NEW INSERTION OPTICS FOR THE SPS P-PBAR COLLIDER

P.E. Faugeras, European Organization for Nuclear Research (CERN), CH - 1211 Geneva - 23, Switzerland

Summary

In order to further increase the luminosity of the SPS collider, beyond its present performances with ACOL, new insertion schemes making use of normal and/or superconducting quadrupoles have been studied, which could provide a gain of up to 4 in peak luminosity. However, a scheme with only normal steel quadrupoles has been preferred, as it makes use of available magnets, is fully compatible with the other SPS modes of operations, while it will permit doubling the peak luminosity of the collider. The higher chromatic aberrations of the new insertions can easily be corrected with the existing sextupoles families but with some minor rearrangement and a better correction algorithm. This scheme implies relatively cheap and simple hardware changes and is being implemented in one of the experimental straight sections. This paper also describes a new "high" beta insertion with β^* adjustable between 500 and 4000 m, designed to allow a better measurement of the real part of the p-pbar elastic scattering amplitude, (UA4 experiment).

Introduction

Over the past few years, the initial luminosity of the SPS p-pbar collider has been increased by almost an order of magnitude and can now exceed 10^{30} cm^{-2}s^{-1}, thanks to the antiproton collector,[1], to a new RF system and to beam separation in the SPS,[2]. Further improvements cannot be expected from an increase in beam intensities, beam energy and/or number of bunches but only from an optics with lower β^* at the crossing points. The actual insertions which are in place since the start of the collider, have been designed so as not to displace any of the standard lattice quadrupole, [3]. The free space for the experiments (+/- 14.4 m) is then optimum, but it is not possible to push the β^*'s at the crossing points beyond the actual values β_x=1.0 m, β_y=0.5m.

Lower β^* s require moving the doublet lenses closer to the crossing point, which in turn implies stronger quadrupoles. One has then assumed a minimum free space of +/- 7.5m which seems adequate for the SPS experiments. Consequently, some of the machine quadrupoles have to be moved away from their standard lattice position, and the compatibility with the normal operation of the SPS for fixed target physics and for LEP injection has to be ensured.

	Bunch length (nanosec)	Reduction factor	Gain w.r.t. actual
a) Actual insertion			
β_x=1.0m, β_y=0.5m	2.0	0.979	1.0
	3.0	0.956	1.0
b) Hybrid doublet			
β_x=0.4m, β_y=0.1m	2.0	0.780	2.815
	3.0	0.671	2.481
c) Superconducting triplet			
β_x= β_y=0.2m	2.0	0.849	3.067
	3.0	0.748	2.767
β_x= β_y=0.15m	2.0	0.781	3.758
	3.0	0.661	3.362
d) New insertion with steel quads			
β_x=0.6m, β_y=0.15m	2.0	0.867	2.087
	3.0	0.780	1.923

Table 1: Calculated luminosity gains

Even with this reduced free space, the lowest achievable β^*'s are limited by the chromatic aberrations induced by the insertions that the machine can tolerate, but another limitation comes from the finite bunch length: when moving away from the crossing point, the β functions increase quadratically, thus leading to a luminosity which depends on the bunch length and which is lower than that of an infinetely short bunch. This effect can be calculated for a parabolic bunch shape, [4], and Table 1 gives the gains in luminosity with respect to the actual insertions for some of the optics presented in this paper and for realistic values of the SPS bunch lengthes, (2 ns at the start of a store and 3 ns on average during the store).

Superconducting insertions

Mini-beta optics using superconducting quadrupoles in the SPS have already been calculated some time ago, [5]. Nevertheless it is worth looking at that problem again, in view of the progress made in superconducting magnet technology. On the other hand and to keep the SPS collider competitve, the earlier a mini-beta scheme can be implemented in the SPS the better. This means that the superconducting quadrupoles must not require a long development period but must either be readily available or be of a proven design. All caculations reported in this chapter are therefore based on the superconducting quadrupoles (named QSC in Fig. 1), designed for the HERA machine, [6], i.e. with the following parameters:

- nominal gradient: 90 T/m,
- magnetic length: 1.874 m
- coil aperture: 75 mm.

