UPC 020

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ENERGY DOUBLER BEAM ABORT SYSTEM

I. INTRODUCTION

Detailed studies have shown that if even a tiny fraction of the 2×10^{13} protons circulating in the Energy Doubler interact in the nearby solid material (e.g. the vacuum chamber wall or injection/extraction devices), then a disruptive quench of one or more of the superconducting magnets will likely result. It is, therefore, imperative that a beam abort system exist which can anticipate the imminent occurrence of such quench-inducing losses and cleanly dispose of the beam before they are allowed to happen. Clearly the most effective strategy is one of prompt single-turn extraction to an external beam dump. The abort system for the Doubler will consist of a fast, full-aperture kicker followed by a Lambertson septum magnet and a magnetic beam channel to a dump. Monte Carlo calculations[1] with a geometry appropriate to a Lambertson septum magnet in a long straight section indicate that the abort process itself must not interact more than 10^{10} protons on this septum; i.e. the extraction inefficiency of the abort system should be less than 0.05%.

The signal to trigger the beam abort will be generated by any one of the following devices; loss monitors viewing aperture stops at six locations around the ring, fast beam position and beam size detectors, power supply malfunction detectors, magnet quench detectors. The circulating beam will have a gap to accommodate the rise time of the kicker; the initial plan would inject only 12 Booster batches into the Main Ring, leading to a 1.6 μs gap. Once an abort condition is recognized by a detector somewhere around the ring, complete beam disposal could be accomplished in less than 60 μs.

In the following sections two solutions to the abort magnet geometry are described. Both solutions involve a vertical kick followed by horizontal extraction in a long straight section. The abort may be required at any time during the Doubler magnet cycle, and so must track the beam energy from 100 GeV at injection to 1000 GeV at extraction. Solution I, which utilizes two adjacent long straight sections, was outlined in a previous report;[2] a more complete design, including that of the beam dump is given here.

II. Abort Geometry - I

The geometry for Solution I is given in Fig. 1. The beam is kicked downward 0.18 mrad by the ferrite kicker MKV placed at the upstream end of a long straight section ($\overline{\beta}_V$ = 106 m); in traversing the following sextant the beam undergoes 3.23 (19.4÷6) betatron oscillations arriving at the next long straight with a -20 mm displacement and a positive slope of 0.18 mrad. Calculation[3] using the explicit non-linear fields of the Double design magnet show that a beam of transverse emittance 0.15π mm-mrad and $\Delta p/p = \pm 0.1\%$ will traverse this orbit without beam loss or substantial enlargement of the transverse phase space.

A second vertical down kick of 1 mrad at the entrance of the downstream straight section is provided by the current sheet septum magnet MSV (3-mm thick septum centered at -10 mm vertically). MSV is followed by a drift space of 11 m and then 30.5 m of Lambertson magnet. At the Lambertson entrance the vertical beam displacement is 29 mm. The Lambertson bends the kicked beam horizontally through 8.4 mrad providing an 18.4 cm displacement at the first Doubler quadrupole downstream (the quad steel ends at 12.7 cm). A fourth magnet, B, 6 m downstream from the quad, is used in order to have the extracted beam exit the Main Ring tunnel wall at a favorable place; the tunnel diameter decreases by 2 feet at a point 63.3 m from the center of the long straight. At the exit point the beam is ∿16 cm above the tunnel floor. The beam dump is placed ∿60 m from the exit point; at this distance the extracted beam is 4.1 m away from the outside wall of the Main Ring tunnel (see Fig. 4).

The basic parameters of the four magnets are listed on Fig. 1. Magnet MSV will have a half-sine wave current pulse with a 200 μs duration; the relative timing of MKV and MSV will be such that the kicked beam enters MSV 90 μs after the start of the half-sine wave ($I = .99\ I_{max}$). A fifth magnet, MD, is placed just downstream of magnet B; the purpose of MD is to sweep the beam vertically in order to increase the effective beam area at the beam dump. MD is a single turn picture frame dipole with a half-sine wave pulse 70 μs long; the field rises from 0 to 4 kG during the 21μs of beam passage resulting in an angular sweep of 0.24 mrad.

