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CAN AN ENERGY DOUBLER BE USED TO IMPLEMENT A SIMPLE 350 GEV STORAGE RING SYSTEM AT NAL?

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I. INTRODUCTION

Recently Wilson[1] has suggested the possibility of incorporating a superconducting ring in the present main ring tunnel. This "Energy Doubler" scheme offers a remarkable technique for achieving laboratory energies up to 1000 GeV.

At the same time the turn-on of the CERN ISR has been distinctly successful. Currents of several amps have been achieved easily. Parameters (other than the maximum current) have reached design expectations. There is already solid information indicating that the design is conservative. Vertical beam height is smaller than originally anticipated. Important physics results have followed quickly, indicating that proton storage ring experimentation may be somewhat less difficult than originally anticipated.[2]

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The conjunction of two rings within one tunnel and the CERN ISR success leads one to consider the possibility of constructing a simple storage ring system using a doubler and the present main ring. To some extent the idea parallels the beam bypass plan suggested at NAL several years ago.[3]

II. BASIC CONCEPT

In this scheme a second 8 GeV transfer system is installed to inject into the main ring in the opposite sense to the normal beam direction. Injection might be into the medium straight section upstream of A or through a field free shunt such as the one in the Cornell Synchrotron.[4] Roughly speaking this transfer line will represent one-fourth of the costs of the present booster magnet. The main ring then accelerates the beam and stacks it into a doubler operating dc at 350 GeV. Figure 1a illustrates this phase. Note that the doubler will require an RF system suitable for stacking. Ideally it will have sufficient horizontal aperture to hold about a 1% momentum bite. A current of 20 amps can be stored with about 50 pulses, assuming the main ring holds 0.4 amps (i.e. 5×10^{13} protons).

After the doubler is filled the main ring field is reversed. The present 8 GeV transfer line is used to inject into the main ring in the normal sense. This is shown in Fig. 1b. The design beam of 0.4 amp is accelerated to 350 GeV and the magnet flat topped for a time equivalent to about 100 or more pulses. An energy of 350 GeV is suggested so that the main ring can easily be flat topped for long periods. For this energy the storage ring system will supply a center of mass energy equivalent to a synchrotron with an energy of 230 TeV.

With this arrangement the current-current term in the luminosity is down by a factor of 50 from the CERN ISR[5] or the NAL storage ring design study[6] since 20 amps is circulating in the doubler and 0.4 amp in the main ring in contrast to 20 amps in both directions in these designs. In detail, the luminosity is 0.3×10^{30} cm^{-2} sec^{-1} with these assumptions on the currents and assuming a crossing angle of 15 mrad with a half width of 2.0 cm (based on considerations to be discussed later). This should be compared with the CERN design luminosity of 4×10^{30} cm^{-2} sec^{-1} and the NAL 100 GeV design luminosity of 100×10^{30} cm^{-2} sec^{-1}. The interacting region will be roughly 50 cm long. If the aperture of the doubler was sufficient to accommodate only one turn, the horizontal half width would diminish to 0.5 cm and the luminosity would be further reduced to 0.025×10^{-30} cm^{-2} sec^{-1}. Note that neither of these estimates include the real possibility of matching sections to reduce the horizontal spot size.

To implement two intersecting regions (logically at B and E), the doubler may have to be tilted about a line through these points. That is to say it would have to be above the main ring in the region from B to E (clockwise from above) and below from E to B. The doubler is kept below from E to B to avoid the injection and extraction line at A and the RF at Section F. Crossing would be in the vertical plane and at an angle of 10 to 20 mrad (compared to 50 mrad in the 100 GeV study). A 15 mrad crossing angle at 350 GeV corresponds to a linear scaling of the crossing angle used for the NAL design and the CERN ISR. Note that the smaller angle correspondingly increases the luminosity. Fifteen mrad corresponds to a doubler located 1.25 feet above (or below) the main ring line. The tilt is shown schematically in Fig. 1c. Provisions would have to be made for achromatic matching of the two sections. Vertical crossing may present some problems. Note however that vertical crossing is planned for the DESY storage rings.[7]

III. SOME CONSEQUENCES OF THIS SCHEME

Accelerator Design

The aperture planned for the doubler is approximately one inch in diameter. Of this perhaps one-third may be good field. This is too small to store currents of 20 amps. For contrast consider the apertures of some other devices:

	Width	Height
CERN ISR	9.6" pole width	2.54"
NAL (100 GeV ISR, B1)	2.5" good field	1.0"
NAL (200 GeV)[8]	2.5" good field	1.0"
NAL Main Ring	5.0" vacuum can	2.0"

