Operation of the S$\bar{P}$PS Separation Scheme

K. Cornelis, L. Evans, A. Faugier, A. Hilaire, R. Schmidt
CERN - 1121 Geneva, Switzerland

Summary

In order for the SPS proton-antiproton collider to operate effectively with 6 dense proton and antiproton bunches per beam it is necessary to minimise the total tune spread due to the beam-beam interaction by separating the beams at the maximum possible number of unwanted collision points during injection, energy ramping and storage. Earlier experiments [1] with 3 bunches per beam and a prototype separation scheme using electrostatic deflectors produced encouraging results. In 1986 the full separation scheme for 6 bunches per beam was implemented. This involves the additional complication that, in order to obtain a reasonable separation at all crossing points, the radial tune of the SPS has to be split into two halves.

On the 26 GeV injection platform there is a considerable tune spread due to both the beam-beam interaction and incoherent space-charge detuning [2], making it difficult to keep both protons and antiprotons away from low-order nonlinear resonances. For the first time an attempt was made to minimize the contribution of the beam-beam interaction by separating the beams at all crossing points using a single electrostatic deflector. This resulted in an improved transmission and substantially brighter antiproton bunches.

Hardware layout

The normal SPS lattice is built from 6 identical arcs separated by long straight sections (LSS1-6). For collider operation, two adjacent straight sections have been transformed to incorporate the two major experiments UA1 and UA2. In these regions the lattice has been considerably modified to make two low-beta insertions at the experimental interaction points (IP's). With 6 bunches per beam and no separation, collisions occur at 12 symmetrically distributed points, the 6 long straight sections and the centres of the arcs. Ten of these collision points are of no use for physics, only contributing to the beam-beam tune spread and nonlinear resonance excitation.

The beams can be separated horizontally at nine of these collision points by a global orbit distortion in the opposite sense for protons and antiprotons using three sets of electrostatic deflectors near the two experimental insertions (fig. 1). In order to obtain roughly equal separation at all of the crossing points the machine must be operated in the so-called "Q-split" mode. The radial phase advance per period is fixed at exactly $\pi/2$ over half of the machine between IP6 and IP3 using two separate power supplies for the radially focussing quadrupoles. Fortunately, the normal phase advance of the SPS is already close to $\pi/2$ so this modification introduces only minor perturbations to the lattice functions. Nevertheless it must be taken into account when matching the low-beta insertions and in calculating the chromaticity corrections.

A separator unit consists of a pair of 3 metre long, 160 mm wide titanium alloy (6% Aℓ - 4% Va) electrodes in a 3.2 metre long tank [3]. The distance between the electrodes can be remotely adjusted between 160 mm and 20 mm. Normally one of the electrodes is kept at ground potential and the other

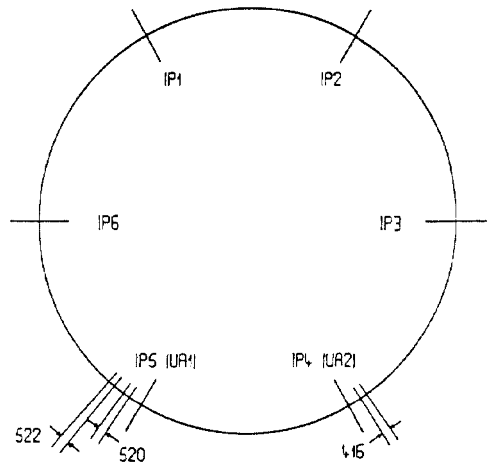


Fig. 2 Schematic of separator layout

charged to a negative high voltage. In view of the scarcity of antiprotons and the time required to refill the machine when the beams are lost, the sparking rate must be very low (<< 1 per day). Consequently, the field is limited to less than 30 kV cm^{-1}. In order to achieve sufficient kick strength, three separator tanks are installed at position 522 (fig. 1), two tanks at position 416 and one at position 520. The different units are powered by three independent high voltage supplies possessing a common interlock so that if one of the supplies fails then the others automatically switch off, resulting in a loss of separation but not of the beams.