Hybrid doublet

For a storage energy of 315 GeV, the usual doublet configuration requires to have twin QSC quadrupoles per doublet lens, i.e. 8 QSC per insertion, which are not powered at their maximum. It is more interesting and economical to have hybrid lenses, each one made of a QSC, followed by a steel quadrupole, used in the SPS transfer lines and called QTL in Fig 1b. In an insertion, the QSC's of the two D-lenses share

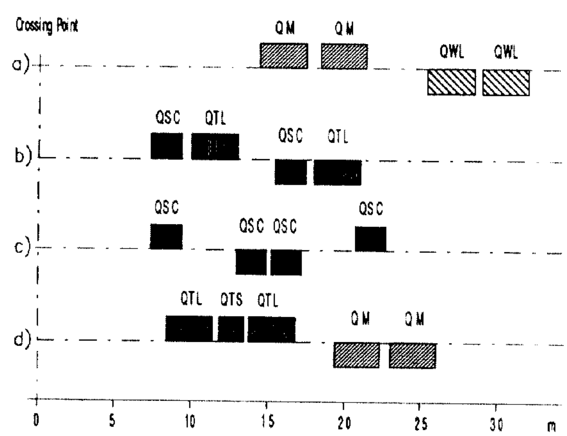

Fig.1: Layouts of mini-beta schemes
a) Actual layout (+/- 14.4m)
b) Hybrid doublet - c) SC triplet with +/- 7.5 m free space
d) New scheme with steel magnets (+/- 8.4 m free space)

the same power supply, while the two QSC's of the F-lenses have another supply. The 4 QTL's are individually powered and are used to match the insertion to the desired β^*. Finally, the lattice quadrupoles 17 and 20, which are immediately upstream and downstream of the insertion doublet, must both be reinforced by a companion quadrupole QM. In this way one can reach β_x=0.4 m, β_y=0.1m, with maximum beta-values of β_x=2650 m, β_y=665 m, i.e. very close to those of the actual optics.

This hybrid doublet configuration can be easily detuned by a large factor, first by increasing β_y to 0.2 m, then by keeping the β aspect ratio equal to 2. This process is done with a constant strength for all QSC's until one reaches β_x=2.0 m, β_y=1.0m. One can then reduce the strengthes of the QSC's and increase those of the QTL's, while keeping the β^*'s constant, until the QSC's are at zero current. This fall-back insertion with only the QTL's powered can also be detuned in turn, in order to get an optics providing enough machine acceptance for beam injection. One would then inject the beams as usual with this latter optics and raise the SPS energy till 130 GeV about, which is compatible with the maximum QTL gradient. During a coast at that energy, the injection optics will be sqeezed to 2.0*1.0m, the QSC's will then be turned on, and finally, the SPS energy can be progressively increased up to the usual storage energy, at a speed compatible with the superconducting quadrupoles.

Superconducting triplet

Higher luminosity gains could be expected for if the β^* are equal in the two planes. This calls for a triplet optics and Fig. 1c shows an example using 8 superconducting quadrupoles QSC per insertion. Note that the best arrangement for the SPS is the configuration F-D-F-Crossing-D-F-D, the inner lens being made of 2 QSC powered in series, while the outer D-lenses of each triplet share the same supply. As for the hybrid doublet, the lattice quadrupoles 17 and 20 (in the SPS numerology) have to be doubled by another QM-type quadrupole, in order to reach β_x=β_y=0.15m at the crossing point, thus giving an expected luminosity gain of 3.76.

However, this configuration has two main drawbacks: there is no place left to install normal quads which could make an optics suitable for injection with all superconducting quadrupoles switched off. One would then have to inject and to ramp slowly the SPS with the QSC's on, which may be detrimental to the beams. Also, the chromatic aberrations which are more equally shared between the H and V planes for a triplet, are much higher in the vertical plane than for the hybrid doublet, and are very difficult to compensate in the case of the SPS, because of the 90° phase advance per cell in the regular lattice.

