BEAM SEPARATION FOR p-$\bar{p}$ COLLISIONS IN A SINGLE RING IN THE MULTIBUNCH MODE*

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e^+e^- storage rings are operated with very few bunches. Designing for a very high volume density gives the optimum luminosity limited by the beam-beam interaction. A value of the tune shift of 0.03-0.06 per bunch interaction is normally assumed in the design stage. Operating e^+e^- rings tend to achieve this.

p-$\bar{p}$ single ring operation presents a different situation in that such high tune shifts may not be stable. Normally, it is assumed that proton tune shifts should be limited to ~ 0.005, an order of magnitude smaller than for electrons. For head-on collisions, coupling the three phase space dimensions, the limit could well be less than this value. In any case, it is clear that some gain could be visualized by dividing the available beam into a sequence of bunches. Then, if the limit is determined by the tune shift per bunch, a luminosity increase at a given collision region could be attained. For a given number of particles per bunch, the luminosity will increase linearly with the number of bunches while the tune shift per bunch remains unchanged. However, as the number of bunches is increased, the number of collision points around the ring also increases. For n bunches, there are in fact 2n collision regions. Because, in general, there is no symmetry of collision points, it is not clear that the relevant limitation is the tune shift per bunch. We could indeed guess that under such conditions as would be present either at Fermilab or the SPS at CERN, the total tune shift per revolution might be a more relevant parameter reflecting the performance limitation. Thus, some means of separating the beams at points where no experiment is being performed seems to be an important feature for a p-$\bar{p}$ colliding beam ring.

For many bunches, it does not seem to be a practical solution to separate the beams locally by a group of electrostatic deflectors. The energy of the beams is too high and the number of units required would be too high. A feasible arrangement would not appear to be possible. Thus, both at Fermilab and at the SPS, it has been proposed to use a different method. By exciting a betatron oscillation in some appropriate, localized region, one could create a specific collision point while at the same time cause the p and $\bar{p}$ beams to oscillate in opposition so that their orbits meet at only a small number of points, roughly given by twice the tune, 2ν. This situation is depicted schematically in Fig. 1.

Thus, we have 2n collision points and ~ 2ν orbit crossings. The question is: what oscillation amplitude, i.e., what deflector strengths are required so that the beam separation at all undesired collision points is sufficient to prevent harmful beam-beam interaction? Furthermore, we might ask if we can reasonably expect to reach the goal of sufficient separation in the existing machines for a large number of bunches.

These questions are, of course, difficult to respond to and we will not attempt any general answer. However, by performing a simplified calculation for the Fermilab situation, perhaps some feeling for the difficulties involved will become clearer.

We consider the case of 6 bunches of p's and $\bar{p}$'s. There are, therefore, 12 points of collision. Three deflectors are sufficient to give the situation sketched in Fig. 1. Since the total tune is about 19.4, we expect about 38 orbit crossings around the ring. Thus, if the collisions were randomly distributed, there would, in general, be a couple of places where the orbits would come very close. In fact, we might expect that unless extraordinary measures were taken (some symmetry) this type of situation could not be avoided.

To be a little more quantitative, take the following model:

Consider i interaction points from D1 to D2 and a phase advance between these points of $2\pi\nu_R$ (ν_R is a tune slightly reduced from $\nu = 19.4$). Then, for the ℓth collision point, the beam separation is given by,

$$\Delta_\ell = 2\theta\ \beta\ \sin\frac{2\pi\nu_R}{i}\ \ell,$$

where β is the average β-function, θ is the effective deflector kick, and we have assumed the phase advance to be linear in distance, which is only roughly valid.

If we take a deflector field of E = 50 kV/cm and a length L = 6 m, then for a beam of momentum p = 1000 GeV/c, the deflection angle is,

$$\theta = EL/P = 3\times 10^{-5} \text{ radians.}$$

For $\beta \approx R/\nu \approx 50$ m, $\nu_R = 19.4 - 0.25 = 19.15$ and i = 11, we have for the separation at collision ℓ,

$$\Delta_\ell = 3\ \sin(3.4818\ \pi\ell)\ \text{(mm)}.$$

We list in Table 1 the values of Δ_ℓ for $\ell = 1$ through 11.

Table 1. Beam Separation at Collision Points

Collision Point ℓ	Beam Separation Δ_ℓ (mm)
0	C*
1	3.00
2	0.34
3	2.96
4	0.68
5	2.88
6	1.01
7	2.76
8	1.32
9	2.61
10	1.62
11	2.43

Before commenting on the results in Table 1, we might ask what the desired separation is. Let us take a beam of normalized emittance, E = 30 μrad-m (Emittance ≡ phase space Area/π). For a 1000 GeV beam, this gives for β = 50 m a 1/2 beam size, b = 1.19 mm or an rms size, σ = 0.6 mm. We might guess that the required separation is 10 σ or 6 mm. Then we would need at least twice as much kick as assumed above. However, even if we take 5σ as being sufficient, it becomes clear from Table 1 that most of the points violate this condition. In fact, there are points where the phase advance is such that essentially no separation results - points 2 or 4 in the case computed here—almost independent of the amplitude of the betatron oscillation.

A more accurate calculation using the Doubler lattice yields results not differing essentially from those in Table 1.

*Work performed under the auspices of the U. S. Department of Energy.

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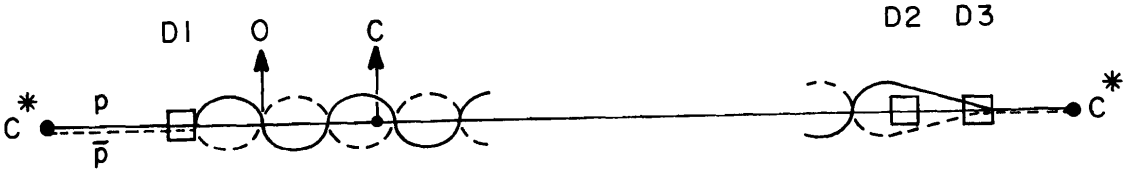

Fig. 1. Beam separation by localized set of Electrostatic Beam Deflectors. D1, D2, D3 = deflectors. C* = desired collision point. O = orbit crossing. C = undesired collision point.