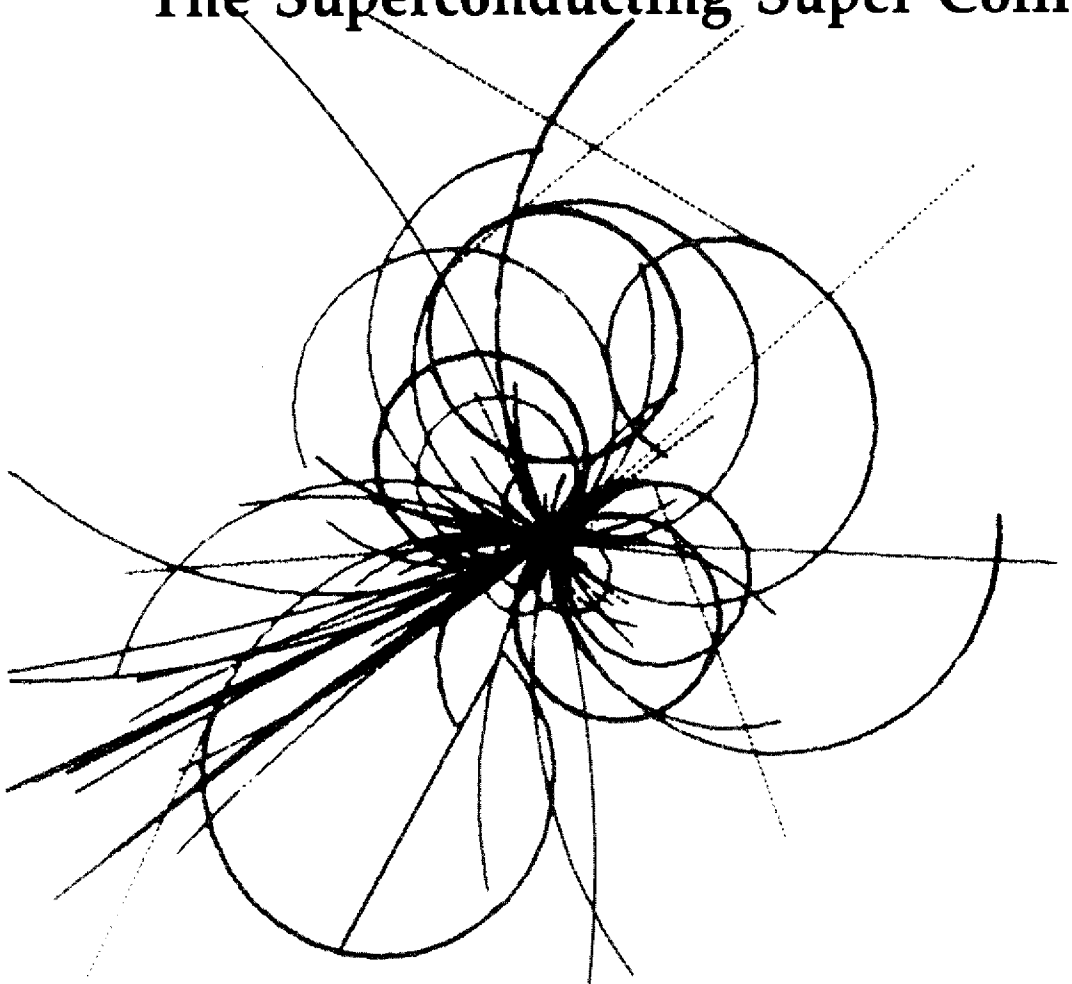
SSC-139

The Superconducting Super Collider



Layout and Performance of a High-Luminosity Insertion for the SSC

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ABSTRACT

An experimental insertion with the beta functions at the crossing point as low as a quarter of a meter has been designed for the SSC by using quadrupoles with 330 T/m gradients. A free space of ±3 m around the interaction point is available to install an experimental device dedicated to the observation of large transverse momentum reactions. A phase advance of 90° across the overall insertion ensures to some extent the mutual compensation of the chromatic aberrations of the quadrupoles triplets with those of the next experimental region.