A cross section of the Lambertson magnet at the upstream end is shown in Fig. 2. In addition to the 8-10 kG dipole field (at 1000 GeV), it has a gradient of 0.5 kG/cm (horizontally defocussing), which is used to increase the horizontal beam size at the dump. At the center of the long straight the beam size at 100 GeV is ±3.7 mm; at 1000 GeV the main beam is ±1.2 mm, but during slow extraction has horizontal "wings" extending ±18 mm on either side. It is these wings that determine the horizontal aperture in the field free region of the Lambertson. Both the Lambertson and the dipole B are ramped to track the beam energy.

Without the vertical sweeping action of MD or the focussing action of the Lambertson, the 1000-GeV beam spot size (2σ) at the beam dump would be ±3.3 mm horizontally by ±2.1 mm vertically. A beam of 2×10^{13} protons with this size would cause physical damage to practically any solid material used in the beam dump. For the most readily available material, aluminum, the beam area should approach 1000 mm^2 to avoid damage. From the lens action of the gradient

Lambertson, the horizontal spot size at the dump becomes ±16 mm ; the vertical sweep of MD yields a vertical motion of 2 cm, resulting in an effective area of 900 mm^2. A calculation using the CASIM program indicates that a 1 TeV beam of 2×10^{13} protons and this effective area will give a peak temperature rise of ~250 °C in an aluminum absorber; the peak occurs about 85 cm into the absorber.

III. Abort Geometry - II

A second possible solution for the abort system is shown in Fig. 3. The first vertical kick is now done much closer to the extraction straight section; a 6 m long, 2 kG ferrite kicker, MKV1, is placed at station 33. A 0.36 mrad deflection there results in a 13 mm displacement and zero slope at the beginning of the long straight (a 37° phase advance). Since this is not sufficient to jump a septum, a second full aperture ferrite magnet, MKV2, of length 15.6 m is inserted. MKV2 kicks down by 0.94 mrad, resulting in a -20 mm displacement at the entrance to the Lambertson. From the Lambertson on down the orbit is approximately the same in both I and II except that the clearance at the down-stream quadrupole is slightly less (16.7 cm vs. 18.4 cm) in II since the Lambertson has been moved 2 m downstream. The essential parameters of the five magnets are listed on Fig. 3.

The advantages of II over I are: (a) it does not depend on knowing what the orbit will be through one sextant of the Doubler at the time of aborting; (b) a somewhat larger beam size can be aborted; and (c) the beam is aborted in less than 60 μs, whereas in I it takes ~120 μs. The disadvantages are: (a) II uses an additional 16 m of fast kickers with fields 2.5 times larger; and (b) the vertical displacement of the beam at the entrance to the Lambertson is somewhat smaller.

IV. Beam Dump

A possible plan for the beam dump is displayed in Fig. 4. It is designed to take 3.5×10^{17} protons per year (1000 GeV); at that level it will utilize 20%

of the Laboratory limit for tritium contamination of the ground water. The beam impinges on a 6' long block of aluminum followed by 5' of steel. The membrane shown in a barrier to prevent activation produced above it from passing into the ground water.

V. Abort for $\bar{p}p$ Colliding Beams

The simultaneous presence of counter-moving proton and antiproton beams adds additional constraints on an abort system. Since the expected $\bar{p}$ intensity is $\sim 1 \times 10^{11}$, the $\bar{p}$ abort system need not be as efficient as that for P's. Another complication is that the presence of low β (at the interaction region for attaining higher luminosity) may result in betatron motion phase shifts that reduce the effectiveness of the fast kickers; solution I above is vulnerable to this effect. Suffice it to say that a complete solution has not yet been worked out for the simultaneous abort at this time; some preliminary ideas favor a system with a single fast aperture kicker such as that in solution I.