Separation during storage

Once the machine is in storage the separation is brought up by simultaneously triggering three function generators which provide reference voltages to the high-voltage power supplies.

Figure 2 shows the theoretical separation at each of the twelve crossing points. In the Q-split region the separation is identical everywhere,

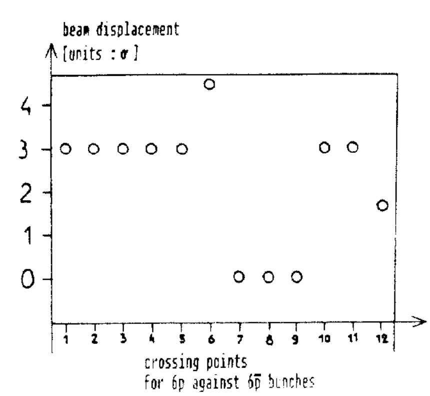


Fig. 2 Beam displacements at the crossing points for coast separation (calculated).

CH2387-9/87/0000-0133 $1.00 © IEEE
PAC 1987

corresponding to $\pm$ 3 sigma (~ 6 mm between beam centres) for a normalized emittance $\epsilon\beta\gamma$ = 25π mm mrad. In the arc between IP5 and 6 the separation is slightly more and in the arc IP3-4, slightly less than this due to the fact that Q-split does not extend all the way around to these crossing points. At the experimental insertions and the arc between them there is no separation. Figure 3 shows the measured difference between two closed orbits taken before and after separation is switched on. The orbit is compensated to within the precision of the monitors ($\pm$ 0.1 mm) between IP4 and IP5.

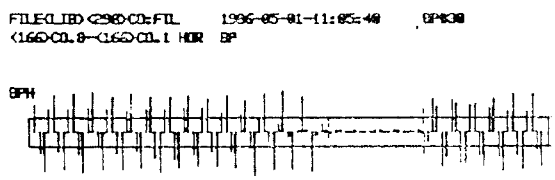


Fig. 3 Difference between proton closed orbit with separation and without separation (after optimization)

Finally, the effect on the decay rate of an antiproton bunch in the presence of six dense proton bunches (linear tune shift ≃ 0.003 per crossing) can be observed in fig. 4. When the separation is switched on, the antiproton tune moves out of a nest of tenth order resonances and the lifetime improves dramatically.

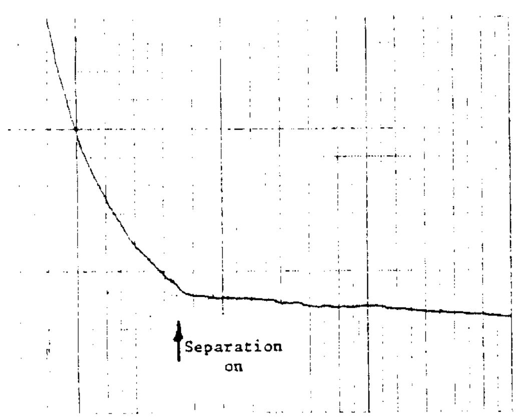


Fig. 4 Intensity decay of antiproton bunch as separation is switched on (zero suppressed). The bunch lifetime improves from about 2 hours before separation to above 100 hours with separation.

One side effect of the separation is that radial orbit distortion in the chromaticity sextupoles results in a tune shift in opposite directions for protons and antiprotons. The effect is small because the distribution of sextupoles is such that they largely compensate one another. The measured tune shift (fig. 5) agrees well with that computed by the program PETROS [4]. In the future it is intended to compensate for this effect using two sextupoles, one near a focussing quadrupole and the other near a defocussing quadrupole where the separation is large.