Introduction

A possible increase of luminosity of the SSC above the present design is of obvious interest to the HEP community. We consider here one route to such an increase. In a hadron collider with round beams at the collision points, the luminosity is expressed by the following formula:

$$\mathcal{L} = \frac{kN_b^2 f\gamma}{4\pi\epsilon_N\beta^*} \tag{1}$$

with
- k = number of bunches per beam
- N_b = number of protons per bunch
- f = revolution frequency
- γ = relativistic factor
- ϵ_N = $\gamma\sigma^2/\beta$ = normalized emittance
- σ = rms beam radius
- β^* = beta function at the crossing point

An increase in luminosity is possible by increasing the number of protons per bunch, by increasing the number of bunches, or by decreasing the beta function at the crossing point. The first issues have been extensively considered.[1] Here we focus our attention on the third issue.

In a given insertion, the beta at the crossing point can be reduced by using a triplet closer to the interaction point, with stronger gradient quadrupoles. The lower limit of β^* that produces a luminosity consistent with Eq. (1) is determined by the longitudinal rms bunch length, and is about 7 cm for the SSC. Such a low value is beyond present

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technical feasibility in the SSC, due to the excessively high gradient required in the triplet to maintain the associated peak beta values within a reasonable range. A more realistic goal is a beta of 25 cm, *i.e.* a factor of two below the nominal value. We assume that quadrupoles with a gradient of the order of 330 T/m and a bore winding diameter of 4 cm will be available. This gradient is generally consistent with that planned for the LHC, which uses 250 T/m quadrupoles with a 5 cm winding diameter.[2]

Geometry of the high-luminosity insertion

The geometrical layout of the high-luminosity insertion proposed here is derived from the nominal SSC insertion.[3] The layout and collision lattice functions for one half of this insertion are shown in Figure 1.