Mini-beta insertions with steel quads

In view of the relatively high cost and long delivery of SC quadrupoles, not to mention the operational problems they imply for the SPS, one has sought for a cheaper optics based on normal steel magnets but still providing a substantial gain in peak luminosity for the collider. As compared to the machine quadrupoles QM, the quadrupoles used in the external primary transfer lines of the SPS are stronger: 24 T/m instead of 21 T/m, thanks to their reduced aperture,(diameter of the inscribed circle 80 mm, versus 88 mm). These elements are available in two lengthes: 3.0 m for QTL and 1.5 m for QTS.

Fig. 1d shows the downstream half of the central part of a doublet insertion, which can be built with these magnets. The D-lens is made of two QTL and one QTS powered in series and starting 8.4 m away from the crossing point: this is the shortest free space compatible with the maximum gradient of 24 T/m and with the collider operation at 315 GeV, (this distance must be increased to +/- 8.9 m in LSS5, in order to accomodate the UA1 experiment). The F-lens of the doublet needs not be as strong as the D-lens and is thus made of a pair of machine-type quads QM. Matching this new doublet to the regular part of the machine is

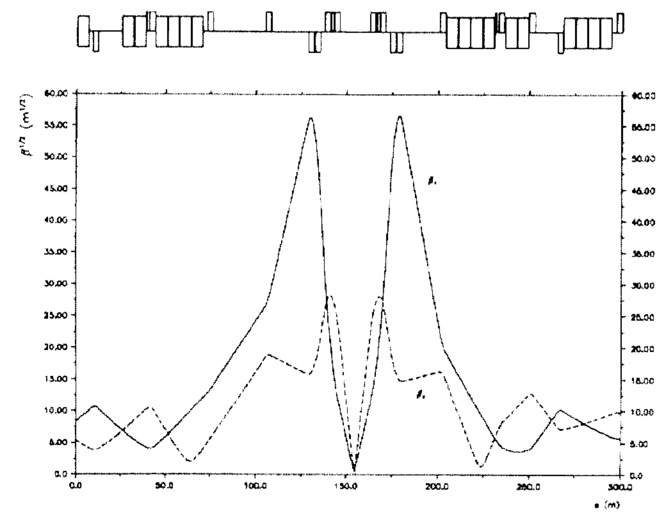

Fig.2: Betatron functions for minibeta-schemeβ_x=0.6 m, β_y=0.15 m

obtained with exactly the same elements than for the present insertions: contrary to the hybrid and SC triplet optics discussed above, it is no longer necessary to double the lattice quadrupoles 17 and 20.

Fig. 2 shows the resulting betatron functions in the central part of the insertion, as calculated with the computer programme MAD ,[7]. The expected gain in luminosity for β_x=0.6 m, β_y=0.15m at the crossing point is around 2, but at the expense large maxima of β_x=3100 m, β_y=820 m, i.e. larger than for the actual optics. Increasing further the length of the D-lens or using a triplet optics does not yield higher luminosity gains.

Operating the collider with this new mini-beta scheme does not pose any problem: as for the actual insertions, it can be sufficiently detuned to provide enough machine acceptance for beam injection and energy ramping, and the operating procedures can be kept unchanged as compared to now.

Similarly, the operation of the SPS for fixed target physics and as a LEP injector can easily be ensured with this new mini-beta insertion left in place: the outermost QTL of fig.1d is very close to the regular lattice position QD19, which is occupied by the first QM of fig. 1a. On the upstream side of the crossing point, which is the mirror image of fig. 1d, the outer QTL is also close to the lattice quad QF18. These two QTL can thus be used to restore the regular pattern of the betatron functions in the long straight section, the small focusing defects induced by their position, which is slightly different from that of the normal lattice, being compensated by powering suitably the 3 lattice quads QF16, QD17 and QF20.

