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SLOW EXTRACTION OF ANTIPROTONS FROM THE PS

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ABSTRACT

Some interest has arisen recently in the slow extraction of antiprotons from the PS at energies ranging from a few GeV/c to a maximum of 20 GeV/c and a momentum spread of the order of .1 %. This preliminary study proposes a detailed layout for the resonance and the transversal aspect of the extraction which could take place from SS 58 or SS 26. Expected performances are given and discussed, showing that limiting the momentum at 18 GeV/c is advisable. One could use many existing elements (electrostatic septum, dipoles, quadrupoles and sextupoles), but a new extractor septum magnet has to be designed and built. The spill techniques and ripple compensation are discussed, but further studies are required to finalize this aspect. Neither the transfer from the AA machine nor the extraction beam line and the experimental area are considered.

INTRODUCTION

Some interest has arisen recently in the slow extraction of antiprotons from the PS, at energies ranging from a few GeV/c to a maximum of 20 GeV/c. The energy spread required by the Physicists is of the order of .1 % (Ref.1).

This is a preliminary study of feasibility for such an extraction. It has been assumed that the extraction channel is FT58, that the flat top length is of the order of several seconds (10 s for instance), the antiprotons being transferred from the AA machine and accelerated every few supercycles in, say, one bunch of 10^9 particles. The possibility of extracting the antiprotons from other straight sections such as SS 26 has also been considered. The beam would be debunched after the beginning of the flat top, and then pushed into the resonance by a slope of the main magnetic field or RF noise (stochastic extraction).

POSSIBLE SCHEME

The third integer resonance is proposed for several reasons: it is not too far from the natural working point, it fits well to the acceptance of the PS, and the drawback of its zero width does not matter very much for low intensities.

The first idea was to organize a scheme where the electrostatic septum(essential to achieve a good efficiency) is placed towards the inside of the PS circumference, in order to avoid damage from the synchrotron radiation during the lepton cycles, as proposed for the new proton extraction scheme (Ref.2). The same scheme, however, is not possible due to unavailability of straight sections.

Since the use of two magnetic septa is not necessary at the maximum energy of 20 GeV/c required by the physicists, it is proposed to use a simpler layout. One pushes the circulating beam into resonance towards an electrostatic septum placed on the inside of the machine. It kicks the particles inwards, giving the required separation (hole) between extracted and circulating beam towards the outside of the machine, about 3/4 (plus an integer number) of betatron wavelength later. Straight section 58, equipped with the extractor magnet, should be located there.

The beta-functions at both septa must be increased in order to enlarge the hole between extracted and circulating beam at the extractor septum. In addition, one should take care that this holes superimpose for all energies of particles extracted. This is achieved with the help of the dispersion coefficients at both septa. A careful examination of the phase plane at both septa shows that these coefficients should be large and of the same sign as the perturbed chromaticity. In the PS, it is easier to achieve a positive perturbed chromaticity than negative dispersion coefficients. Moreover, the choice of negative sextupolar effect will help to obtain a positive perturbed chromaticity without having to change the naked machine chromaticity with large currents in the pole face windings.

It is therefore proposed, as in ref.2, to increase the beta-functions and the dispersion coefficients at the septa with the help of a carefully located pair of quadrupoles.

THE EXTRACTOR SEPTUM MAGNET

At present, the extractor magnet of SS 58 is used for fast extraction of antiprotons at 26 GeV/c. It is 3 mm thick and powered by a capacitor discharge supply giving a half sine pulse of 3 msec. The current of 32 kA corresponds to a field of 1.6 T and a deflection of 18.5 mrad at 26 GeV/c. If this septum was used for slow extraction, in almost d.c. mode, it would be limited to a current of 4 kA, so that the maximum energy would be only 3.2 GeV/c.

A specially designed septum for a 20 GeV/c slow extraction would require a 12 mm width septum (Ref.3), with a four turn coil and 6.2 kA. The jump given by the present kickers and quadrupole arrangement of fast extraction can cope with such a septum thickness in order to maintain compatibility with the SPS collider mode (Ref.4). In fast extraction mode for 26 GeV/c antiprotons, the same flat top type power supply could be used with a current of 8 kA during a few msec (even with 100 msec ramps). The compatibility with electrons does not raise any difficulty. For extraction from SS 26, the extractor magnet could be longer (up to 2 m) and so easier to design.

LAYOUT IN THE PS

We must now arrange the extraction elements according to the principles exposed earlier so as to obtain a slow extraction giving a hole larger than 12 mm at the extractor magnet location in SS 58. The implementation of this scheme in the PS can be summarized by the following list of installations in staight sections.