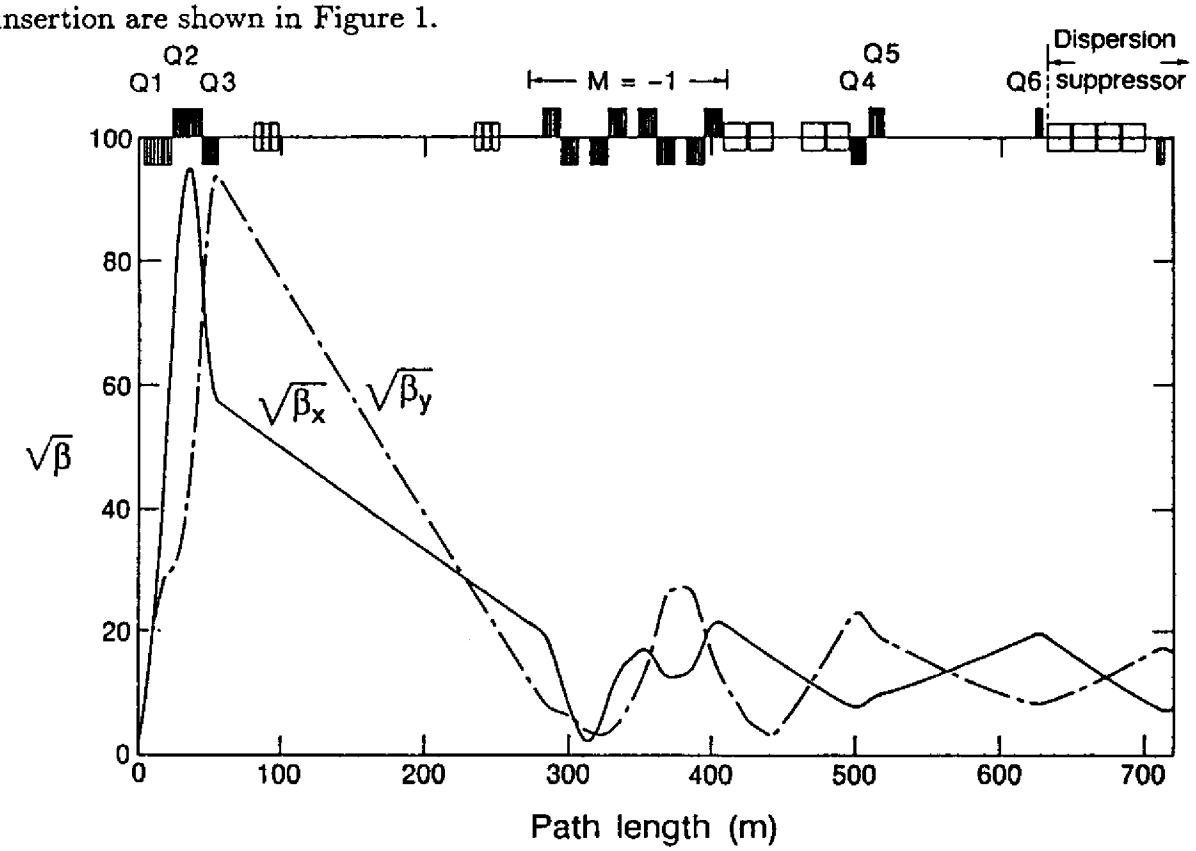

Figure 1 – Right half of the high-luminosity insertion.

Two triplets of quadrupoles separated by an M = -1 matrix vertical dispersion matching section and by the vertical crossing magnets are used on either side of the crossing point. The dispersion suppressor is unchanged. The first triplet starts 3 m from the crossing and is 55.5 m long. Its midpoint is 15.5 m closer to the interaction point, compared with the same triplet of the nominal insertion, which is 20 m from the crossing and 52.5 m long. The second triplet, next to the dispersion suppressor, has the same purpose of tuning the

beta function between the injection and collision values and is about the same in the high-luminosity insertion as in the nominal one, 133.3 m compared to 135 m. The free space of ± 3 m available around the interaction point has to to accommodate the experimental apparatus as well as a cryogenic end connections and a set of collimators which will protect the first triplet of superconducting quadrupoles from radiation caused by the beam-beam interactions.

Optical properties

The high-luminosity insertion is required to obey six optical constraints, namely:

$$\beta_x^* = 0.25\text{m},$$

$$\beta_y^* = 0.25\text{m},$$

$$\alpha_x^* = \alpha_y^* = 0, \tag{2}$$

$$\hat{\beta}_x \approx \hat{\beta}_y,$$

$$\mu_x + \mu_y = \text{const.}$$

The first four relations ensure that the beta functions have an ~~anti~~symmetric shape around the crossing point with vanishing derivatives and match the required value at the interaction point. The fourth equation imposes well balanced peak betas in the two planes. The last applies to the entire module, consisting of the straight section, two dispersion suppressors, and three half-cells. It ensures a phase advance of $\pi/2$ (mod 2π) between the IP and that of the contiguous insertion which will compensate to some extent the chromatic aberrations due to the low beta triplets. The constant is chosen to make the phase advance between adjacent IP's be 3.75 tune units.

A practical solution has been found having primary peak betas in the first triplet smaller than 8.8 km and secondary peak betas in the second triplet smaller than 750 m. These peak values are similar to those of the nominal 0.5 m β^* insertion.

By appropriate tuning of the six low-beta quadrupoles, mainly those in the outer triplet, a smooth path has been found to an injection configuration in which the maximum betas have been greatly reduced. This path resembles that of the nominal low-beta insertion. Along this path the primary peak betas in the first triplet decrease whilst the betas at the crossing point and the secondary peak betas in the second triplet increase. The cross-over point of the primary and the secondary peak beta happens when β^* is 2.826 m and the peak betas are 790 m. Plots of the quadrupole tuning gradients and peak betas as a function of β^* are shown in Figures 2 and 3.