Chromaticity correction

Up to now, the SPS chromaticity in collider mode was corrected with 108 sextupoles regularly distributed around the ring and grouped into 4 unequal families called SFA,SFB,SDA,SDB, [3]. The main strategy for correction is to reduce the quadratic dependence of the machine tunes with the momentum deviation, whilst adjusting the linear chromaticities to the desired values in both planes. Although not perfect, this method has proven to be adequate for the actual insertions fully sqeezed, i.e. down to β_x=1.0 m, β_y=0.5m. Nevertheless, this global scheme can be improved by splitting the SFA family into two subsets: the SFA proper, outside the 2 insertion regions, and the SFC family made of the SFA sextupoles located in the vicinity and in between the insertion regions, [8]. The strengthes of the five families are then calculated by adjusting the linear chromaticities to the desired values as before, while minimizing now the expression:

$$\Sigma w_i[\Delta Q_{x,y}(\delta_i)]^2$$

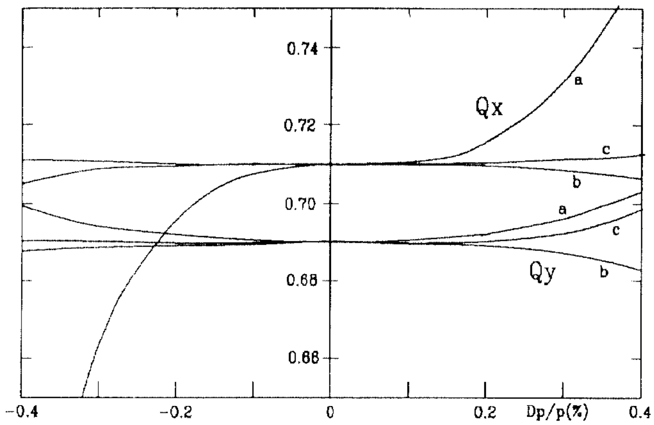

Fig. 3: Chromaticity correction for mini-betas insertions

where $\Delta Q_{x,y}$ represent the non-linear variations of the tunes $Q_{x,y}$ for the relative momentum deviations δ_i, and w_i are weighting factors. This minimization procedure is conveniently done with the particle tracking programme PATRAC, [9].

When this method is applied to the case of two insertions with β_x=0.6 m, β_y=0.15m in LSS4 and in LSS5, one obtains the curves a of Fig. 3. The momentum acceptance of the machine is rather limited, mainly because of the normalized strength of the SFC sextupoles which cannot exceed $B''/B\rho = 0.352\ m^{-3}$ at 315 GeV, (hardware limitation). As shown by the curves b of Fig. 3, the situation can be improved by rearranging the sextupole families as follows:

- the SFA family is further reduced to only 12 elements, equally separated by one and a half betatron wavelength in the four sextants 1,2,3 and 6.
- the sextupoles thus liberated are used to reinforce the SFC family, by grouping them in pairs and having such a pair at positions 4-08 to 5-28 inclusive, every half betatron wavelength in the non-zero dispersion regions, i.e. outside the long straight sections 4 and 5.
- the other three families are not changed.

Such a scheme implies a major reshuffling of the sextupoles. However, as it has been finally decided not to upgrade the LSS5 insertion with the minibeta layout but to leave it as it is, an intermediate arrangement could be found, in which all SFA sextupoles located in between LSS4 and LSS5 are switched to the SFC family, while 2 SFC elements in sextant 6 are put back to the SFA family. In this way, the SFC family is more concentrated around the two insertions and thus more efficient: the curves c of Fig.3 shows the resulting chromaticity acceptance for this last machine configuration, which could be obtained without exceeding the hardware limits of the sextupoles.

High beta configuration

High beta values at the crossing point, at least in one plane, are essential for measuring accurately the real and imaginary parts of the p-pbar elastic scattering amplitude. To this end a pseudo "high-beta" insertion was designed and used for the 1985 measurement made by the UA4 Collaboration, [5]. A focusing defect was created at QF16, i.e. at the entrance of the long straight section, and was compensated by reducing the strength of QF20, at the end of the LSS. In this way, β values up to 2000 m could be achieved in the horizontal plane, but this simple optics has a major drawback, which is its lack of symetry.