- 2 quadrupoles of type 409 in SS29 and 87, in series. These quadrupoles have already been installed for the first tests of the new proton extraction scheme (Ref.2). In the case of extraction from SS 26, the locations of the quadrupoles would be SS 13 and SS 87.
- One sextupole of the ISR type in SS 1 and one of the 608 type in SS 99.
- The electrostatic septum, which could be a copy of the existing one in SS 23, placed in long straight section 1, together with the sextupole.
- Two DNH 206 dipole bumpers in series in SS 5 and 97 (the damper kicker installed at present in this last straight section would have to be moved).
- The vacuum chambers in both magnets 1 and 100 have to be enlarged to 105 mm towards the inside.
- The existing BSM 212 septum bumpers of SS 52, 55, 60 and 63, presently connected to a capacitor discharge power supply can be used, but of course with a trapeze modulated power supply for extraction from SS 58. For extraction from SS 26, a dipole arrangement could be found for the bumps in SS 21, 22, 29 and 30.

STRENGTH OF THE ELEMENTS

The maximum hole in SS 58 is obtained with the highest possible strength in the quadrupoles and in the electrostatic septum. The horizontal chromaticity and the sextupole strength must be chosen to tune the instantaneous extracted momentum spread, the spiral pitch and the superposition of the hole in SS 58 at all extracted energies. The bumper strengths have to be matched to the radial position of both septa.

The horizontal Q of the machine must be tuned to 6.18, so that the quadrupoles drive the beam into resonance at 6.33. The horizontal chromaticity should be decreased in absolute value, but stay negative at -.3 before the sextupoles are switched on. Both these values can be reached with the pole face winding and figure-of-eight coils.

The strength of elements are quoted here, corresponding to the phase plane diagrams of figures 1 and 2. Values of currents and voltages in the elements are quoted approximately for the energy of 20 GeV/c. For dipoles, the guesses may vary by up to 20% due to residual closed orbit distortions.

- Electrostatic septum: 150 Kv on a 15 mm gap, giving a . 4 mrad deflection,
- Quadrupoles in SS 29 (or SS 13) and 87: 650 A (.056 mrad/mm),
- Sextupoles in SS 1 and 99 (in series): 300 A (.00035 and .000125 mrad/mm^2 respectively),
- Bumpers in SS 5 and 97: 600 A (2.8 mrad),
- Bumpers in SS 52, 55, 60 and 63: 1450 A (for 35 mm in SS 58). A low ripple power supply will have to be found for these elements.

The quadrupole current quoted changes the beta-functions and dispersions at the septa according to the following table (values in m):

	beta at ES	disp. at ES	beta at EM	disp. at EM
without quads	20.3	3.0	12.6	2.3
with quads	36.2	5.0	23.6	4.2

RIPPLE COMPENSATION AND SPILL TECHNIQUES

The spill would suffer from severe ripple if nothing is done to reduce it. We have the choice between two possibilities: the stochastic and the phase displacement method.

The stochastic extraction (Ref.5), consists in decelerating the beam into resonance with noise modulated RF power on the 200 MHz cavities. This has already been tried successfully on the PS (Ref.6) as part of the feasibility study for the LEAR slow extraction. It has the advantage of easily providing a fixed average energy, since the RF noise can be used to decelerate the particles into resonance on a constant flat top of the main magnets.

The phase displacement method (Ref.7), uses c.w. power on the 200 MHz cavities. It has been used operationally in the past for the proton East Hall extraction. It normally requires a flat top slope and delivers a beam with a momentum varying during the spill. This variation is equal to the momentum spread after debunching and can be reduced by adiabatic or bunch rotation techniques down to the prescribed value of .1%. The spill ripple and general shape would suffer accordingly.

An alternative method would consist in using the 200 MHz cavities for ripple reduction and phase displacement deceleration at the same time: Empty buckets would be swept through the debunched beam with rising frequency to decelerate it through the resonance. The bucket area must be large enough compared to the momentum spread so that the ripple reduction is sufficient, and to avoid spill interruptions due to several crossings. If a voltage of 200 KV is available on the 200 MHz cavities, the momentum spread after debunching should not exceed .03%. Practical tests are necessary to prove the feasibility of this method, its sensibility to RF noise and see if the low frequency shape of the spill is accepable (Ref.8).

One can even imagine accelerating the beam into resonance with the 9.5 MHz cavities and apply the phase displacement method with the 200 MHz cavities at the same time, but the result is highly doubtful.

