PION-PROTON COLLIDING BEAMS

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In view of the fact that very high intensity broadband pion beams seem to be feasible at NAL,\(^1\) it is interesting to examine the interaction rates that may be possible if such a pion beam encounters the proton beam of a 1-TeV proton storage ring. From the main ring (500 GeV) or the energy doubler (1000 GeV), we expect the extracted beam to yield pion fluxes of \(10^{11} \pi/10^{13}\) protons within \(\Delta p/p < 10\%\) at an average energy of one-half that of the primary protons. Colliding such pion beams with the storage ring would yield center-of-momentum system energies in the region 1-1.4 TeV.

We consider only a single-pass collision scheme. First, suppose there were another ring in which one might store pions. The number of turns, \(n\), for which the pions would persist would be approximately

\[
n = \frac{y_\beta c \tau}{2\pi R},
\]

where \(y_\beta c \tau\) is the distance a pion travels in its mean lifetime \(\tau\), and \(2\pi R\) is the circumference of the storage ring. Setting \(R = \rho\) where \(\rho\) is the radius of curvature \(y_\beta c m/\pi B\) in a magnetic field \(B\) and \(f\) is the circumference factor \(R/\rho:\)

\[
n = \frac{2\pi}{2\pi m} \frac{B}{f} \frac{B_{kG}}{f} = 0.27 \frac{B_{kG}}{f}.
\]

With \(B = 40 \text{ kG}\) and \(f = 1.5\), \(n = 7\) turns. But since the momentum acceptance of the storage ring would be \(-1\%\), in contrast to the \(10\%\) width of the pion beam there is little advantage in attempting to trap a fraction of the pion beam in the storage ring.

To estimate the luminosity, we take

\[
\frac{dL}{ds} = \frac{2}{e c} \frac{1}{F} \left( \frac{1}{A_\pi} \right)
\]

for the luminosity per unit length in the collinear intersection of the stored proton current \(I_p\) with the pion current \(I_\pi\). \(F\) is the duty factor representing the fraction of the time that the pion beam is present. The form of the expression implies that the pion beam is larger in cross section than the proton beam in that \(A_\pi\), the pion beam area, enters. Taking

\[
A_\pi = \frac{4 (\epsilon_H \epsilon_V)^{1/2} s(s)}{\pi}
\]

where \(\epsilon_H\) and \(\epsilon_V\) are the horizontal and vertical emittances of the pion beam respectively and \(s(s) = \beta_H(s) = \beta_V(s)\) is the amplitude function in the interaction region gives for the luminosity
If the interaction region extends a distance $l/2$ on either side of a point at which $\beta(s)$ is a minimum, $\beta^*$, then

$$\beta(s) = \beta^* + \frac{s^2}{2 \beta^*},$$

and

$$L = \frac{1}{\epsilon c} \frac{1}{(e_H c_H)^{1/2}} \int_p \frac{L F \tan^{-1} \left( \frac{f}{2 \beta^*} \right)}{p}$$

Let

$$L = 10 \text{ A}$$

$$(e_H c_H)^{1/2} = \pi/4 \text{ mm- mrad}$$

$$\tan^{-1} \left( \frac{f}{2 \beta^*} \right) = \frac{1}{2}.$$ 

Then

$$L = 0.26 \times 10^{33} \text{ F cm}^{-2} \text{ sec}^{-1}.$$ 

Suppose that the entire main-ring beam at its design intensity of $5 \times 10^{13}$ protons per pulse was fast extracted and used to produce the pion beam. Then, for $20 \mu$s, we would have $I_p = 3 \text{ mA}$. If this event occurred every 10 seconds, $F = 2 \times 10^{-6}$, and

$$L = 0.26 \times 10^{33} \times 3 \times 10^{-3} \times 2 \times 10^{-6} = 1.6 \times 10^{24} \text{ cm}^{-2} \text{ sec}^{-1}.$$ 

The event rate corresponding to a $38 \text{ mb}$ cross section would be $0.06/\sec$. Were the energy doubler to be used as a source of 1-TeV protons for the pion beam, the slow doubler cycle--100 seconds as presently conceived--would reduce the luminosity by an order of magnitude.

In principle, one might consider increasing the luminosity by bunching both beams. However, the potential for longitudinal instabilities in the bunched storage-ring beam is likely to prevent any dramatic gain by this means.

References