Separation at Injection

At injection energy (26 GeV/c), proton bunches of 25π mm.mrad normalised emittance and 2×10^{11} particles experience an incoherent

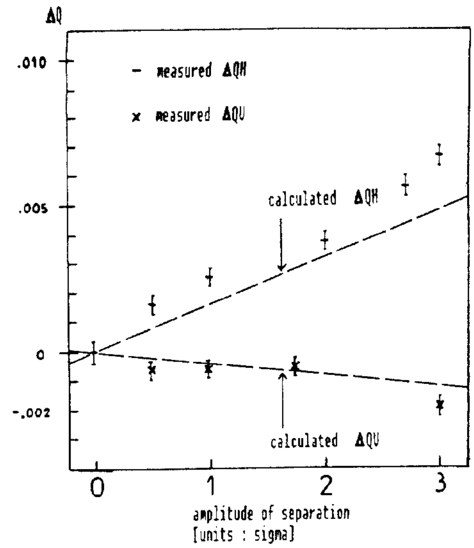


Fig. 5 Tune shift as a function of beam separation

space-charge detuning of the order of -0.05 in both planes. In addition, the beam-beam interaction with 6 bunches per beam introduces a tune shift of the same magnitude but in the opposite direction. Therefore, in the weak-strong régime in which the collider has operated up to now, the total tune spread is of the order of 0.1 and cannot be accommodated between third and fourth order resonances without emittance blowup and/or beam loss.

Most of the effect of the beam-beam interaction can be eliminated by separating the beams completely during the injection platform and the early part of the ramp. This can be conveniently accomplished by using only one separator at position 522 (fig. 1).The maximum radial orbit excursion which can be achieved without hitting the aperture is around 17 mm. In order to allow some margin, the separator is powered to give a maximum excursion of $\pm$ 10 mm.

The amount of separation varies depending on the crossing point (fig. 6). The mean separation is about $\pm$ 1.5 sigma, reducing the beam-beam tune spread to less than 20% of its value without separation.

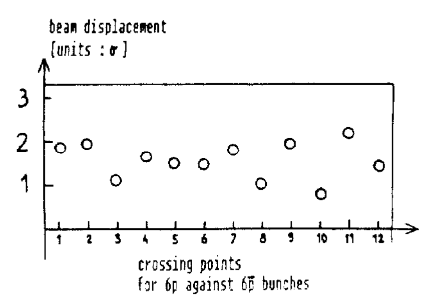


Fig. 6 Beam displacements at the crossing points for injection separation (calculated)

One slight complication when using injected separation arises because the antiproton injection chain is optimized using protons in the reverse direction. This creates no difficulty as long as only magnetic elements are used. Electrostatic deflectors need to have their fields reversed for proton extraction. In addition, the protons must leave the SPS from the antiproton closed orbit. The injection setting-up procedure therefore consists of two steps:

a) The separator is switched on with one polarity (-) opposite to that used for antiproton injection. The proton injection is optimized onto this distorted (antiproton) closed orbit. The beam is extracted at the end of the injection platform and the transfer is optimized in the reverse direction to antiproton injection.

b) The separator is switched to the opposite (+) polarity and the proton injection trajectory reoptimized to this new closed orbit. The SPS is then ready to receive antiprotons.

The effectiveness of this injection separation is illustrated in fig. 7, where the transmission of antiprotons through the 20 second long acceleration cycle with and without injection separation can be compared. With 3 bunches per beam the antiproton transmission is acceptable (~ 90%) whereas the increased beam-beam tune spread with 6 bunches is catastrophic (fig. 7a.) With injection separation (fig. 7b) the transmission is once more acceptable.

