse phase spaces. At the end of the process, the beam emittances are compatible with the accumulation requirements. The machine acceptance, the beam momentum spread after debunching and the phase space compression after stochastic cooling are reported and discussed.

Introduction

CERN has completed the construction of a new antiproton source[1] (ACOL) which is designed to produce ten times more antiprotons per unit of time than the original antiproton accumulator (AA). The gain in particle intensity is essentially due to a major increase, a factor 16, of the source acceptance by the addition of a new ring, the antiproton collector (AC). In the new configuration, the AC acts as a buffer between the production target and the existing AA which is refurbished with upgraded cooling systems. To collect a large number of particles requests not only a large acceptance but also a cooling system which compresses the beam down to a density amenable to an accumulation rate of $2 \cdot 10^7$ $\bar{p}$ per second in AA. The following manipulations are therefore performed in AC:

i) Just after injection, the short antiproton bunches are elongated with the minimum dilution using the "bunch rotation" technique so that the relative momentum spread is reduced from 6 to 1.5%. The process lasts a small number of turns.

ii) The beam is then compressed from an initial emittance of 200π mm.mrad down to 25π mm.mrad in both horizontal and vertical planes using a novel cooling technique in which the electrodes accompany the beam as it shrinks.

iii) Simultaneously with the transverse cooling or after it, depending on the available electromagnetic power, the momentum cooling takes place during a little more than 2 seconds to confine the beam within $2^0/_{00}$ relative momentum spread.

iv) Rebunching and transfer from AC to AA.

Beam Optics

AC lattice is best understood by comparison with AA lattice (Fig. 1). Both have a 6% momentum acceptance, a FODO cell structure, a twofold superperiodicity with a mirror symmetry in each superperiod about the same axes, a wide beam in the arcs and a narrow beam in the zero dispersion sections and, as a consequence, two sizes of dipoles[18] and quadrupoles for the same magnetic strength. The principle of combined sextupole and quadrupole components in the pole profile[2] of the focusing magnets located in the arcs has been maintained. Injection and ejection occur in the same zero dispersion straight section.

A first difference lies in the bending angle achieved in the arcs: 180° in AA against 90° in AC. Much more basic is the difference in focusing strength imposed by the confinement of the large emittance AC beam within a size compatible with stochastic cooling systems operating in the GHz frequency range (Table 1).

Table 1 - AA and AC lattice characteristics

	FODO cells	tune	β_{max}	D_{max}	$\eta=(df/f)/(dp/p)$
AA	12	2.26	40 m	10 m	-0.1
AC	28	5.45	10 m	3 m	0.018

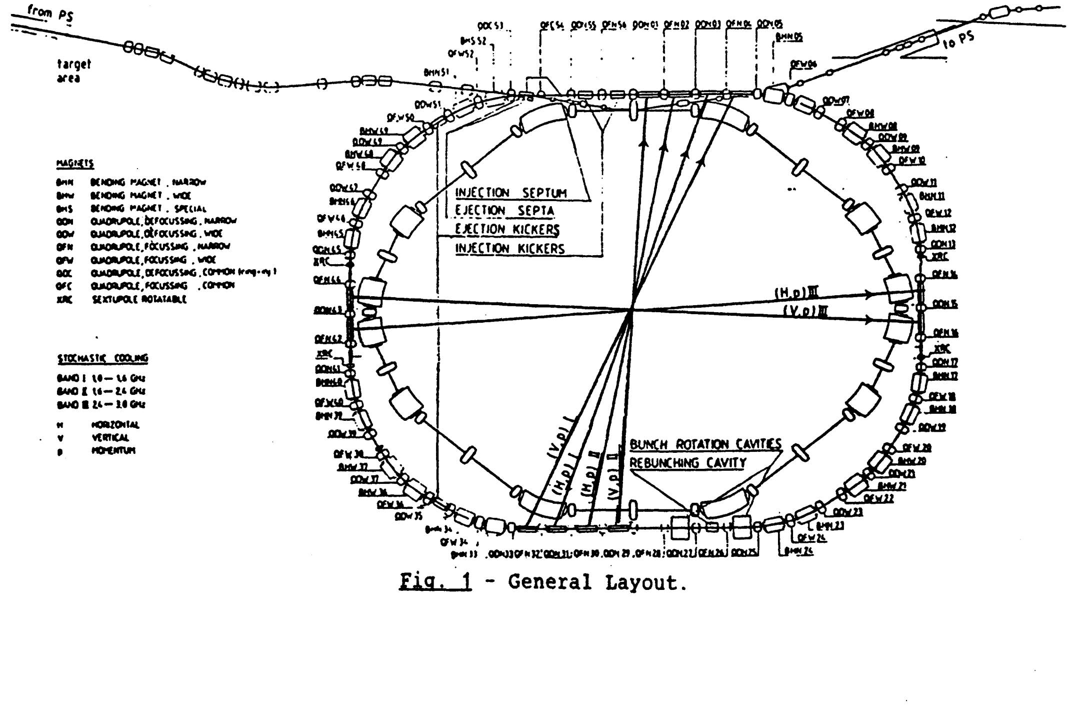

Fig. 1 - General Layout.