In the process of setting up to do $\bar{p}p$ collisions in the Doubler, there will be occasions when the $\bar{p}$ beam alone will be present. In this situation, a possible scheme for the $\bar{p}$ abort would involve a vertical kick just upstream (in the proton direction sense) of the Lambertson in LSS2 (see Fig. 1) resulting in a vertical displacement at the corresponding point in LSS1. As for the proton orbit in solution I, a 0.18 mrad kick would yield a 20 mm displacement. The $\bar{p}$'s will be absorbed in a 1.5 m long steel dump block placed 10 mm off the median plane. A simulation of this geometry with the CASIM program is needed to fully evaluate the adequacy of this scheme. In the abort system of Fig. 1, a second ferrite kicker in the 11 m open space between MSV and the Lambertson is required. For the system of Fig. 3, one will simply use MKV2.

It is appropriate to acknowledge many helpful discussions and assistance in the preparation of this report from H. Edwards, Q. Kerns, J. McCarthy, K. Cahill, and S. Snowdon.

References:

1. Private communication from H. Edwards on a calculation by A. Van Ginneken.
2. Fermilab TeV Program Report, 1977.
3. T. L. Collins, "The Abortable Beam," UPC No. 1, November 1978.

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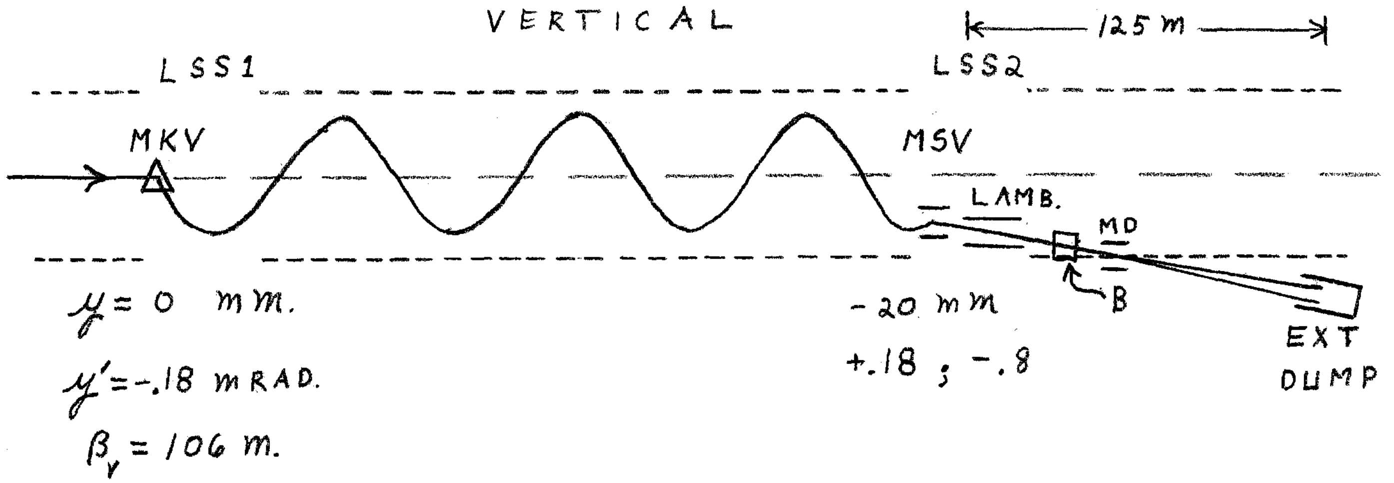
ENGINEERING NOTE

