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INTERSECTING ACCELERATOR RING (INTAR) FOR THE STUDY OF PROTON-PROTON COLLISIONS AT MORE THAN 200 GeV IN THE CENTER OF MASS

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Results of experiments at the ISR have recently shown several qualitative new effects in strong interactions.[1] It is believed that the energy dependence of these new phenomena will provide us with the fundamental asymptotic behavior of strong interactions. There is, therefore, great interest in pursuing a study of the salient features of the proton-proton interaction up to much higher energy.

A reexamination of the potentialities of cosmic rays for this purpose shows that it is extremely difficult, if not impossible, to devise a reasonable method to perform all of the required measurements. In this situation, it is fruitful to study various possibilities at NAL. In these studies it is expedient to maintain as boundary conditions that there be no modification to the existing accelerator, no significant construction (plant) money required, and a maximum of a few million dollars of other funds for the project. In this way, any satisfactory method that is found would then resemble, to some extent, a typical experiment at the Laboratory. Under these circumstances, there would be a good chance that these vital studies of the strong interaction could be carried out in the foreseeable future.

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It appears there is a method to study proton-proton interactions up to over 200 GeV in the center of mass that satisfies the above criteria The basic idea is to construct a low-field accelerator ring running counter to the main-ring accelerator and to observe interactions of these two beams during each acceleration cycle. With the design intensity of 5×10^{13} protons per pulse in each beam, 13-mrad crossing angle, a 4-mm effective beam height at the intersection region, we obtain a design luminosity of 7×10^{28} cm^{-2} sec^{-1}. This corresponds to an event rate of about 3×10^{3} interactions per second during the ramp time of each cycle of the accelerator. This rate of accumulation of data will be adequate to study many of the questions concerning the strong interaction in asymptotic energy region.

The purpose of this note is to indicate the great interest in this kind of physics and also to suggest that a detailed design study of an intersecting accelerator ring (INTAR) may be appropriate at this stage. This study would probably include construction of prototype magnets, study of optimum parameters of the INTAR, detailed cost estimates, and a design of an experimental detection system. In addition, it is likely that an important element of this study would be an attempt to understand the operational problems inherent in having the main-ring accelerator system involved in such a complex procedure.

If the design study for the INTAR experiment shows that it is possible to construct the system within the aforementioned constraints and that it will be possible to successfully study the physics of interest, then it is likely that within two years we could begin to explore this new frontier of strong interactions.

History

In the early days of the design of the National Accelerator Laboratory proton synchrotron the possibility of an injection storage ring or accumulator was considered. The proposal was to place the accumulator ring in the same tunnel with the main ring. It would be filled with successive pulses of protons from the booster and then its accumulated beam would be injected into the main ring. For various reasons the accumulator was not constructed. However, it was realized[2] at that time that there was the possibility of using the accumulator for clashing-beam experiments, assuming some way could be found for reversing the direction of the protons in the accumulator. It is precisely this concept that we wish to adopt. At the time of the design of the accumulator the cost was estimated by Brobeck Associates to be roughly $3 million. The purpose of this note is to consider some aspects of an accelerating ring to work between 8 and 30 GeV and provide an up to date cost estimate.

INTAR (for parameters see Table I)

We assume that we would use the same separated-function lattice for the INTAR as for the main ring. The magnets will be located as shown in Fig. 1 and will be positioned carefully with respect to the known alignment of the main-ring magnets. In Fig. 1 two locations for INTAR magnets are shown. The actual location of the magnets depends on the section of the main ring. Figure 2 shows the vertical relationship of INTAR to the main ring as a function of sector. Two intersection regions are proposed, namely in long straight sections B and E which are opposite each other and do not have any particular activity associated with them at this time. Powerful (a few kilogauss) magnets would be used to manipulate the beams at intersection regions.

The individual magnet design might be similar to the ideas developed for the accumulator.[3] This is shown in Fig. 3. They would each consist of an iron pipe 20 feet long which would contain the simple one-turn coil (which eliminates the need of a bus bar) and donut. H. Hinterberger has made a preliminary cost estimate of this magnet structure using aluminum coils rather than copper as in the accumulator. This is given in Table II. The magnet shown would require several megawatts capacity.

