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INJECTION INTO THE NEW CERN ANTIPROTON COLLECTOR RING

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Introduction

Following the decision to construct a collecting ring, with an enhanced acceptance for antiprotons, around the antiproton accumulator (AA) already in operation at CERN, it became necessary to redesign the transfer line between an improved target station and the new ring (AC). The new design had to satisfy two main requirements. Firstly, it should provide a transmission efficiency as high as possible for antiprotons in the AC acceptance; and secondly, collimate, in the target zone itself, as much as possible all secondary particles coming from the target but which are outside the AC acceptance. The design of the line must provide phase-space matching between the source and the AC, as well as having a region of momentum dispersion. It must also satisfy the constraints imposed by the apertures of the bending and quadrupole magnets which are to a large extent determined by the costs involved and the very limited distance available between the antiproton source and the ring. The design of the components for this line is also dependent on the necessity to provide remote-handling capability, particularly for those elements nearest the source. The detailed design is not yet completed.

Radiation from the AA Hall

The antiproton production target is an intense source of radiation. The shielding for the source is determined by the need to keep the radiation dose at the CERN site boundaries within the accepted norms. This radiation will come mostly from neutrons generated by pions entering the AA hall and interacting in the machine components and shield that will surround the two rings.

The present injection line has a 4.5° bending magnet placed a short distance downstream of the target. Its main purpose is to separate the secondary beam of negative particles going towards the AA from the remnant of the primary 26 GeV/c proton beam which goes on to a beam dump. A shielded collimator placed in the AA hall where the dispersion introduced by this bending magnet is a maximum, intercepts some of the pions outside the momentum acceptance of the ring thereby reducing the radiation levels in the AA hall.

The projected antiproton intensity in the AC is sixteen times that for the AA alone. With an injection line similar to that in use at present, it can be expected that the accompanying pion intensity will increase by the same factor and that the loss distribution will be approximately the same. Using measurements of the radiation coming from the present AA shield, and assuming operation for 5000 hours/year with an increase in pion intensity by this factor, it is estimated[1] that the required shielding is 3.2 m of concrete around the injection line, 2.4 m over the first quarter of the AC and 1.6 m over the rest. The construction of the AC concentric with the AA severely limits the space available for this shield. Around the injection line and in the region where the AC comes close to the wall of the hall, there is not sufficient space even for a minimum volume shield including iron. As a consequence it has been decided to improve the collimation of the beam by building an injection line with greater dispersion and to have the momentum defining collimator in the better shielded target zone. A reduction in the number of pion interactions in the AA hall by a factor of ten will enable an adequate shield, having half this thickness in the critical regions, to be constructed. With this shield and the new injection line in place, and 2×10^{13} protons/pulse on the target, the neutron flux at the site boundary will be below the limit required by the CERN Radiation Safety code.

Momentum Collimation Efficiency

The following simple model of the transmission efficiency for a collimator in a dispersive region gives a guide to the amount of dispersion that has to be built into the injection line. In Fig. 1, the normalized transmission efficiency is drawn as a function of $(dp/p)^*$ which is the momentum error normalized to the momentum acceptance of the ring into which the particles are injected.

