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A 120-GeV SUPERBOOSTER FOR FERMILAB

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Summary

A new superconducting accelerator is proposed which would replace the Fermilab Main Ring as an injector for the Energy Doubler and would be a source of protons for producing antiprotons for the $\bar{p}$ source. This accelerator would provide 2×10^{13}, 120-GeV protons every two and one-half seconds for injection into the Energy Doubler or for antiproton production. The intensity in the Energy Doubler and $\bar{p}$-production rate would be increased by large factors. Magnets similar to the Energy-Doubler magnets would be used.

Introduction

The idea of a Superbooster to replace the Main Ring originated when methods were being explored to avoid running the Fermilab Main-Ring beam through the colliding-beam detectors. However, it was clear that other more important advantages could be achieved with such an accelerator; i.e., higher intensity for the fixed-target Energy Doubler, a higher production rate for antiprotons, delivery of protons ($\sim$100 GeV) to the fixed-target areas during colliding-beam operation, and a straight section (E0) would be made free for another colliding-beam area.

To obtain the above objectives, the following gross parameters have been chosen.

Energy. The invariant cross section for production of antiprotons does not increase much above $\sim$ 100 GeV[1]. The minimum energy for injection into the Energy Doubler[2] is $\sim$ 120 GeV. The lower the energy, the less the cost. Thus, an energy of 120 GeV has been chosen.

Radius. The radius is fixed to be twice the Booster radius by two considerations. Firstly, the desire to use the already developed Energy Doubler superconducting magnets (4T) with some modifications discussed later. Secondly, since the 8-GeV Booster will be used for an injector, it is convenient to have the radius an integral number of Booster radii.

Cycle time. The cycle time should be as small as possible. This is about 2.5 seconds for modified Energy Doubler magnets. This is a reasonable cycle time for loading the Energy Doubler (12.5 seconds) and for producing antiprotons (2.5 seconds).

Intensity. An intensity of 2×10^{13} ppp appears to be feasible. This would provide easy injection of 10^{14} protons into the Energy Doubler (6 Superbooster batches) and a higher rate of protons than the Main Ring for production of antiprotons.

Location. The most convenient location is tangent to the Energy Doubler at F2 (see figure 1). Injection lines for protons at A0 or antiprotons at F0 can be installed in the present Main Ring tunnel. Injection into the Superbooster from the Booster can be achieved via an existing tunnel. The antiproton production target area is also conveniently located at F2. Figure 2 shows more detail of the injection and extraction for the Superbooster.

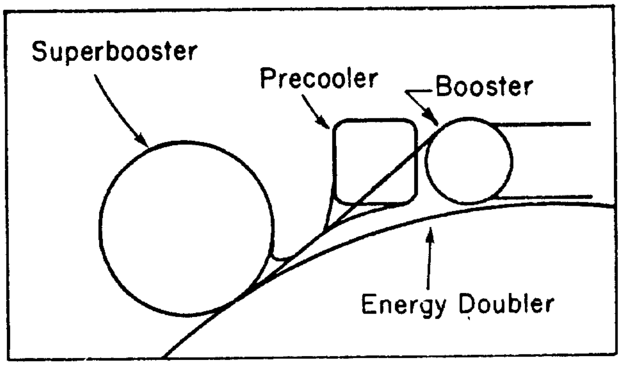

Figure 1. Proposed location of Superbooster

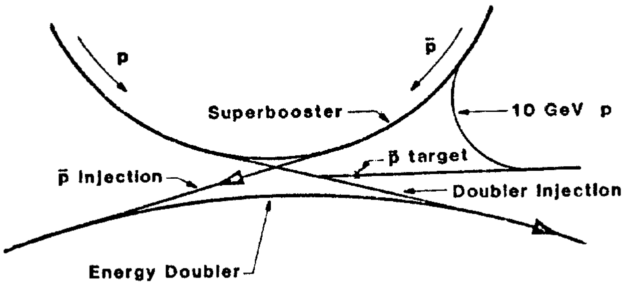

Figure 2. Injection and extraction systems associated with the Superbooster

Accelerator Properties

The basic cell considered for this accelerator is a modified Energy-Doubler dipole, focussing quad, mini-straight, dipole, defocussing quad, mini-straight. Mini-straights would be of sufficient length to contain cryogenic functions, beam detectors, and correction elements. There would be 12 long-straight sections of 17m each. Table I lists the properties of the accelerator.

Table I. Parameters for Superbooster

Energy	10 - 120 GeV
Radius (mean)	155 m
Half cell -	
dipole,	5.5 m
quad,	1.0 m
mini-straight	1.5 m
Long straight (12) (includes 3 quads each)	17 m
Total dipoles	96
Total quads	132
$\nu_h \sim \nu_v$	11.3
γ_t	9
$\beta_{max} \sim 2\bar{R}/\nu$	25 m
$\eta_{max} \sim 2\bar{R}/\gamma_t^2$	3 m

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Table II lists the beam emittances for the Superbooster.