If the storage ring concept is feasible from other standpoints it may be desirable to consider a somewhat larger aperture for the doubler. Based on the main ring internal beam parameters the horizontal betatron spread will be ± 0.5 cm and the dispersion contribution for 50 turns (assuming a beam debunched to $\pm 10^{-4}$ $\Delta p/p$) will be ±1.5 cm (assuming a beam debunched to $\pm 10^{-4}$ $\Delta p/p$). This gives a horizontal width of ±2.0 cm. Space for stacking would require an additional 1.5 cm leading to a full horizontal good field aperture of 5.5 cm (i.e. 2.2 inches).

A serious difficulty with this concept is the short length of the intersection region straight sections. In past designs these regions have been lengthened linearly with increasing momentum. The NAL 200 GeV design[8] proposed a length of 125 m. Scaling this to 350 GeV gives 220 m. The present main ring long straights are 52 m long. Thus they are more than a factor of four shorter than the scaling would suggest. On the other hand, split field magnets in the intersecting region coupled with the use of high resolution wire planes might considerably relieve the requirements.

Three factors act to reduce the vacuum requirements. In the first place the planned storage time of the beam is down by two orders of magnitude compared to the CERN ISR (with a ring vacuum of 10^{-9} torr except in the intersecting regions). The normal vacuum in the main ring (10^{-7} torr) should be suitable except for the intersecting regions. In the second place beam-residual gas interactions in the CERN ISR have proved to be of little consequence experimentally and could be increased somewhat. Finally, the cryopumping of the superconducting doubler should considerably improve the vacuum.

Provisions will have to be made for an extra 8 GeV transfer line, reversible main ring power supplies, and long-time flat topping in the main ring. In addition the doubler will have to be equipped with RF for stacking and probably some extra horizontal aperture.

Magnetic field interference between the main ring and the doubler will have to be calculated. Note, however, that the doubler is well below saturation when it is operating as a storage ring. Hence field leakage should be minimized. A rather thorough DESY design with rings spaced a similar distance apart anticipates no difficulty on this point.

Operations

While the accelerator is being used for storage ring experiments, it will not be available for other activities. This is in contrast to the CERN ISR. Similarly, the accelerator must be shut off while the rather complicated experiments are rigged in. These features certainly would represent serious operational constraints. At present it is thought that the original installation of the doubler would take place over a long period of time by using short maintenance periods so that initial installation would not interfere with operation of the accelerator.

The restrictions of incorporating the two rings in the present tunnel probably limits the intersecting points to two. This is a reduction of a factor of two from the 100 GeV storage ring design report. Note that at one intersection region (E) the center of mass is traveling up while at the other point (B) it is traveling down. The upward region may be more desirable since the outgoing particles can be routed up to ground level.

Physics

Simply stated this arrangement offers a storage ring concept with an interaction rate down by more than an order of magnitude from the CERN ISR. Put another way it is equivalent to a laboratory system beam of about 10^4 particles/sec on a target. While this is not high it is certainly sufficient to perform many pp interaction experiments and at least some particle searches.

IV. COSTS

Some rough cost estimates can be made based on the NAL design study and the 100 GeV storage ring study.

Extra 8 GeV transfer (1/4 booster without RF)	$ 3	M
Switching	1	(?)
Flat Top	1	(?)
RF for stacking (100 GeV study)	0.2	
Auxiliary magnets (100 GeV study)	5	
Experimental halls (1/2 of 100 GeV study)	2	
TOTAL (excluding doubler)	$ 12.2M	

These numbers should be compared to roughly $ 50M for the 100 GeV ring study. (Neither estimate includes EDIA or contingencies. The doubler ISR estimate is a mix of 68 and 71 dollars, while the 100 GeV study is all 68 dollars.) Detailed cost estimates for the doubler have not been made. Note that a satisfactory doubler ring for this purpose would consist of a second set of main ring magnets. These could be supplied (with power) for a cost in the neighborhood of $ 30M. Thus an upper limit on doubler costs is something like $ 30M.

V. A SECOND ALTERNATIVE

The luminosity could be increased by an order of magnitude if a second doubler ring (perhaps using normal main ring magnets) was added in the tunnel. In planning the doubler some consideration should be given to this possibility in allotting space in the tunnel. The operations difficulties mentioned above would continue to exist.

VI. SUMMARY

A simple concept for achieving very high energy storage rings has been presented. Most probably there are serious if not impossible theoretical problems associated with the scheme. Certainly two serious operational problems exist, i.e. lower luminosity and restricted accelerator operation. Nevertheless the idea probably deserves some consideration in view of the obvious possibilities that exist.