The vacuum donut would consist of a stainless-steel pipe through each magnet with a small bellow section at each end. The quality of the vacuum would be similar to the main ring as this is adequate for holding a 30-GeV beam for a few seconds with minimal losses. For a few hundred feet around the interaction points a very high vacuum would be achieved. A preliminary cost estimate of the vacuum system was prepared by E. Malamud and is summarized in Table II.

In order to keep the beam bunched during acceleration to 30 GeV it would be necessary to supply an rf voltage of about 450 kV. This would be over a frequency range almost identical to that encountered in the main-ring rf system. The actual main-ring frequencies are listed:

8 GeV	52.8
30 GeV	53.08
400 GeV	53.10.

Two main-ring cavities would suffice for this purpose. The chosen harmonic number would ensure no migration of bunches relative to the interaction point. The present rf building has space for the power supplies, low-level systems, etc. J. Griffin has supplied a cost estimate for the required components and this is given in Table II.

Beam Transfer

It is not possible to use the present extraction channel from the booster as there is inadequate space to turn the beam around the required 180 degrees. A new extraction channel, at straight section 6 or 7, would be constructed. This beam would be brought through a new 450-foot long tunnel connecting the booster to the main ring. The ring would be bent through about 90 degrees in an achromatic and isochronous bend in this tunnel before entering the main-ring tunnel. The geometry is shown in Fig. 4. Injection into the INTAR would occur at a medium straight section. A preliminary cost estimate of the ejection, transport, and injection system has been given by E. Bleser. This is shown in Table II. In addition, the cost of the construction of the 140 m of tunnel has been estimated as $350 K.

Interaction Region Characteristics

The expected emittances at the design intensity in the booster and main ring are:

	Booster (8 GeV)	Main Ring (300 GeV)
Half width x, y	2 cm	6 mm, 2 mm
β	33 m	96 m
Emittance $\epsilon_H = \pi x^2/\beta$	4π mm-mrad	0.1π mm-mrad
ϵ_V	π mm-mrad	

Thus, after acceleration to 30 GeV the emittance of the beam is expected to be $\epsilon_{30,H} \approx 2\pi$ mm-mrad.

Because of our self-imposed constraint to not make any change in the main ring (e.g., insert a low-β section) we wish to match the 30-GeV beam size with the 300-GeV beam size at the intersection point. Thus we need

$$\beta_{30,H}^{min} = 2 \text{ m}.$$

Since the interaction length is given by

$$\frac{\text{Beam Size}}{\text{Crossing Angle}} = \frac{0.4 \text{ cm}}{13 \times 10^{-3}} \approx 0.3 \text{ m}$$

and is much less than $\beta_{30,H}^{min}$ there is no significant change of beam size over the interaction region.

The quadrupole lens apertures at the end of the long straight section are given by the β-values at the lenses which are

$$\beta^{end} = \beta^{min} + \frac{(30 \text{ M})^2}{\beta^{min}} \approx 450 \text{ m}.$$

The half-apertures for the low-β forming lenses are therefore 30 mm in the horizontal plane and less in the vertical plane. We see that the required aperture is quite small.

The interaction rate at each crossing point is $\sigma_T L$ sec^{-1}, where σ_T is the total proton-proton cross section and L is the luminosity. The luminosity is related to the beam characteristics by

$$L = \frac{c}{\alpha b}\left(\frac{N}{2\pi R}\right)^2 ,$$

where N = number of protons per ring = 5×10^{13}

R = ring radius ≈ 1000 m

α = crossing angle = 13 mrad

b = beam half height at crossing point - 2 mm.

For the present design we obtain

$$L = 7 \times 10^{28}\ \mathrm{cm}^{-2}\ \mathrm{sec}^{-1} ,$$

and this results in an interaction rate of 3.2×10^3/second.

Operational Procedure

At this time we envisage a possible sequence of operations shown in Fig. 5. This seems a rather efficient mode of filling the INTAR during the main-ring cycle and allowing the beams to collide during the acceleration period in the main ring.