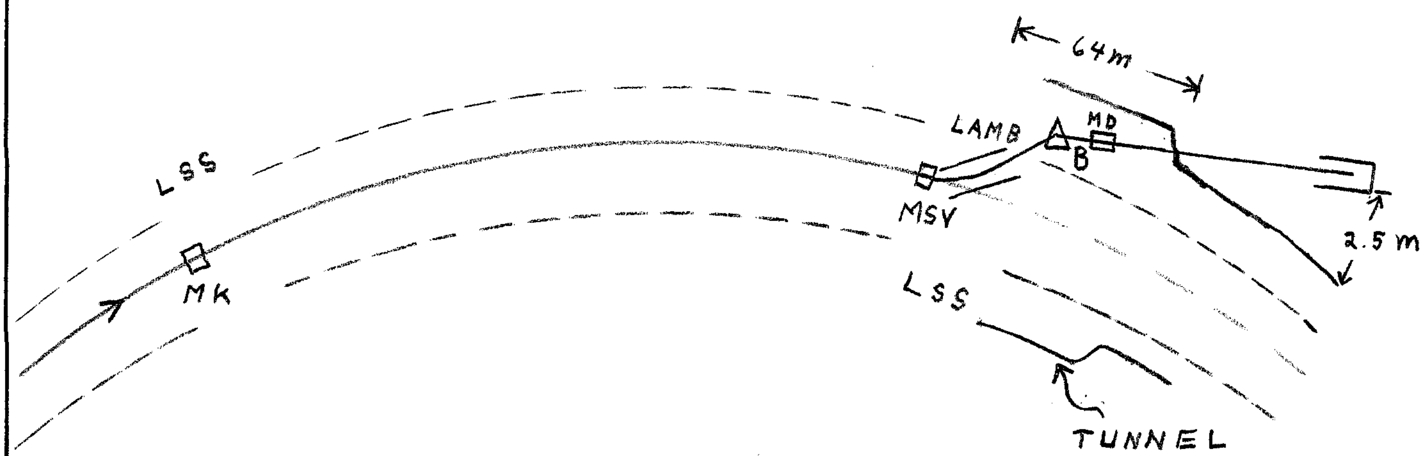
SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: FIG. 1

NAME:
DATE:
REVISION DATE:

E. D. ABORT ORBIT - I





	MKV	MSV	LAMB.	B	MD
TYPE	FERRITE	Fe	Fe	Fe	Fe
$\Delta\theta$	0.18 mRAD	1.0	8.4	3.6	0.24
LENGTH	8.3 m	3.3	30.5	6	2.0
FIELD*	0.84 KG	10	8, 10	20	5
APER- H×V	5×4 cm.	3.8×3.8		5×5	3×3
RISE TIME	0.4 μs	100 μs	RAMPED	RAMPED	35 μs