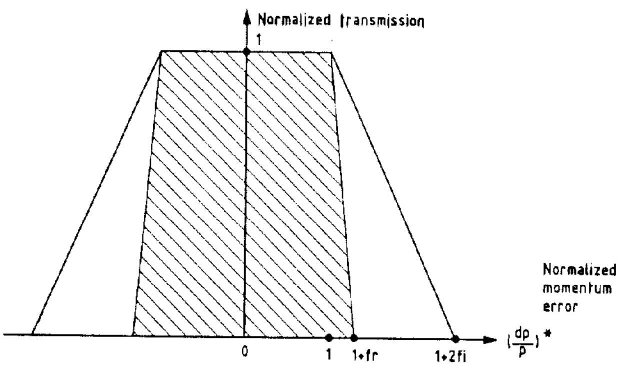

Fig. 1. Simple model, momentum collimation transmission

The number, f_i, is the ratio of the beam half-width, which depends on the ring transverse acceptance, to the orbit displacement at the collimator, for a momentum error equal to the ring nominal acceptance. It is assumed that collimators placed between the source and the first of the bending magnets already limit the transverse emittance to the ring acceptance. The value f_r is the minimum for this parameter around the ring itself and corresponds to the position of the momentum limiting aperture. The model assumes that the sloping edge is straight and that the transmission within the momentum acceptance of the ring is constant. The pion intensity passing through the collimator is proportional to the area in the diagram. The inner, shaded part corresponds to pions that will circulate in the ring. These will decay in flight and will not contribute significantly to the neutron flux leaving the shield.

The number of pions that contribute to the neutron flux is proportional to

$$(2 \cdot f_i - f_m).$$

The values, f_r, are about 0.3 for both the AA and AC, while the value of f_i, at the collimator in the AA injection line, is 5.0. We require that

$$(2 \cdot f_i - f_r)_{AC} = (2 \cdot f_i - f_r)_{AA}/10$$

or

$$(f_i)_{AC} = 0.64 .$$

Beam Optical Requirements

The AC is a strong focusing ring with a FODO structure. It is designed to have a transverse acceptance of $200 \cdot 10^{-6}\pi$ m.rad and a momentum acceptance of ±3%. Apertures are set for an acceptance of $240 \cdot 10^{-6}$ to provide some reserve space. Injection is via a septum magnet[2] followed by pulsed ferrite kicker magnets one-quarter betatron period downstream. The whole injection system is in a region of zero dispersion.

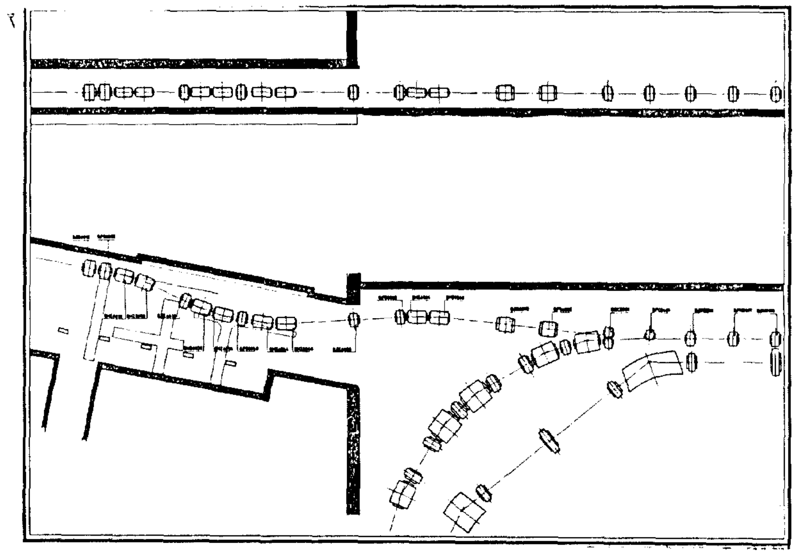

Fig. 2. Layout at injection line and junction with AC ring

The target[3] at the beginning of the line will consist of a thin rod of metal (Ø 2 mm, length about 15 cm) carrying a large, pulsed, longitudinal current (100 to 200 kA). A high intensity 26 GeV/c proton beam will be focused at the target to produce antiprotons at production angles up to between 70 and 90 mrad. These particles will then be collected by a very short focal-length lens, about 15 cm long, which will have an azimuthal magnetic field, again created by a large, pulsed current (700 kA). This lens will have a radius of 18 mm and will be used to reduce the transverse angles of the antiprotons into a range not exceeding 14 m.rad. The injection line, which then consists of bending and quadrupole magnets, transports the beam and matches it to the AC. It was thought, initially, to use magnets with apertures similar to those in the AC and perhaps to use magnets of the same design. This influenced the choice of beam envelope dimensions and, indeed, the latter part of the line is a FODO structure matched to the AC. However, most of the space available has been used to produce the required dispersion region and then, with a further set of bending magnets, to cancel the dispersion.