PERFORMANCES

1) MAXIMUM ENERGY
Computer simulation has been performed with the program described in Ref.2, and the strengths of elements quoted above. It gives a result of 12.3 mm for the hole created at the extractor septum in SS 58 at 20 GeV/c. The phase plane at both septa is shown on figures 1 and 2 respectively. One sees the separatrices for zero and .8 pi mm mrad emittances and a .05% momentum bite. In fact, the hole at the extractor magnet is probably somewhat less, because calculations have been performed with a simplified model which does not take into account the octupolar components of the PS main magnets, as in Ref.2. More accurate calculations using the program MAD for the proton extraction, have shown that the first result was optimistic by 10 to 15 % (Ref.9). Moreover, some extra clearance at the extractor septum magnet is welcome, even if efficiency is not of primary importance. In conclusion, we need 15 % more deflection at the electrostatic septum if we want a clean extraction up to 20 GeV/c. It could be obtained by the use of a 1m septum instead of the existing .8 m model, and a longer tank. This would increase the price of the installation, since this device cannot be recuperated from existing hardware. But space is not a problem, since SS 1 is a long straight section. If one keeps the existing electrostatic septum, the maximum momentum possible would drop to 18 GeV/c. Note that the first elements of the transfer line FT 58 are powered in d.c. , so that no change would be necessary.

2) MOMENTUM SPREAD
The instantaneous momentum spread depends on the horizontal emittance of the beam. Calculations give .05 % for a .8 pi mm mr emittance, and .1 % for 2.8 pi mm mr. A well cooled AA beam emittance is below this last value, so that the momentum spread requirement can be theoretically met down to 3.5 GeV/c. But it should be carefully checked that the foreseen rapid repetition rate of extractions from the AA machine is really compatible with transverse emittances below 2.6 pi mm mr.

3) SPILL RIPPLE
The experience gained during tests on the PS (Ref. 6) shows that we can expect a duty factor better than 90% if we use the stochastic method. As for the phase displacement techniques, one can calculate that the natural duty factor of a 1.0 s spill extraction would drop to a very low value (an estimation gives the figure of .003%), but the ripple reduction provided by the cavities would be so large that the duty factor should finaly theoretically be above 90%. As mentioned earlier, this must be verified experimentally.

4) SPILL LENGTH
Due to the temperature limitations in the main generator and magnets, the spill length of 10 s can be obtained up to the energy of 18 GeV/c. At 20 GeV/c, it has to be reduced to 4 s (Ref.10). The SPG1 supply can be used to power the extractor magnet in SS 58 for the same spill lengths. The case of the Tekelecs is not so clear, and some tests would have to be done to check if they can power the quadrupoles, the sextupoles, the bumpers in SS 5 and 97(Ref.11), and the dipoles in SS 21, 22, 29 and 30 in the case of extraction from SS 26. For the SS 58 extraction, the chosen power supply for the bumps around the extractor magnet should of course provide a sufficient duty cycle.

5) EFFICIENCY
The main losses will occur on the electrostatic septum. With the foreseen spiral pitch of 8 mm, the effective thickness of the septum being .15 mm, we expect an efficiency better than 95 %.

CONCLUSION

We have restricted ourselves in this study to the subject of extraction of antiprotons in itself. To be complete, more thought should be devoted to the role of the AAC machines, the transfer to the PS, the extracted beam transport and the experimental hall. In the meantime, we can conclude that it is possible to extract antiprotons from straight section 58 or 26 at momenta ranging from 3.5 to 20 GeV/c, with an instantaneous momentum spread of .1 % at the lower energies and better than .05 % at the upper ones. The only important new piece of equipment to be designed and built is the extractor septum magnet. If an existing electrostatic septum is used, the energy is limited to 18 GeV/c, but it can be increased to 20 GeV/c if a longer one is built. At this energy, the maximum spill length is 4 s. For momenta below 18 GeV/c, it goes up to 10 s. It seems obviously reasonable to propose to keep the maximum momentum at 18 GeV/c, a threshold above which the cost rises and the spill length decreases. As for the longitudinal aspect of this slow extraction, several possibilities exist and further studies are required to find the best one. This choice will determine the duty factor of the extraction spill, but estimations show that it should be above 90% anyway.