* AT 1 TeV

GRAD = 0.5 kG/cm

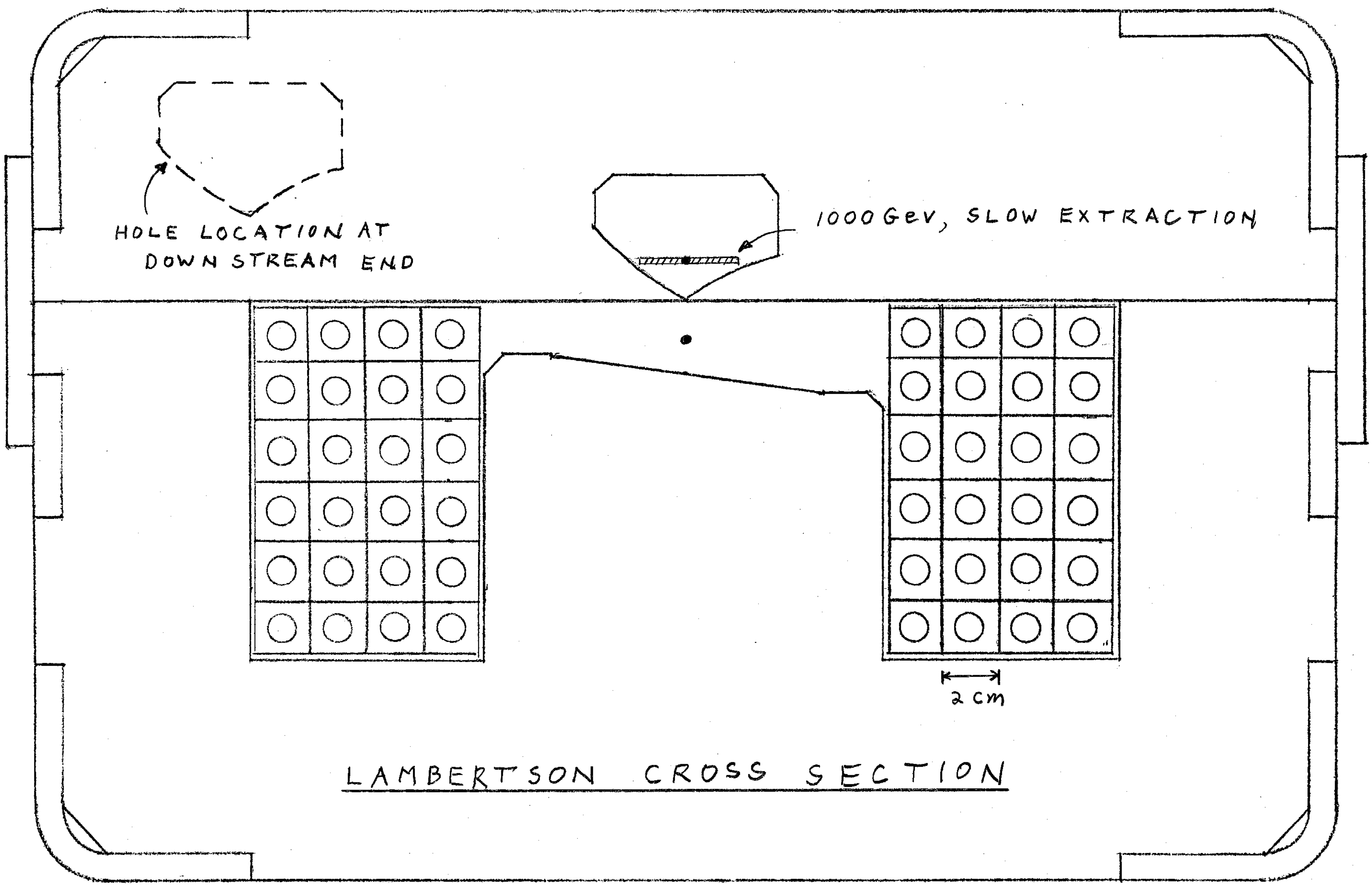

HOLE LOCATION AT
DOWN STREAM END
1000 GeV, SLOW EXTRACTION
2 cm
LAMBERTSON CROSS SECTION