Other Possibilities

The question of multicycle injection of electrons into the INTAR relying on radiation damping to decrease phase space should be investigated. If adequate luminosity for $e^{\pm}$ proton collisions could be achieved it seems an interesting possibility to use one intersection region for electromagnetic studies and the other for proton-proton interactions.

Finally, H. Hinterberger has pointed out that perhaps the wheel has turned and we might use the INTAR as an accumulator and build it with a larger aperture to stack more protons then inject into the main ring at 30 GeV (thereby helping space-charge problems) and increase the current from the machine.

Conclusion

It would seem that a new frontier could be reached in strong interactions for cost in the neighborhood of a few million dollars. It appears justified to study these ideas in much more detail.

Acknowledgments

Stimulating discussions with T. Collins, L. Teng, and D. Edwards are acknowledged.

REFERENCES

[1] An example of the present theoretical prejudices in this regard is the Impact Picture of H. Cheng, J. K. Walker, and T. T. Wu, National Accelerator Laboratory Preprint NAL-Pub-73/33-THY/EXP, May 1973.

[2] R. R. Wilson, Injection Accumulator NAL Proton Synchrotron, National Accelerator Laboratory Report NAL-11, May 13, 1968.

[3] Very likely the magnets would have to be laminated to reduce sextupole fields induced by eddy currents.

Table I. Preliminary Parameters of INTAR.

Energy	30 GeV
Average Radius	~1000 m
Length of dipoles and quadrupoles same as main ring	
Cell structure as main ring except for two low β insertions at intersection regions	
Magnetic Field	1320 G
Voltage per magnet	1.8 V
Current	5400 A
Total Power	7 MW
Magnet gap height	2.0 in.
Magnet gap width	5.0 in.
RF frequency approximately the same as for main ring	
Number of cavities	2

Table II.

(All Costs in Thousands of Dollars)

INTAR Magnets	
Steel	$240
Aluminum and Cooling Cost	200
Assembly	100
Prototype, Tooling, etc.	150
Power Supplies plus Cabling	1,000
	1,690
Vacuum	
Stainless Chamber	400
Bellows	75
Ion Pumps	150
Power Supplies	200
Fore pumps (same as for main ring)	
Ion Pump readout	25
	850
RF	
2 cavities	100
Power amplifiers, modulators, etc.	150
Bus work and cabling	10
	260
8-GeV Line	
Extraction and injection system of magnets (septa, etc.) plus power supplies	700
90° Bend plus transport and power supplies	300
	1,000
Conventional Construction (Plant Funds)	300
Total	$4,100