The choice of a working point close to a half integer in the tune diagram is rather unusual for a hadron storage ring. However, the quadrupole resonance is not systematic since 2Q is odd. Furthermore, several important advantages are gathered: no low order non-linear resonances, a convenient disposition of the stochastic cooling pick-ups and kickers which are symmetric with respect to the machine centre, a simple ejection system which uses two fast deflectors distant by 2π in betatron phase. In order to avoid excessive gradient stopband-widths, the gradient uniformity from magnet to magnet was kept within $1^0/_{00}$ over the full momentum range[3]. As a result, the tune (Fig. 2) and dispersion variations with momentum were found small enough not to be corrected during the machine commissioning. It is likely that the anomalous sextupole component has its origin in the wide bending magnets. The octupole shape of the horizontal tune is consistent with the cubic component of the quadrupole fringe field[4,19]. In contrast with AA, the tolerance on chromaticity is not very stringent because the particles which circulate on remote off-momentum orbits are quickly brought back towards the central orbit by the rf field of the bunch rotation systems.

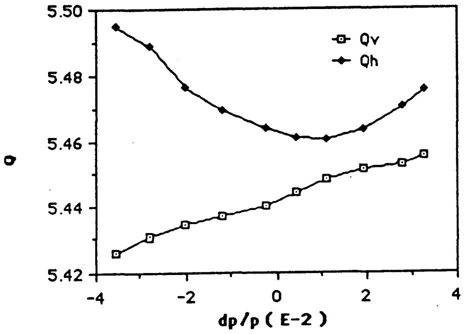

Fig. 2 - AC chromaticities.

The AC physical aperture results from the contradictory requirements of maximum acceptance, injection efficiency[5,6,7,8,20] and stochastic cooling sensitivity. Needless to say that the nominal acceptances (Fig. 3) were not obtained the first day but after a patient and precise alignment of all the elements: quadrupoles, vacuum chamber and miscellaneous tanks and after a global closed orbit correction[9]. The linear coupling was corrected by energizing a single skew quadrupole.

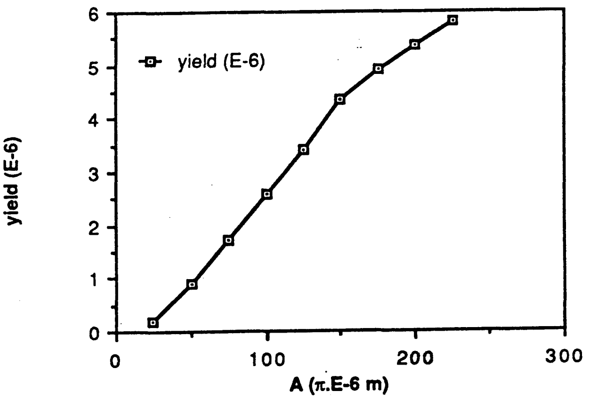

Fig. 3 - Yield versus acceptance.

Last, the acceptance is not only a matter of geometry and field quality, it is ultimately limited by non-linear effects. The sextupole fields indeed do not only correct the chromatic properties, they also enlarge the beam envelope by distorting the particle oscillations as a function of their initial phase and amplitude. A special compensation scheme[10] will be implemented. It consists of a single family of sextupole windings[11] located in the gap of some defocusing quadrupoles belonging to zero dispersion straight sections. Their effect, calculated analytically and checked by particle tracking, will be tested experimentally by observing the position of a bunch centre of gravity turn after turn[12] and, hopefully, by a noticeable increase in particle yield.

Beam Dynamics

The performance of the machine is characterised by its yield, the ratio of the number of stored antiprotons to the number of protons on the target, and by the evolution of the momentum and betatron distributions during the various manipulations.