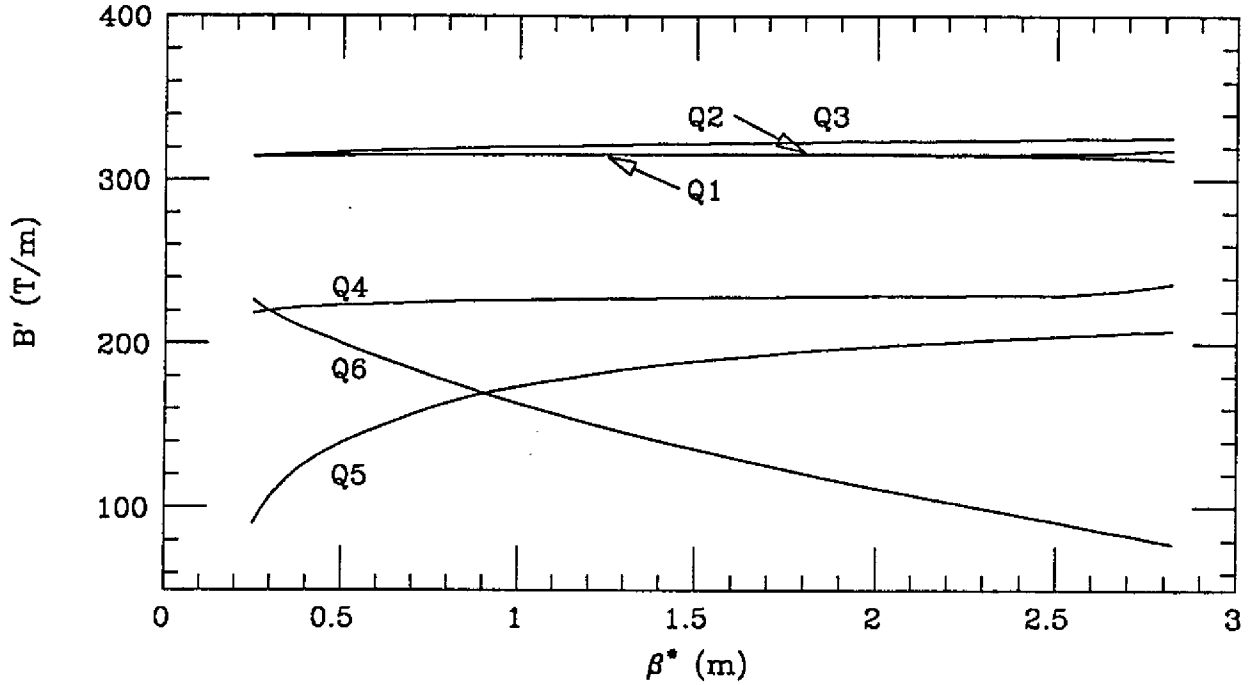

Figure 2 – Tuning curves for the high-luminosity insertion.