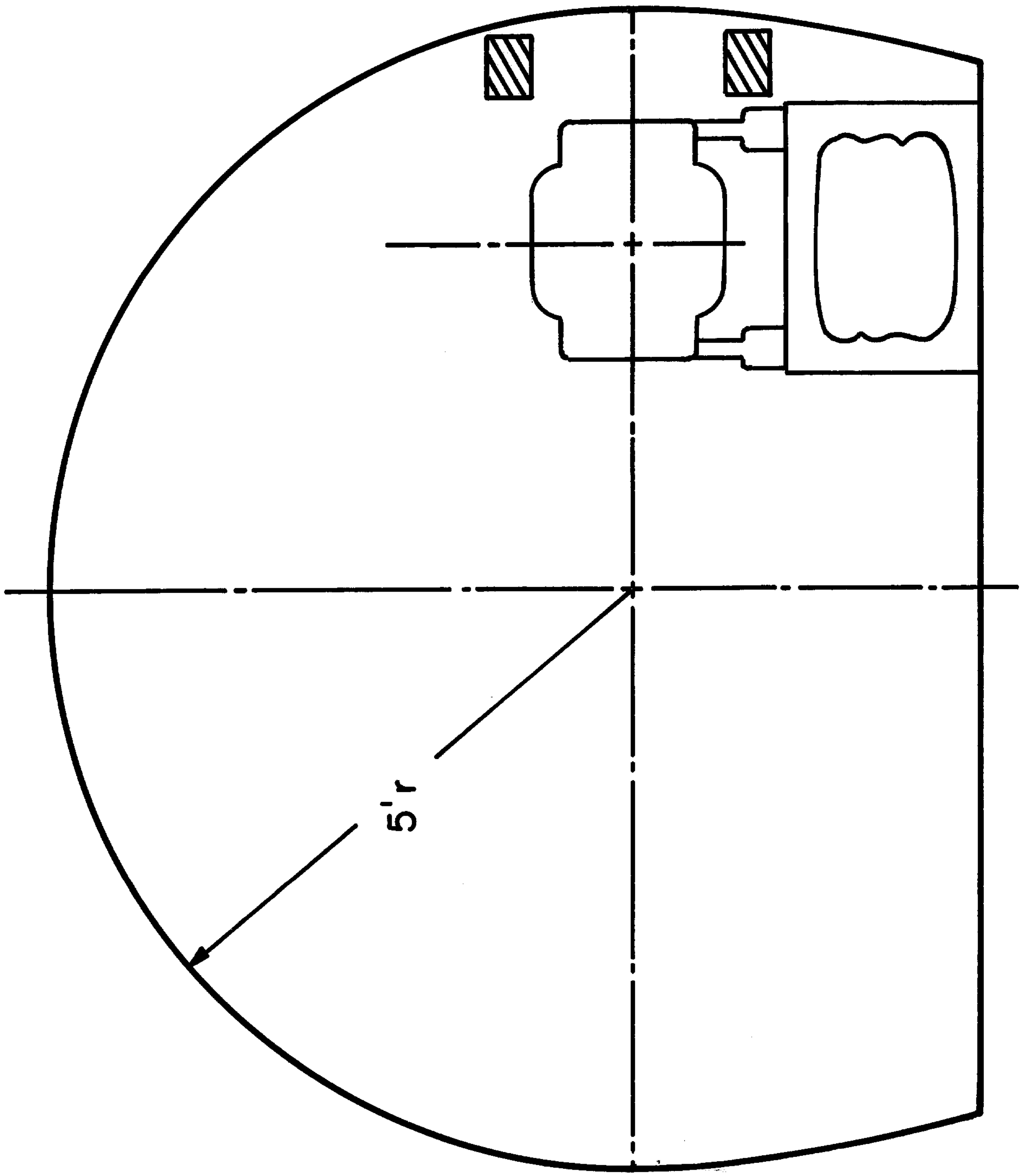

Fig. 1

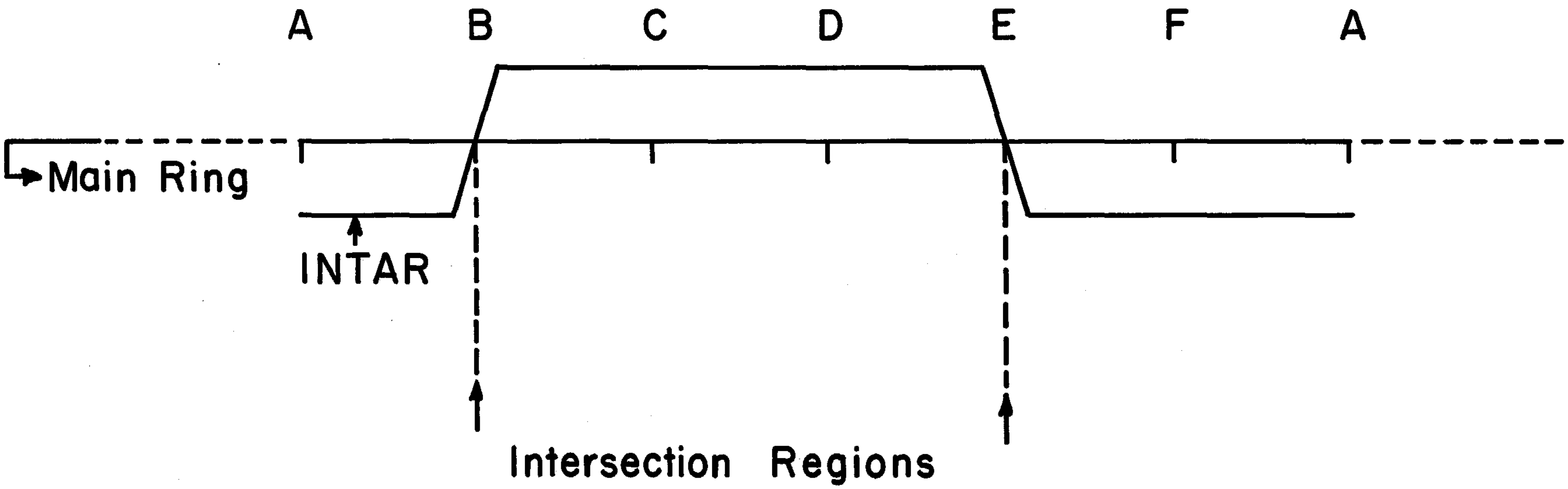

Fig. 2

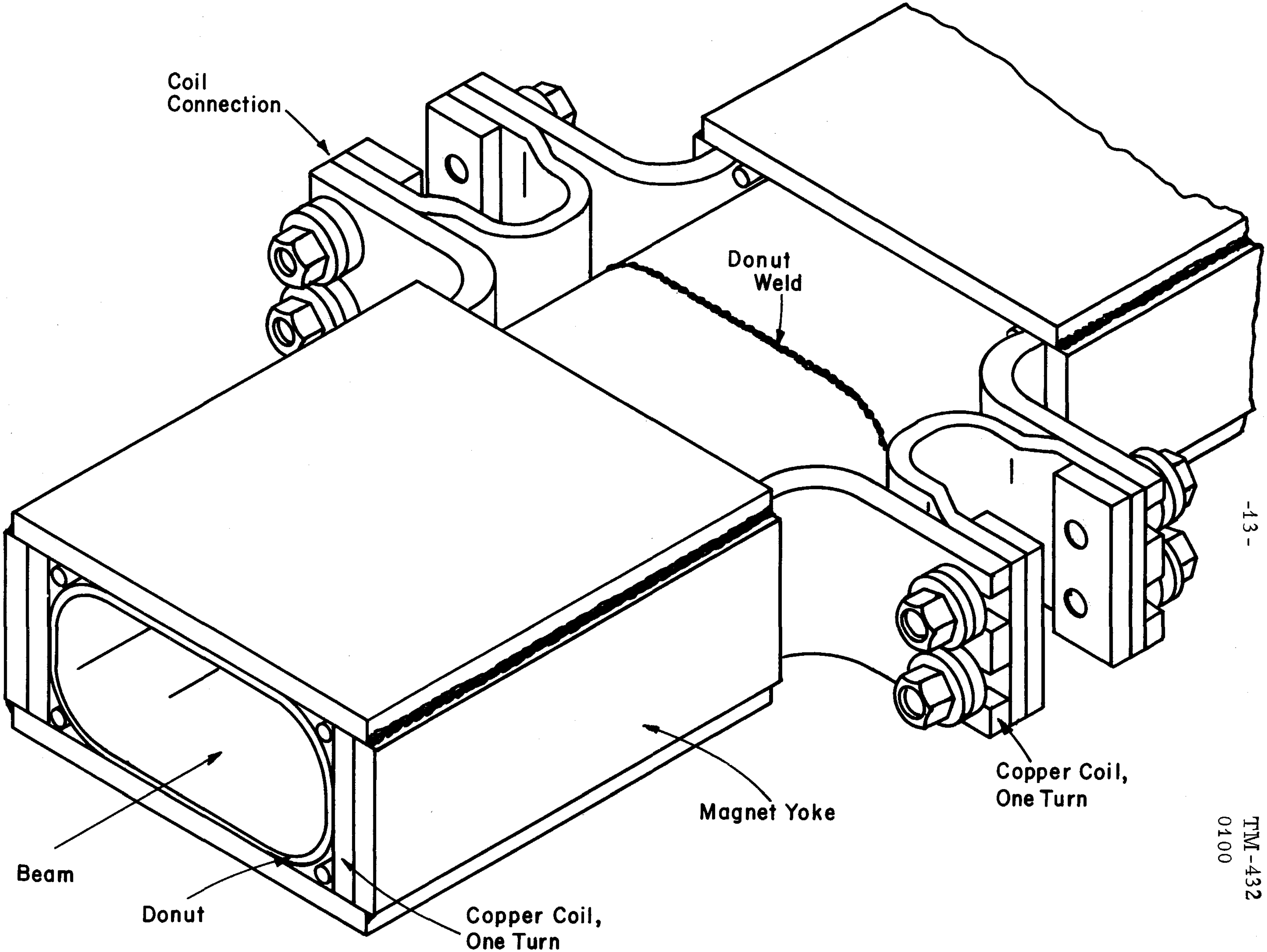

Fig. 3

Cross section of a bending magnet which also shows connection between two successive magnet units