Because of the unexpected results of UA4, [10], more precise measurements are being proposed, which require a more symetrical insertion. This is obtained with the same principle as before, but instead of compensating the focusing defect created by the pair of QM at the entrance of the LSS, another pair of machine-type quadrupoles makes a

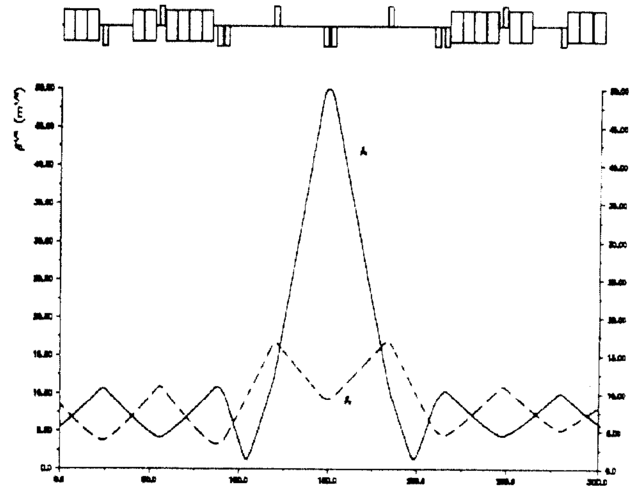

Fig.4: High beta insertion for scattering experiment, β_x=2500 m, β_y=87 m

symetric perturbation at the end of the LSS, thus giving high beta-values in the center of the LSS. An additional requirement is to have no magnetic field at the collision point: this is why the lattice quadrupole QF18 is split in two identical QM, as shown on fig.4. In order to minimize the modifications in the SPS for implementing this optics, this pair of QMs is in fact made by the upstream D-lens of the usual insertion doublet. The resulting small asymetry is quite acceptable and the collision point is not exactly at the centre of the LSS, but is moved upstream in the middle of the 2 QMs. Also, with this optics, the measuring points, at the locations where β is minimum, are both in the LSS, where the dispersion is made equal to zero, when matching the optics in the usual way. Finally, β_x can be varied easily between 500 m and 4000m.

Acknowledgements

This work was suggested to me by L. Evans. Discussions with him and with B. de Raad and A. Hilaire have been very helpful and are gratefully acknowledged.

References

[1] E. Jones, The CERN ppbar facility, Proc. of the European Particle Accelerator Conference, p.215, Rome, June 1988.

[2] L.R. Evans, The SPS collider: status and outlook, Proc. of the 1987 IEEE Particle Accelerator Conf., p.24, Washington, March 1987.

[3] P.E. Faugeras et al., The low beta insertions of the SPS proton-antiproton collider, 12th. Int. Conf. on High-Energy Accelerarors, Fermilab, Batavia, August 1983, (also CERN SPS/83-29 ARF).

[4] C. Bovet, Luminosity at very low betas, SPS/EA/Note 81-11, 1981, unpublished.

[5] P.E. Faugeras, Mini-beta insertion schemes for the p-pbar collider, CERN/SPS/82-4 (DI-MST), 1982. See also CERN SPS/ARF/84-7, March1984.

[6] R. Auzolle, P. Le Marrec et al. , Superconducting quadrupoles for HERA, Workshop on SC Magnets and Cryogenics, BNL, May 19896.

[7] F.C. Iselin, J. Niederer, The MAD program, Reference manual, CERN/LEP TH/88-38, Geneva, July 1988.

[8] Yong Ho Chin, The widening of the chromaticity acceptance in the SPS, CERN SPS 85-45/DI-MST, and CERN SPS 85-48,Dec. 1985.

[9] A. Hilaire, A. Warman, PATRAC: a programme for single particle tracking, CERN SPS/88-8 (AMS), updated version, August 1989.

[10] D. Bernard et al., UA4 Collaboration, The real part of the p-pbar elastic scattering amplitude at the centre of mass energy of 546 Gev, Physics Letters B, 198, 4, p.583, December 1987. See also M. Bozzo et al., CERN/SPSC 90-9, SPSC/P 250, February 1990.