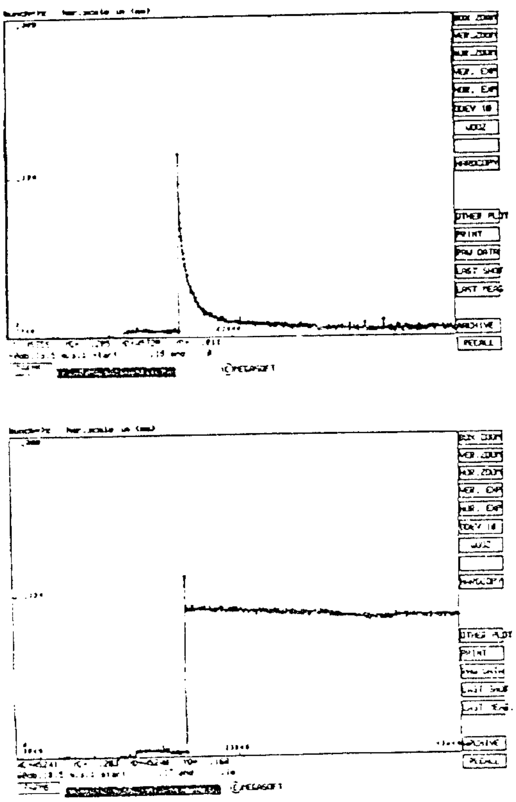
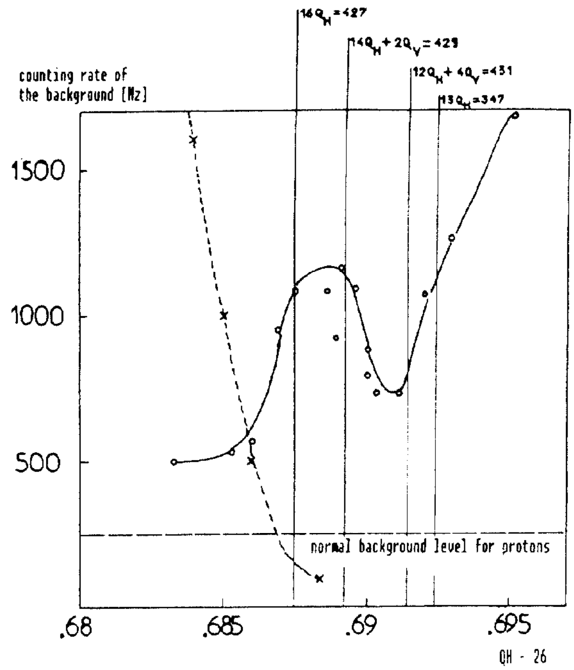


Fig. 7 Antiproton transmission through the 20 sec long acceleration cycle without (top) and with injection separation.

Observation of beam-beam resonances

The catastrophic effect of 10th order beam-beam resonances on the weak antiproton beam driven by the dense proton beam has already been documented. When injection separation is used, somewhat brighter antiproton bunches can be obtained in storage, resulting in an imbalance between the emittances of proton and antiproton beams. Under these conditions, the effect of the beam-beam interaction driven by the antiproton on the proton could be observed for the first time.

Figure 8 shows the relative proton decay rate as monitored by the background counters in one of the experimental areas. During this experiment the normalised proton emittance was 25π mm.rad whereas the antiproton emittance was 13π mm.mrad. The bunch intensities were 1.5 x 10^{11} and 1.9 x 10^{10} particles per bunch for protons and antiprotons respectively. Under these conditions the proton background rises to more than an order of magnitude above that acceptable for physics data taking. The strong dependence of background with tune correlates well with the presence of 16th and 10th order resonances. This effect can be at least qualitatively explained by the very strong amplitude dependence of he beam-beam resonance excitation strength [5]. In order to obtain acceptable working conditions it is important to equalise the emittance of the two beams.



Conclusions

Beam separation with 6 bunches per beam and a Q-split lattice gives good results in storage. Separation of the beams at injection and through the early part of acceleration helps to reduce the beam-beam tune spread and improves transmission. It has been observed that the smaller emittance antiproton bunches obtained as a result of separation start to perturb the proton bunches even at modest intensty. In future their emittance will be selectively blown up to minimise this effect.

Acknowledgements

We are indebted to R. Dubois, A. Ferrari and M. Laffin, for their work on the separator hardware and software.

References

1] Evans, L.R., et al. IEEE Trans. Nucl. Sci. Vol. NS-32, 2209, 1985.

2] Evans, L.R., Gareyte, J. IEEE Trans. Nucl. Sci. Vol. NS-30, 2397, 1983.

3] R. Bonvin et al., CERN/SPS/82-10 (ABT), 1982.

4] J. Kewisch, PETROS/Diplomarbeit, DESY 1978.

5] K. Cornelis, et al., CERN/SPS/86-14 (MS) 1986.