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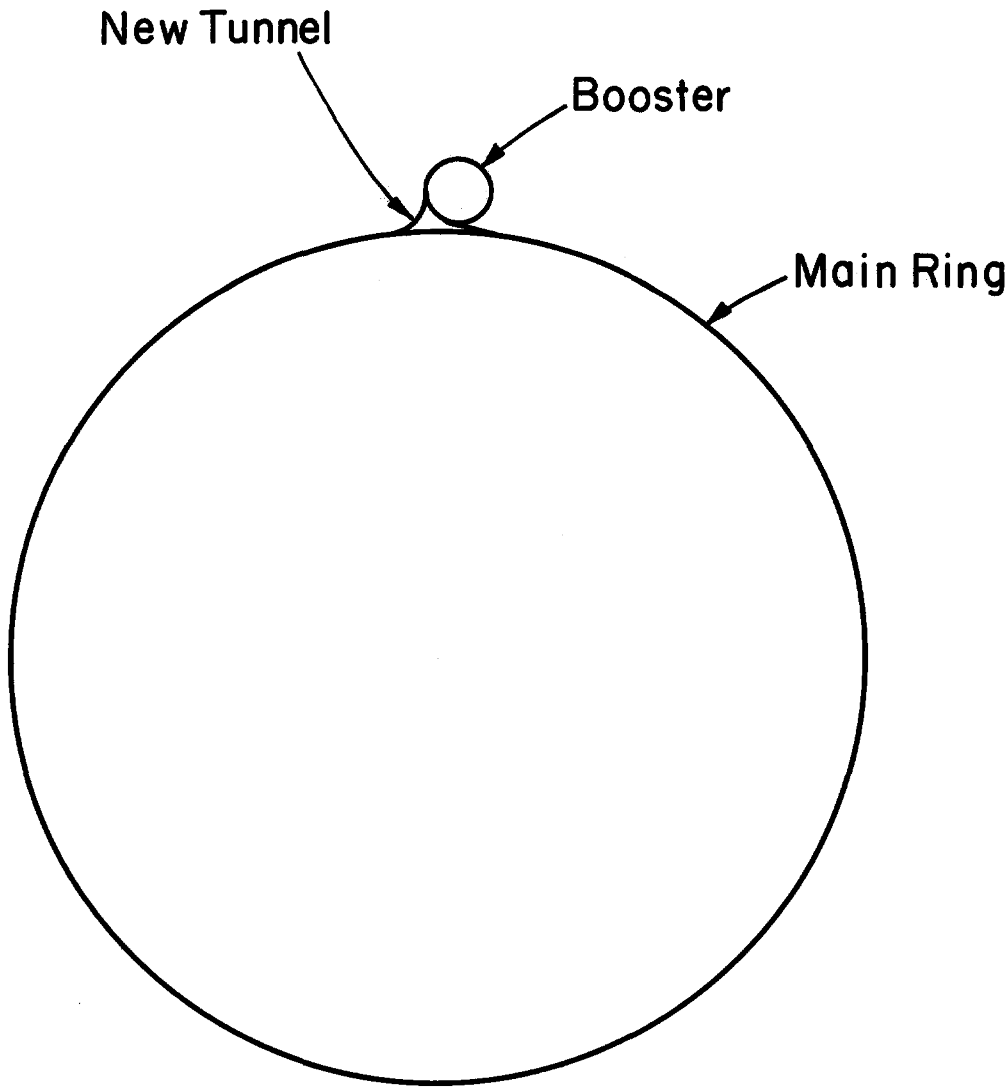