Figure 2 shows the layout of the line, while Fig. 3 shows the beam envelopes and momentum dispersion for an emittance of 240 $\cdot 10^{-6}\pi$ m.rad and a momentum error of 3%. The computer code TRANSPORT[4] has been used to solve the matching problem and ensure that the positioning of the elements in the line is also correct.

Design of the Dispersion Region

The design of the dispersion region is essentially that of a spectrometer using one bending magnet. The *momentum resolving power* (P), as defined for TRANSPORT, is given by:

$$P = 1/(2f_i \cdot (dp/p)_{acc}) \quad ,$$

where f_i has been defined earlier and $(dp/p)_{acc}$ is the momentum acceptance of the ring.

The optimum resolving power, P_m, is given by

$$P_m = \sin(\alpha) \cdot x_{bend}/(2 \cdot \varepsilon) \quad ,$$

where α is the bending angle, x_{bend} the half-width of the beam at the centre of the bending magnet and ε is

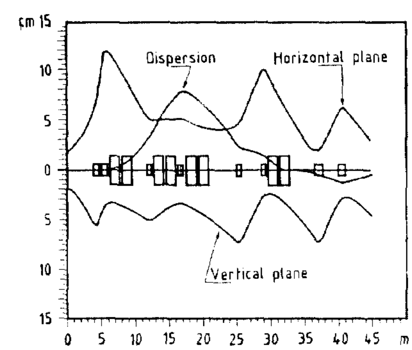

Fig. 3. Beam envelopes, dispersion curve

the transverse acceptance of the ring. P_m does not depend on the position of the collimating point or on the beam elements between this point and the bending magnet, provided the beam coming from the source is focused, by lenses placed between the source and bending magnet, to ensure that the collimating point is a quarter betatron period downstream of the bending magnet. For the acceptance parameters of the AC, a minimum value of 0.0125 m is needed for the product

$$\sin(\alpha) \cdot x_{bend}.$$

However, the conditions for achieving the optimum resolving power cannot be met for a number of reasons; the resolving power, (P), is given by:

$$P = P_m \sin(\Phi)$$

where Φ is the betatron phase angle between the bending magnet and collimator.

The lateral space in the target zone is limited, as is the total distance between the source and ring. Room must be found, not only to produce sufficient dispersion, but also to cancel it and have a matching section as well. For these reasons the collimating point must be placed less than a quarter betatron period downstream from the bending magnet. It is not possible to increase the phase advance by increasing the divergence at the magnet, and decreasing the beam size at the collimator, as it is then impossible to satisfy the matching requirements and keep the vertical beam envelopes within reasonable limits. Furthermore, we have to introduce bending in the opposite sense and this reduces the dispersion at the position of the collimator. The final choice for the first bending magnet angle was also influenced by the availability of pulse power supplies capable of supplying 25 kJ/ pulse. It was therefore decided to split each of the bending magnets and build them with the largest apertures compatible with the stored energy from these supplies. Magnet lengths were chosen as long as possible while still providing space for collimators and beam observation equipment.

The final solution for the beam optics starts then with a quadrupole doublet to give a horizontal beam half-width of 0.1 m at the centre of the first pair of bending magnets which have a combined bending angle of 14.1° and a magnetic induction of 1 Tesla. This gives the required value of 0.64 for f_i. If it had been possible to use these magnets in the optimum way, the value of f_i would have been 0.3.

The remaining bending magnets are required to cancel the dispersion and bring the beam to the AC. We lacked the luxury of having sufficient space to insert an independent matching section, but had to use the quadrupole magnets in the dispersive region for simultaneous transverse and momentum matching.

