national accelerator laboratory

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Subject NUCLEAR AND COULOMB SCATTERING IN STORAGE RING

The estimates by Paterson in TM-61 (9/17/68) are revised in the light of the orbit parameters distributed October 3, 1968.

Gas scattering produces an increase in the emittance of the beam; the emittance grows linearly with time as long as it is small compared to the chamber admittance. Using the numbers from Fischer' report ISR-VAC/67-16, we find that, with nitrogen at 10^{-9} torr, the emittance grows as

$$E = E_o + 1.37 \times 10^{-6}\, t \qquad (1)$$

(emittance in mm-mrad, t in seconds). For $E_o = 0.36$ (as given in the parameter list) we have a quadrupling of the emittance, and therefore a doubling of the beam height and a halving of luminosity, in a time

$$t_1 = \frac{3\, E_o}{1.37 \times 10^{-6}} = .788 \times 10^6 \text{ seconds} \qquad (2)$$

$$= 219 \text{ hours}$$

If the admittance of the vacuum chamber is not large compared to the emittance, particles are lost. The formulas of Courant and Blachman (Phys Rev. 74, 140 (1948) can be approximated very roughly by

$$P = \exp\left[-(2.405)^2\, (E-E_o)/4A\right] \qquad (3)$$

Where A is the admittance, P the survival fraction.

We assume that the admittance is determined by the aperture at the long end of the low-β section, where β = 1350 meters. Assuming that the semi aperture there is 4 and we retain A = 1.19, leading tc $P = \frac{1}{\sqrt{2}}$ at

$$t_z = .41 \times 10^6 \text{ sec} = 115 \text{ hours}$$

If, on the other hand, the ring is operated without low-beta sections the admittance is determined by the aperture in the B2 bending magnet, assumed to be 1.25 inches (total aperture), with β = 37 meters: A = 6.8. This leads to a time of 655 hours for decay of the beam to $1/\sqrt{2}$ of initial intensity.

Finally, loss by nuclear interaction is the same as given by Paterson. The time for decay of the beam by a factor $\sqrt{2}$ is 130 hour as stated in TM-61.

Putting these results together, we have the luminosity decaying approximately as

$$\frac{L}{L_o} \quad \frac{e^{-t(2.66 + 3.96/A)}}{(1 + 3.80\ t)^{1/2}} \tag{4}$$

Where t is measured in megaseconds (1 Ms = 278 hours). Here the first term in the exponent measures nuclear loss, the second term as well as the denominator arise from multiple scattering.

This gives $L/L_o = \frac{1}{2}$, i.e. the luminosity decaying to half its initial value, at t = 0.09 Ms = 25 hrs (with low-beta insertion)

35 hrs (no low-beta insertion)

The situation is quantitatively different if the gas in the chamber is hydrogen. At a given pressure, the coefficient of t in (1) is reduced by a factor of 40 (because multiple scattering goes approximately as Z^2), while nuclear loss is reduced by a factor 9.5 (assuming that the nuclear cross section is 40 millibarns for H_2). Thus, at 10^{-8} torr of hydrogen rather than 10^{-9} torr of nitrogen we have, instead of (4)

$$\frac{L}{L_o} = \frac{e^{-t(2.80 + 0.99/A)}}{(1 + 0.95\ t)^{1/2}} \tag{5}$$

so that L/L_o = 1/2 at .17 Ms = 47 hours with the low beta section, and at 0.205 Ms = 57 hours without it.

The conclusion is that the ambient vacuum around the ring should be at least equivalent to 10^{-9} torr of N_2 or 10^{-8} torr of H_2.