FIG. 2

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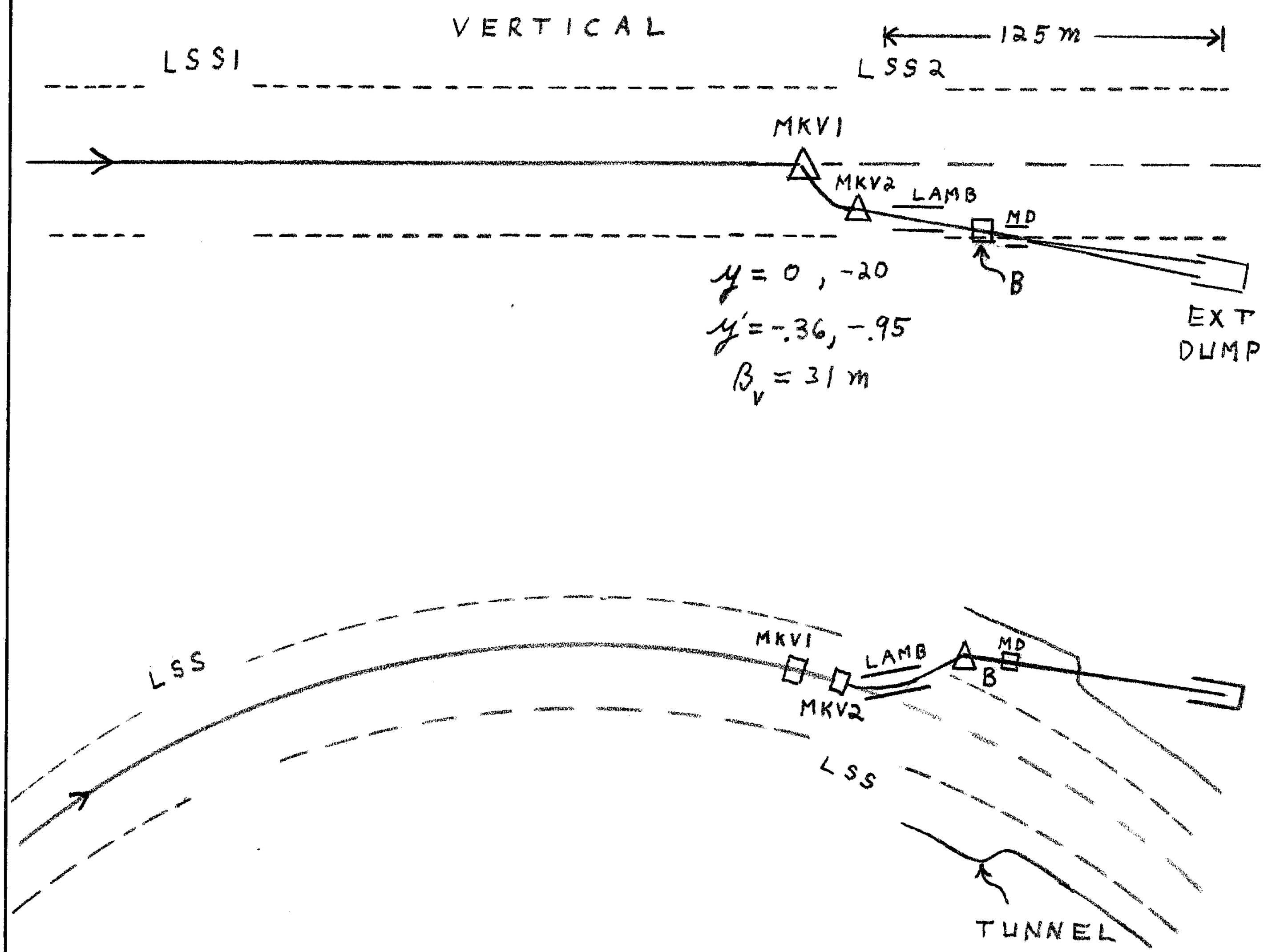
SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: FIG. 3