Before proceeding much further with the concept it would be necessary to answer several questions:

1) What are the minimum aperture requirements for beams of the order of 10 amps?
2) How serious is the problem of the short straight sections?
3) In detail, what luminosity could be achieved with this scheme?

A relatively short design study could probably make great headway on these points.

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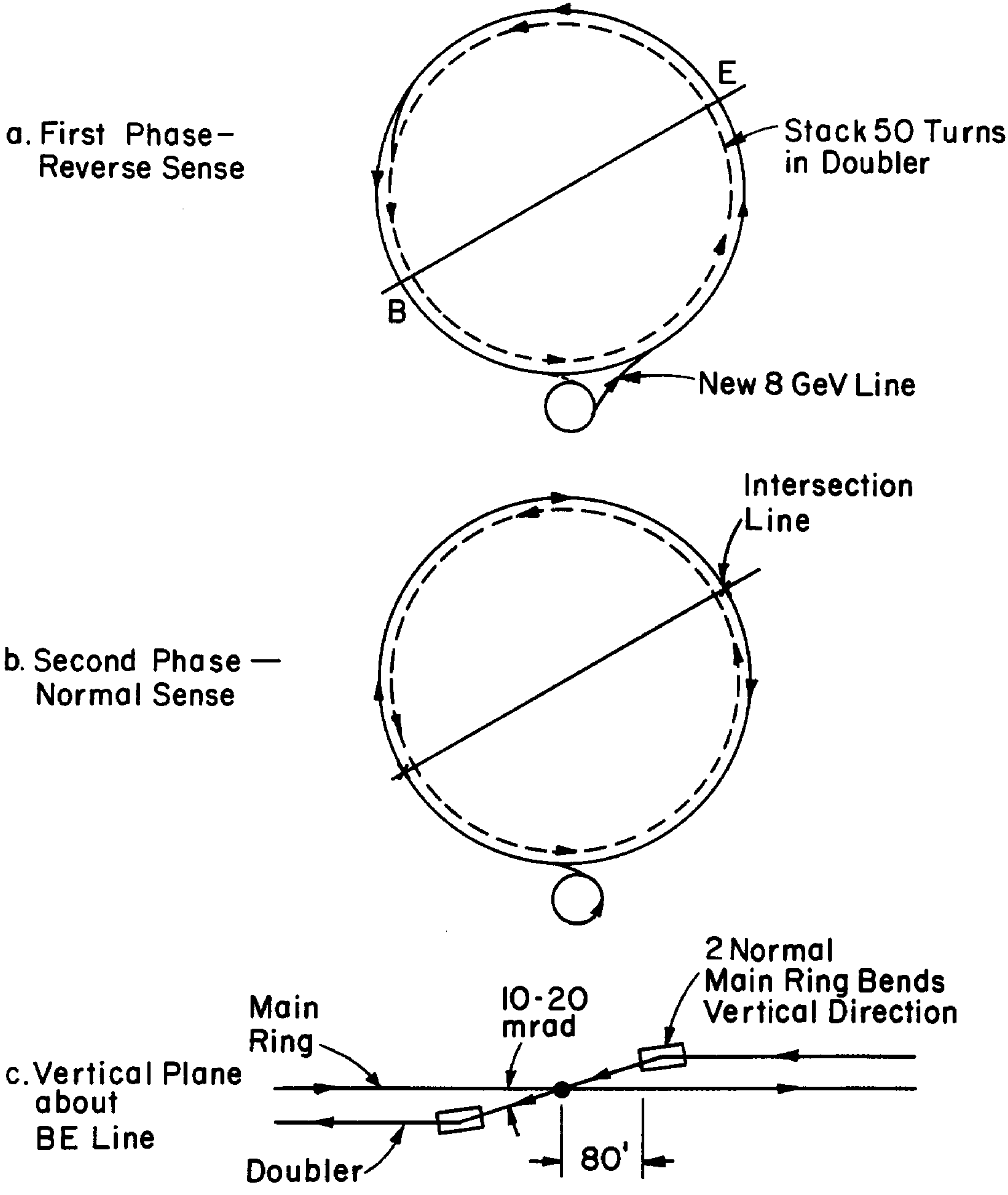

Fig. 1. Schematic illustration of the doubler storage-ring concept. a) Reversed main ring fills doubler. b) Normal polarity of main ring used to provide colliding beam. c) View showing vertical crossing angle.