Simulation of the Injection Line Transmission Efficiency

Both the transverse and momentum acceptances of the AC are large compared with normal proton accelerators or storage rings. It might be expected that second-order effects, especially chromatic aberrations in the quadrupole magnets, may cause some particles that would appear to be inside the AC acceptance to fall outside. Inspection of the second-order coefficients generated by the TRANSPORT code reinforces this view; trajectories for particles with all coordinates at the limits of the acceptance can deviate by as much as 1 cm from their first-order path. On the other hand, there may just as well be some particles that fall inside the acceptance just because of these terms. If an estimate of the transmission efficiency of the line is to be made, the density distribution of the antiprotons needs to be known.

A computer code has therefore been written to track particles through the line using first- and second-order coefficients generated by TRANSPORT. It is used in conjunction with another program that generates particles coordinates, using Monte-Carlo techniques, and can simulate density distributions for antiprotons created in a number of different target situations. We give here some of the results obtained with these programs.

A source, similar to that described in the Antiproton Collector Design Study[3], was simulated and the emerging antiprotons were tracked down the new injection line. All limiting apertures were defined and each trajectory tested for loss of particle. The beam is collimated at the source by the size of the cylindrical collecting lens and at the first quadrupole magnet doublet which is about a quarter betatron period downstream. This is a realistic limitation of the transverse phase-space but does not cut out all particles outside the transverse acceptance of the AC. Another collimator is placed at the position of maximum dispersion.

Figure 4 shows the transmission efficiency of the line for both first- and second-order trajectories. The outside curves represent all particles that pass the injection system, while the inner ones are for

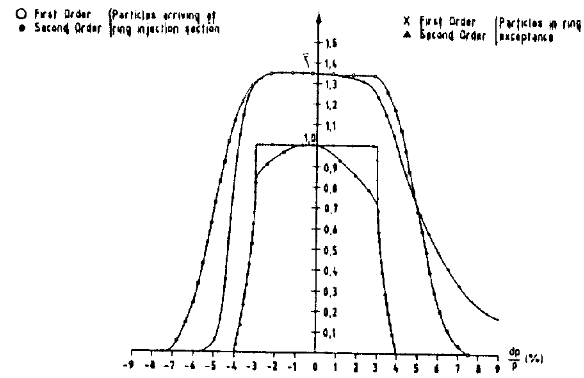

Fig. 4. Simulation results for collimator dispersion

those particles that are accepted into the AC. The presence of unaccepted particles at low values of dp/p indicates that the transverse collimation is incomplete. This does not invalidate our conclusion that there is adequate shielding with the new design because a similar situation existed when the measurements of neutron flux were made.

The shoulders on the second-order curve for accepted particles are due to chromatic aberrations. The loss in particles accepted amounts to 8.5%.

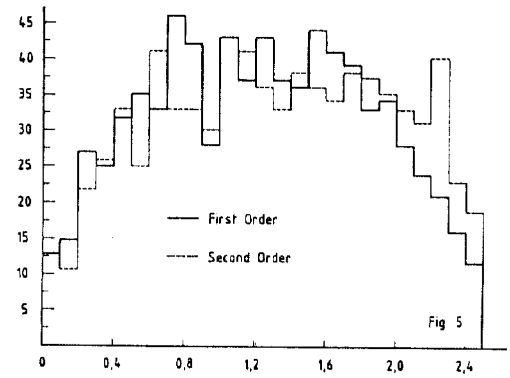

Fig. 5

Figure 5 is a histogram of horizontal betatron oscillation amplitudes for particles that should circulate in the AC. This is a function that can be determined experimentally with scrappers in the ring. In the AA, we have observed a lack of particles with large amplitudes. This is thought to be due to nonlinear coupling effects[5]. The AC lattice has been designed to minimize this loss and it will be interesting to see how well the measured curves agree with the results from the simulations.

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