Fig. 4

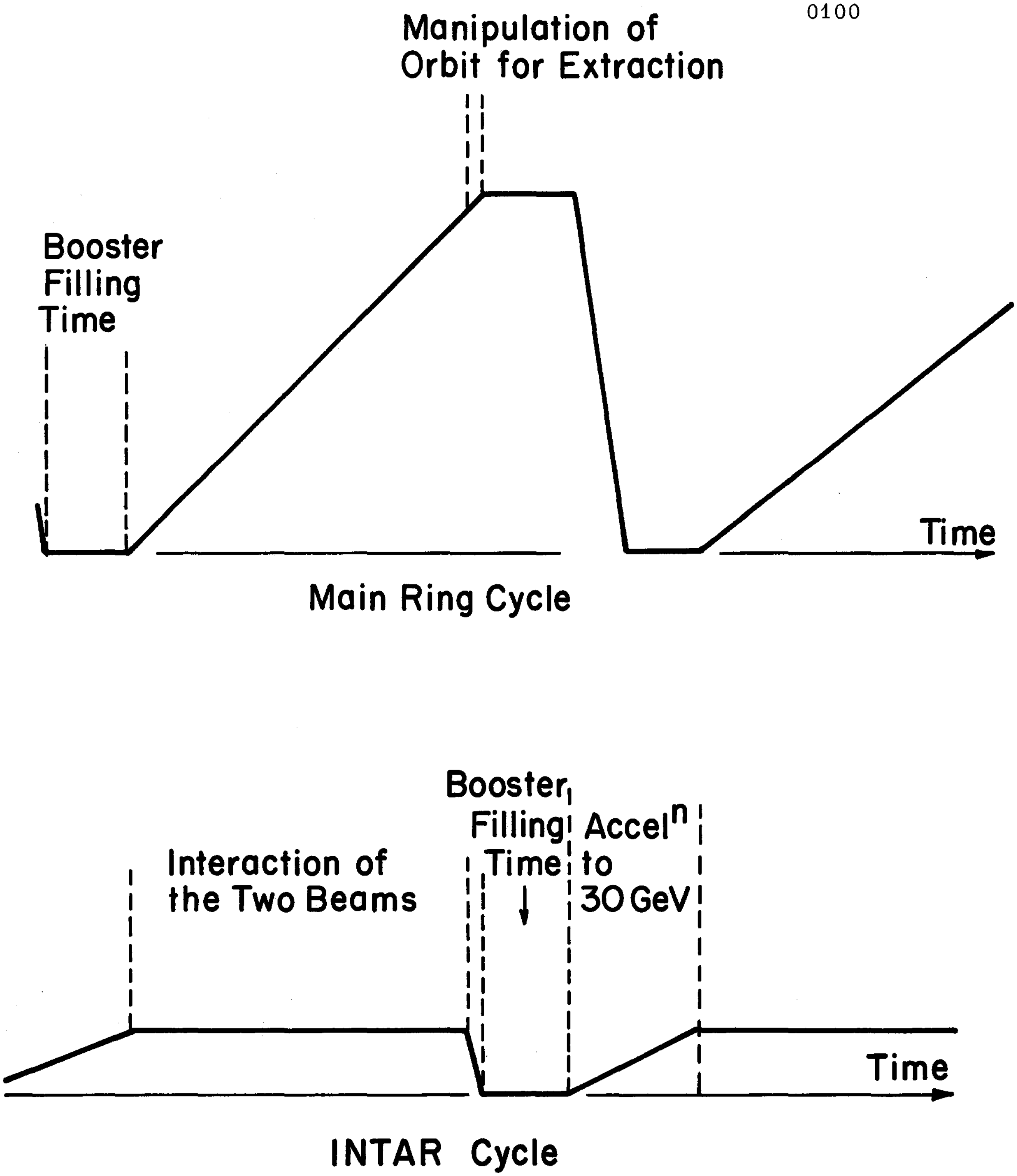
Manipulation of
Orbit for Extraction
Booster
Filling
Time
Time
Main Ring Cycle
Booster
Filling
Time
Acceln
to
30 GeV
Interaction of
the Two Beams
Time
INTAR Cycle

Fig. 5