Although the best conditions are not always easy to reproduce, the present yield reaches $6 \cdot 10^{-6}$ for the combination of an iridium target and of a magnetic horn pulsed at 400 kA. This figure is roughly a factor 10 above the yield in the AA alone. The beam spectral density at injection is extracted from the longitudinal Schottky signal and converted into a momentum distribution (Fig. 4) by taking into account the variation of η with dp/p. During the bunch rotation and the stochastic cooling, the spectral density is observed in real time using a dynamic signal analyser which performs a fast Fourier transform of the longitudinal signal (Fig. 5). The emittances are measured by moving a scraper into the beam and detecting the particle shower in a scintillator followed by a photomultiplier.

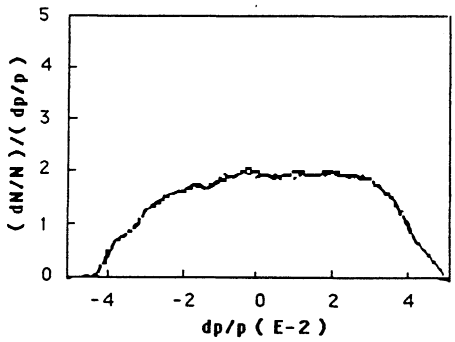

Fig. 4 - Momentum distribution in AC.

The bunch rotation[13] RF voltage program consists of a plateau at 1 MV followed by a fast decay to 150 kV and an isoadiabatic decay. The fast decay presents a technical difficulty which has been alleviated[14] by adding to the initial half wavelength feeder line a quarter wavelength line. In the present configuration, the discharge of the cavity is not controlled and the antiprotons contained within 1.5% of momentum spread amounts to 75% of the injected antiprotons. It is expected that the efficiency will be much improved when the adiabatic debunching system will be implemented.

The performance of AC stochastic cooling[15,16,21] is summarized in Table 2.

Table 2 - AC stochastic cooling performance

Cycle time (s)	$\frac{N_{\bar{p}}\ (\Delta p/p = .0018)}{N_{\bar{p}}\ (\Delta p/p = .053)}$	E_h(π E-6m)	E_v(π E-6m)
2.4	.47	27	33
4.8	.75	14	18

In the long cycle, the beam cross section is small enough for the AC-AA transmission to be lossless. When the cycle is short, the electrodes move too quickly and scrape the beam. An immediate measure consists of starting from a lower electrode aperture to improve the particle flux, but, clearly, more basic remedies are needed. In spite of the cold pick-up structures[17] and of the cryogenic preamplifiers, the electronic power is dominated by thermal noise power; as a complementary measure, a peak periodic filter operating between 1 and 1.6 GHz will be installed soon to cut the noise signal outside the betatron Schottky bands; in the future, the improvements in the target area and the more intense proton beams[22] will contribute to raise the signal to noise power ratio. Another deficiency is due to the variation in delay during the electrode motion; it will be cured using a dynamic phase correction controlled by the electrode displacement. Last, power sharing between longitudinal and transverse channels may have to be optimized.

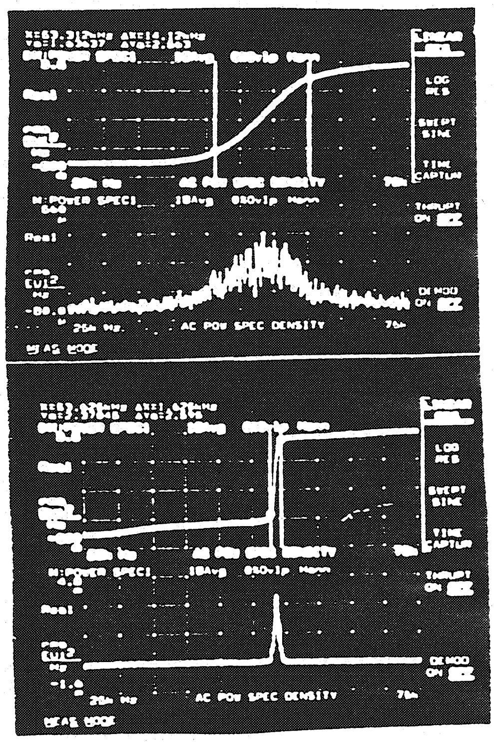

Fig. 5 - Oscillograms of the number of antiprotons N(f) (upper trace) and of the spectral density dN/df (f) (lower trace) after debunching (a) and after momentum cooling (b) for a 4.8 s cycle time.

Conclusion

With a 4.5 million antiprotons per second flux in the Antiproton Collector Ring, the new CERN antiproton source can fulfil the present requirements of low energy antiproton physics in the LEAR complex. More demanding will be the high energy physics in the SppS collider. Short term significant improvements are expected in several domains: the new PS merging scheme of intense and short bunches, a high current lithium lens in the target area, an enlarged dynamic aperture, the iso-adiabatic debunching in AC and the cooling systems upgrading.

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