Table II. 10-GeV Beam Emittance

Injected Booster beam at 10 GeV and 2.5 x 10^{12} ppp	
ε_v	.6π mm-mr
ε_h	.7π mm-mr
S (with improvements)	∿ .1 eV-sec
Betatron stack 3v x 2h x 2 long = 12 Booster batches	
ε_v	3π mm-mr
ε_h	2.8π mm-mr
S (per bunch)	.1 eV-sec

Table III reflects the functions of the long-straight sections.

Table III. Tentative Utilization of Long-Straight Sections

Straight Section	Function
1	10 GeV p injection (horizontal)
2	10 GeV p injection (vertical)
3	120 GeV $\bar{p}$ extraction
4	120 GeV p extraction & 10 GeV $\bar{p}$ injection
5	rf
6	Extraction kicker
7	Abort
8	Dampers
9	Free
10	Free
11	rf
12	Extraction kicker

The head-to-tail injection of 2 turns is trivial; however, the horizontal and vertical betatron stacking is more complicated and will require two straight sections. Since it is important to keep longitudinal phase space minimum for $\bar{p}$ production, the beam is stacked in transverse phase space. The transverse beam size is about 2 cm. The good-field aperture of an Energy-Doubler magnet is about 4 cm.

The rf required for capture and acceleration is less than 3 megavolts, thus a system very similar to the Main Ring (4 MV) will suffice. The normal bunching at 120 GeV will be about 8 to 1. Each bunch will contain 1.1 x 10^{11} protons.

The power-supply system would be similar to that developed for the Energy Doubler[2], e.g., 12 supplies of ±1.5 kV.

Magnets

Since Fermilab has developed an accelerator-quality superconducting magnet for the Energy Doubler, the design of the Superbooster magnet will evolve from it. Field quality, field strength, aperture and length are appropriate; however, a.c. losses are a problem and will be discussed below. A sagitta of 5 cm would have to be put in the magnet and the length slightly changed.

Eddy currents within superconductor-hysteresis. An Energy-Doubler magnet has hysteresis heating of 500 joules per cycle or 200 watts per magnet for the Superbooster. A simple model for the superconductor in the magnet gives the heating in watts per magnet as

$$W \sim g\, I_c\, I_m \frac{d\, \ell_m}{r} f,$$

where g depends on the properties of the superconductor; I_c is total critical current; I_m is the total current in magnet; d is the superconductor filament diameter; ℓ_m is the magnet length; r is the mean radius of the coils (bore) and f is the magnet cycle frequency. We note that $I_m < I_c$ and thus to minimize W, I_m should be as close to I_c as feasible. The momentum of the particles in the magnet $p \sim I_m R_m / r$ and thus the total heat in all magnets (n dipoles on radius R_m) is

$$Wn \sim \frac{g p^2 r d f}{R_m}.$$

To minimize Wn for fixed p and f:

(1) the radius of the coils (bore) should be minimized (we have picked the Doubler dimensions since this gives sufficient good-field aperture);

(2) the lower the field (greater R_m), the less heat (we pick 4T since a lower field would force a larger radius and higher construction costs[4]);

(3) the diameter of the superconducting filaments should be minimized (it appears 2μ diameters can be achieved, the Energy Doubler has 8μ filaments);

(4) the development of the superconductor continues and thus g will decrease with time (at this moment, Nb-Ti is the only feasible material for a large project).

The above magnet system, i.e., with 2μ superconducting filaments, would have 50 watts per magnet of hysteresis heating.

Eddy currents between superconducting filaments or wires. The small eddy current loops, achieved by twisting the wire or cable (∿ twist/cm), are sufficiently small to keep these losses less than 15 watts per magnet. Note this loss is proportional to $(dB/dt)^2$ and would become a problem for fields above 4T. If these do become a problem, they can be controlled by the dimensions of the wire, cable, twisting, and resistivities of the matrix material.

Eddy currents in cryostats. The cryostats of the Energy-Doubler magnet would need to be changed to reduce eddy-current losses (estimated to be ∿ 300 watts for Superbooster) by a factor of ten. This is being studied.

Beam-resistive wall heating. For 1.1 x 10^{11} protons per rf bunch, this loss should be only a few watts. Since this loss is proportional to the square of the number of protons per bunch, the above intensity could not be increased very much without design changes to the magnet.

Conclusion

It appears quite feasible to construct a 120-GeV, 2.5-second cycle superconducting accelerator with modified Energy-Doubler magnets. The principal changes to the Energy-Doubler magnet would be smaller superconducting filaments (2μ) and different cryostats to minimize eddy currents.

The author wishes to express his gratitude to A. McInturff and R. Shafer for their helpful discussions.

Reference

1. J. W. Cronin, "Antiproton Production at Rest in the Center of Mass," 1977 Summer Study, Fermilab, page 269.

2. Design Report, 1979 Superconducting Accelerator, Fermilab.

3. The a.c. losses in the quads are about equal to those in the dipoles and will have to receive the same attention.

4. A cost optimization has not been completed; however, around 3-5T and the corresponding larger or smaller radius, the cost is roughly constant for a given energy and cycle time.