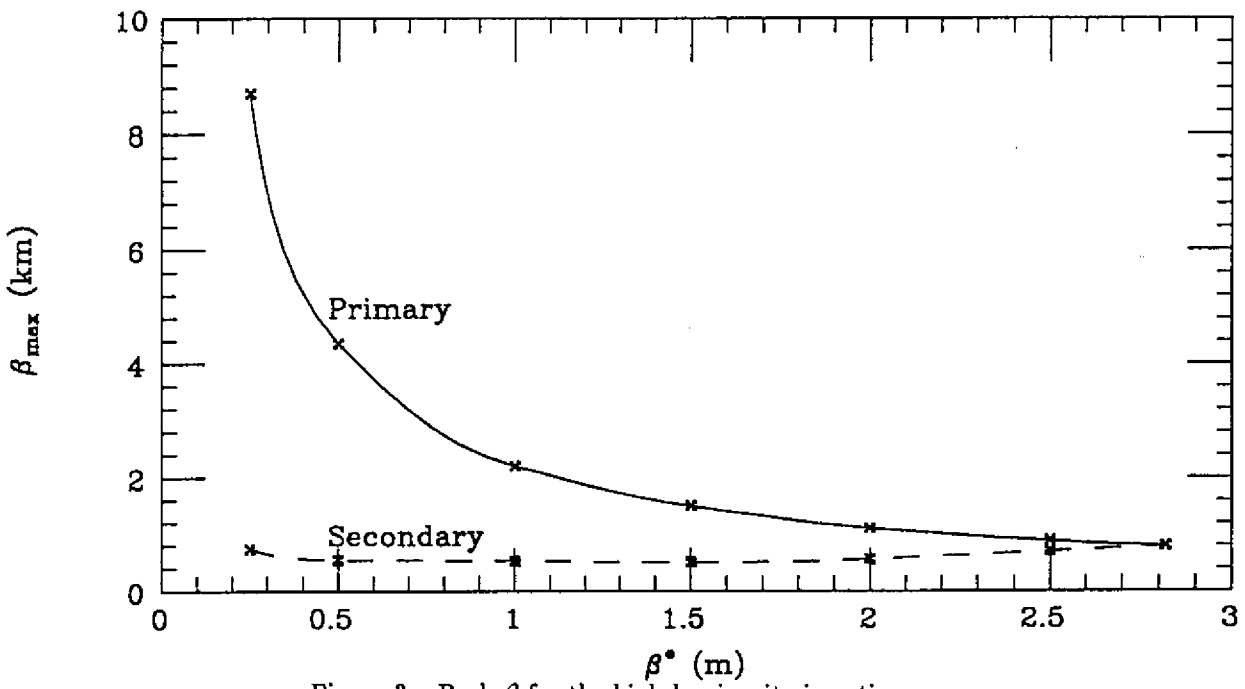

Figure 3 – Peak β for the high-luminosity insertion.

The injection path can be continued to provide configurations with a primary peak beta smaller than the secondary peak beta up to the following values:

$$\beta^* = 5.0\text{m},$$

$$\text{primary } \hat{\beta} = 454\text{m}, \tag{3}$$

$$\text{secondary } \hat{\beta} = 1298\text{m}.$$

Overall design of the ring and chromatic aberrations

The high-luminosity insertion has been included in the SSC lattice in order to evaluate its global chromatic effects. Starting from the nominal lattice with 90° phase advance per cell, we built a lattice where the 0.5 m low-beta insertion at the edge of the cluster was replaced by the 0.25 m low-beta insertion. As a consequence the chromatic aberrations become worse but are still in the tolerable range. The standard 90° cell SSC design, containing two $\beta^* = 0.5$ m low-beta insertions and two $\beta^* = 10$ m medium-beta insertions has a natural chromaticity of $\Delta\nu/(\Delta p/p) = -219$. Replacing one of the low-beta insertions with the one described above increases the overall chromaticity to -235. The effects of this increased chromaticity have been examined and are plotted in Figures 4–6. These are to be compared with those for the nominal SSC lattice.[4] The tune spread stays below 0.011 over a momentum spread range of $\Delta p/p = \pm 0.001$, which may be compared to 0.007 for the standard lattice.