NAME

DATE | REVISION DATE

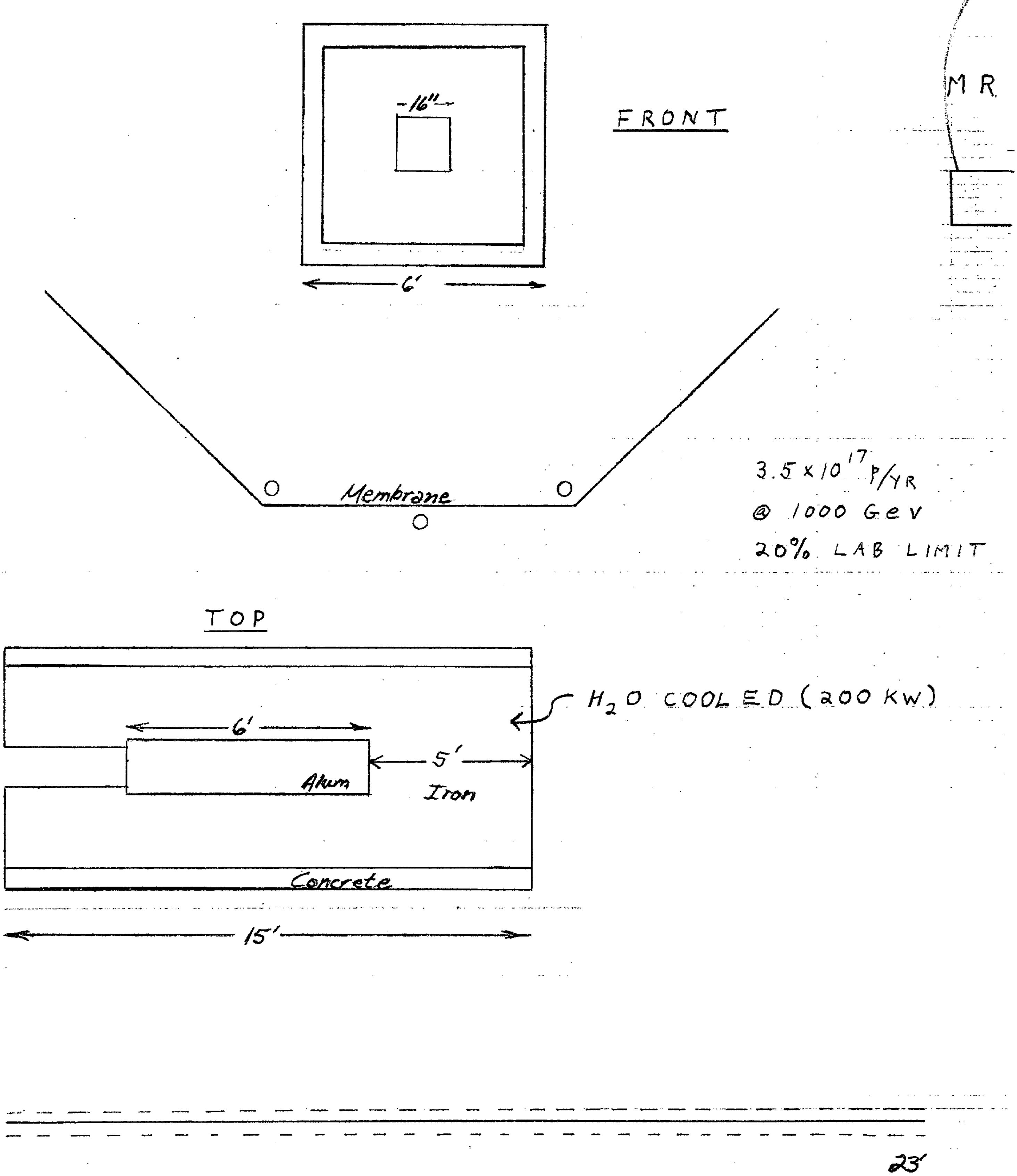
E. D. ABORT ORBIT - II



	MKV1	MKV2	LAMB.	B	MD
TYPE	FERRITE	FERRITE	Fe	Fe	Fe
$\Delta\theta$	0.36 m RAD	0.94 ±.05	8.4	3.5	0.24
LENGTH	6 m	15.6	30.5	6	2.0
FIELD*	2 KG	2	8, 10	19.5	5
APER-H×V	5 × 3 cm	5 × 4		5 × 5	3 × 3
RISE TIME	1.6 μS	1.6	RAMPED	RAMPED	35 μS
			GRAD = 0.5 KG/cm		

* AT 1TeV

ED BEAM DUMP - FIG. 4



Doubler Dump

Scale: 1" = 3⅓'