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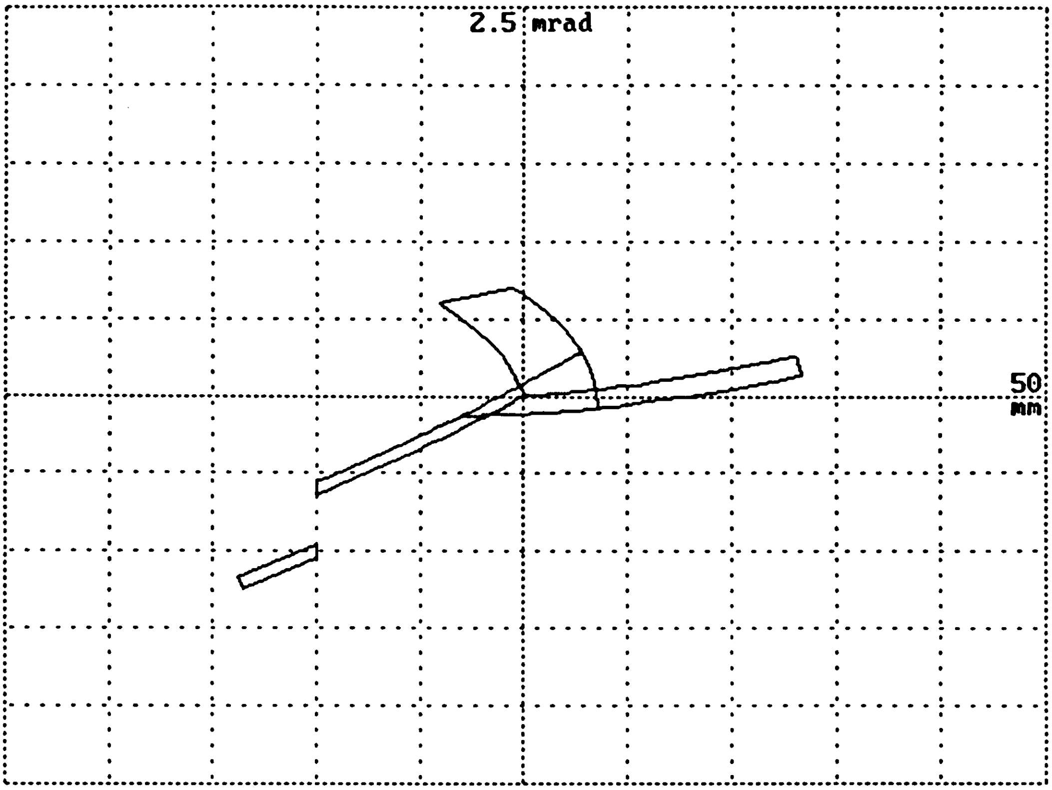

Fig.1: PHASE PLANE AT ELECTROSTATIC SEPTUM

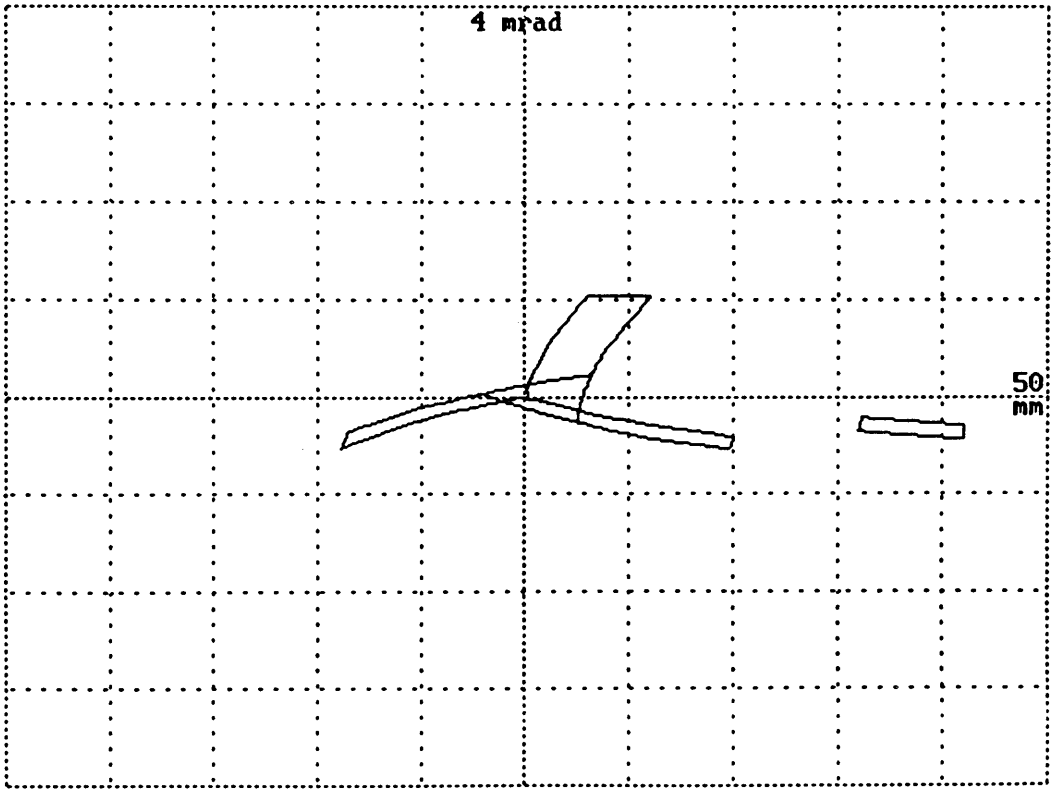

Fig.2: PHASE PLANE AT EXTRACTION SEPTUM

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