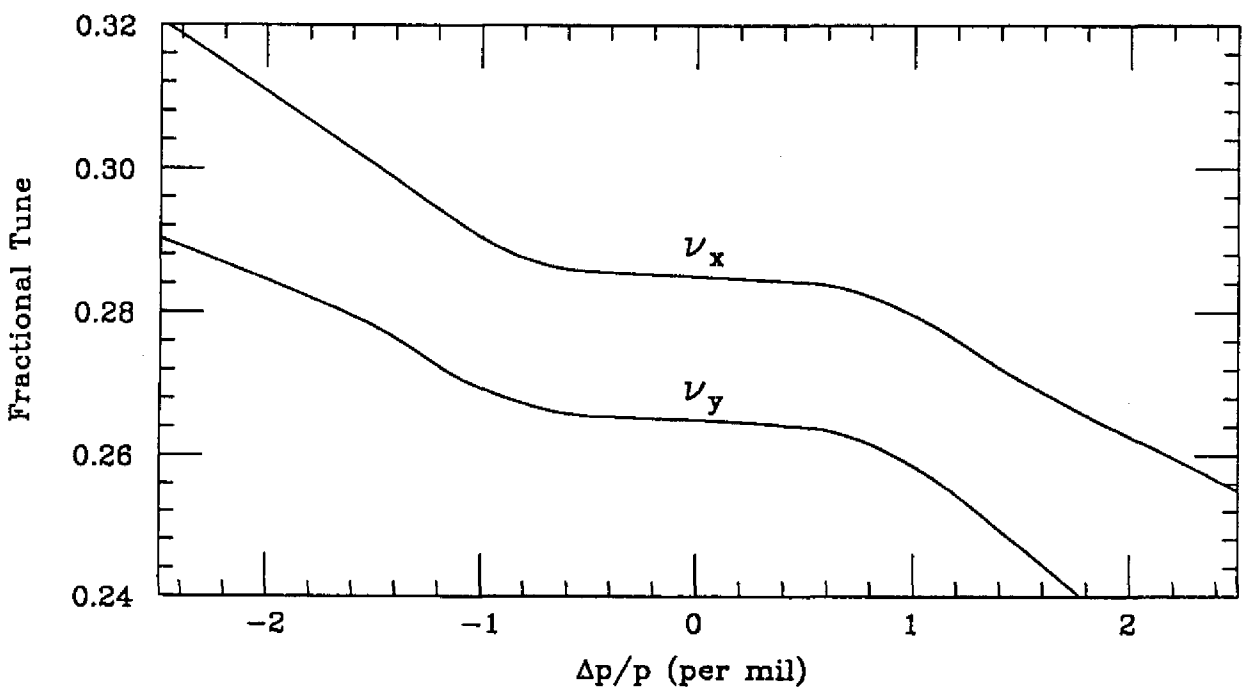

Figure 4 – Tune plot for the SSC with one $\beta^* = 0.25$m insertion.

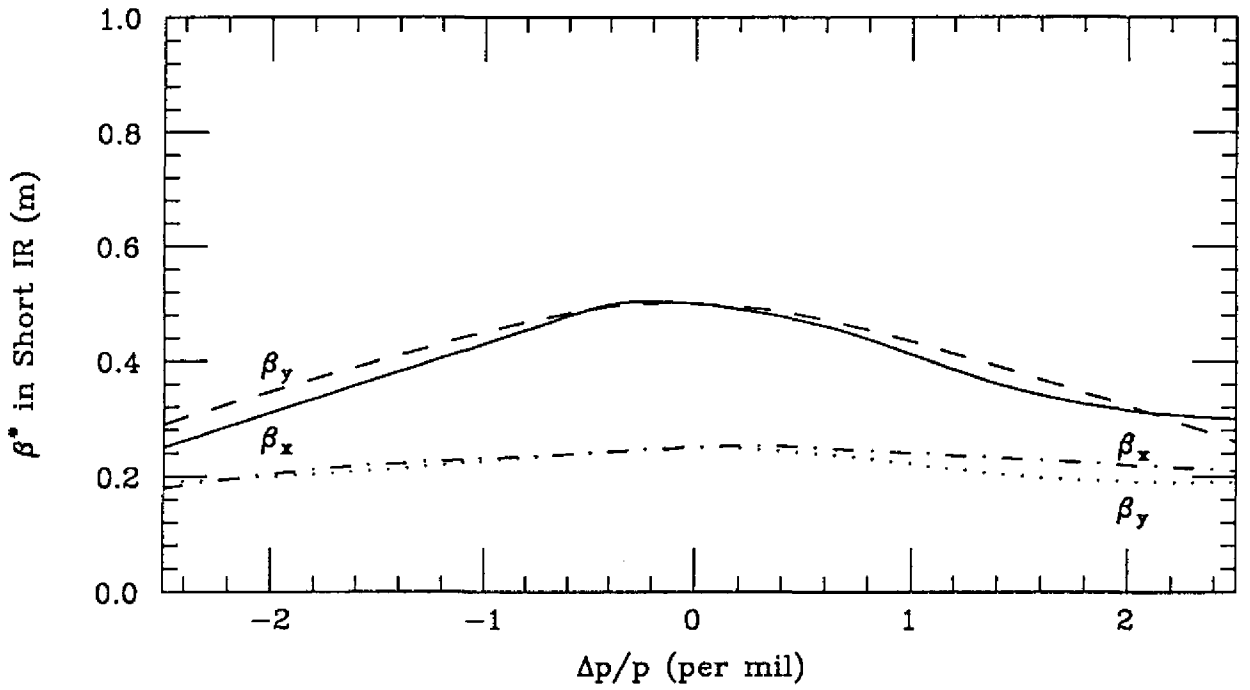

Figure 5 – β^* for 0.25m & 0.5m insertions.

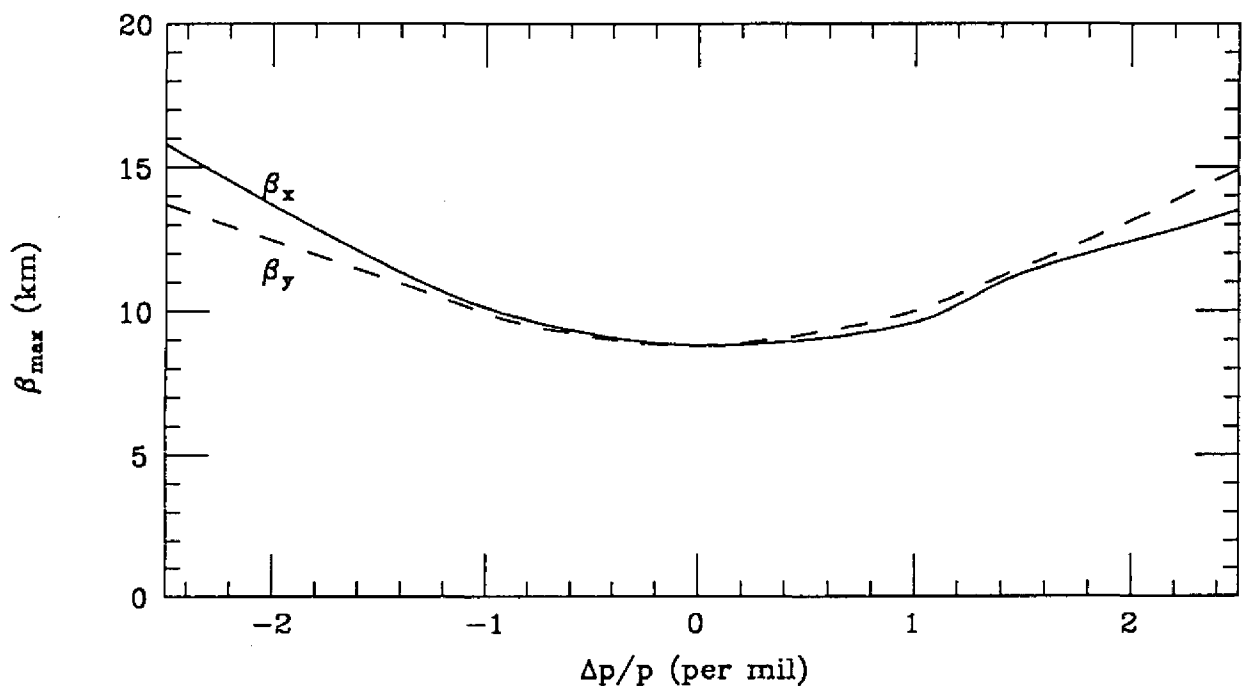

Figure 6 – Peak β for the SSC with one $\beta^* = 0.25$m insertion.

Conclusions

A high-luminosity insertion has been found for the SSC with 90° cells, by which the initial luminosity can be doubled. In terms of average luminosity the effective gain depends

on the operational conditions and is smaller than a factor of two because of the faster depletion of the beam intensity by the increased rate of beam-beam interactions.

Higher performance insertions with still smaller betas at the crossing point are possible only if stronger gradient quadrupoles are available. However, the margin for a further decrease of β^* is possibly limited by the increase of the chromatic aberrations.

References

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2. *The Large Hadron Collider in the LEP Tunnel,* (G. Brianti and K. Hübner, ed.), **CERN 87–05**.
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