W. Chou
February 15, 2000

Proton Driver Design for a Neutrino Factory

OUTLINE

- Parameter set
- Physical layout
- Sub-Systems

(mostly site-specific)

- Technical design issues
- R&D program for FY00-01

(mostly "generic")

- Schedule for completing the TDR
- R&D list in a five-year plan (FY00-04)

Required number of protons by a neutrino factory:

$$2 \times 10^{20}\ \mu/\text{year for experiments}$$

$$\Downarrow$$

$$1/3 \text{ useful muons} \longrightarrow 6 \times 10^{20}\ \mu/\text{year in the ring}$$

$$\Downarrow$$

$$0.1\ \mu/p \longrightarrow 6 \times 10^{21}\ p/\text{year}$$

$$\Downarrow$$

$$2 \times 10^{7}\ \text{sec/year} \longrightarrow 3 \times 10^{14}\ p/\text{sec}$$

$$\Downarrow$$

$$15\ \text{Hz} \longrightarrow 2 \times 10^{13}\ p/\text{cycle}$$

Proton driver design goals:

$$2.5 \times 10^{13}\ p/\text{cycle} \qquad (3 \times 10^{13})$$

$$\Downarrow$$

$$15\ \text{Hz} \longrightarrow 60\ \mu\text{A average current} \qquad (72\ \mu A)$$

$$\Downarrow$$

$$16\ \text{GeV} \longrightarrow 1\ \text{MW beam power} \qquad (1.2\ MW)$$

Table 1: Proton Driver Parameters of Present, Phase I and Phase II

	Present	Phase I (ν-factory)	Phase II ($\mu\mu$-collider)
Linac (operating at 15 Hz)			
Kinetic energy (MeV)	400	400	1000
Peak current (mA)	40	50 (60)	80
Pulse length (μs)	25	80	200
H^- per pulse	6.3×10^{12}	2.5×10^{13}	1×10^{14}
Average beam current (μA)	15	60	240
Beam power (kW)	6	24	96
Pre-booster (operating at 15 Hz)			
Extraction kinetic energy (GeV)			3
Protons per bunch			2.5×10^{13}
Number of bunches			4
Total number of protons			1×10^{14}
Normalized transverse emittance (mm-mrad)			200π
Longitudinal emittance (eV-s)			2
RF frequency (MHz)			7.5
Average beam current (μA)			240
Beam power (kW)			720
Booster (operating at 15 Hz)			
Extraction kinetic energy (GeV)	8	16	16
Protons per bunch	6×10^{10}	6.25×10^{12} (7.5×10^{12})	2.5×10^{13}
Number of bunches	84	4	4
Total number of protons	5×10^{12}	2.5×10^{13} (3×10^{13})	1×10^{14}
Normalized transverse emittance (mm-mrad)	15π	50π (60π)	200π
Longitudinal emittance (eV-s)	0.1	2	2
RF frequency (MHz)	53	1.9	7.5
Extracted bunch length σ_t (ns)	0.2	3	1
Average beam current (μA)	12	60	240
Target beam power (kW)	100	1000	4000

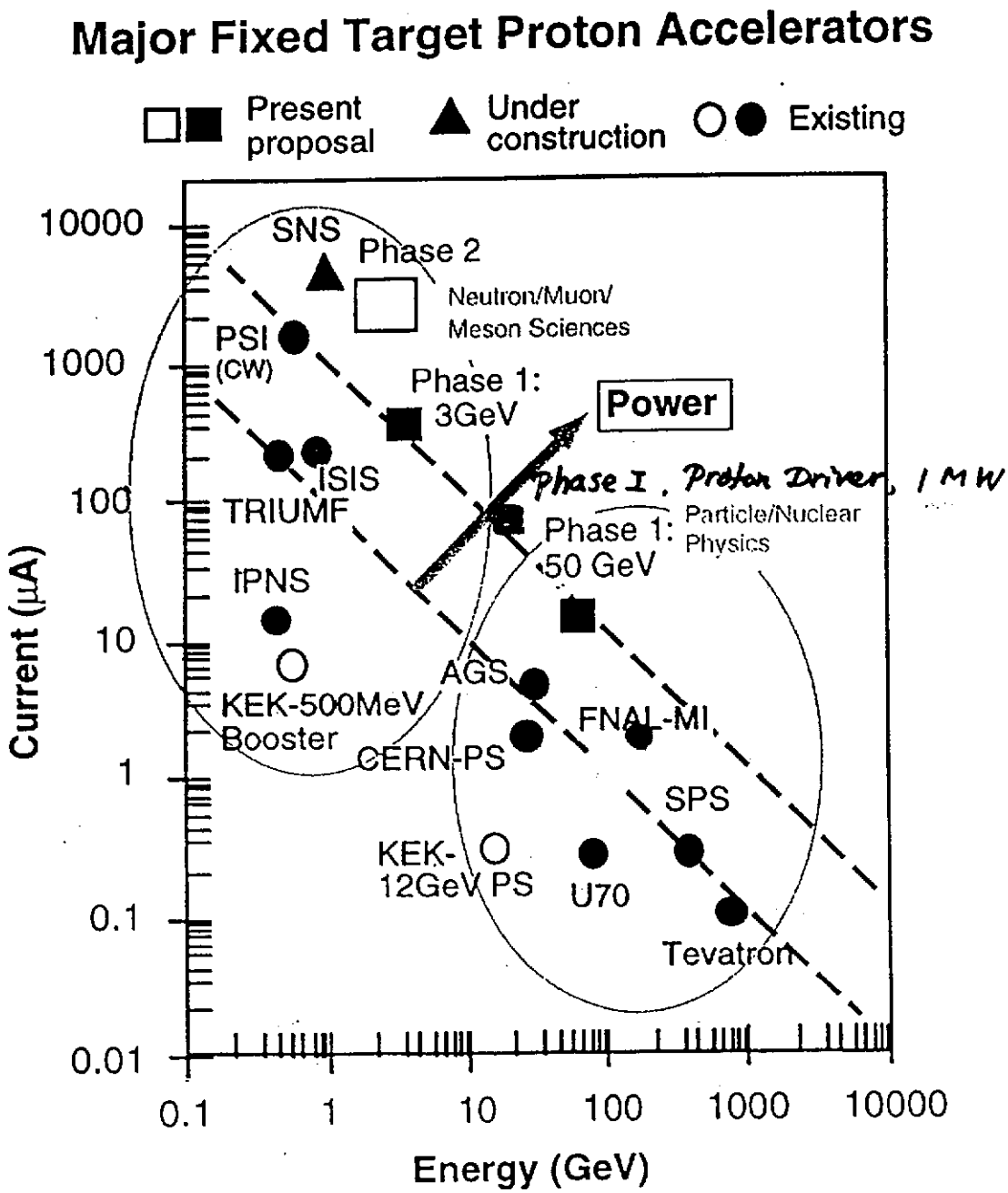


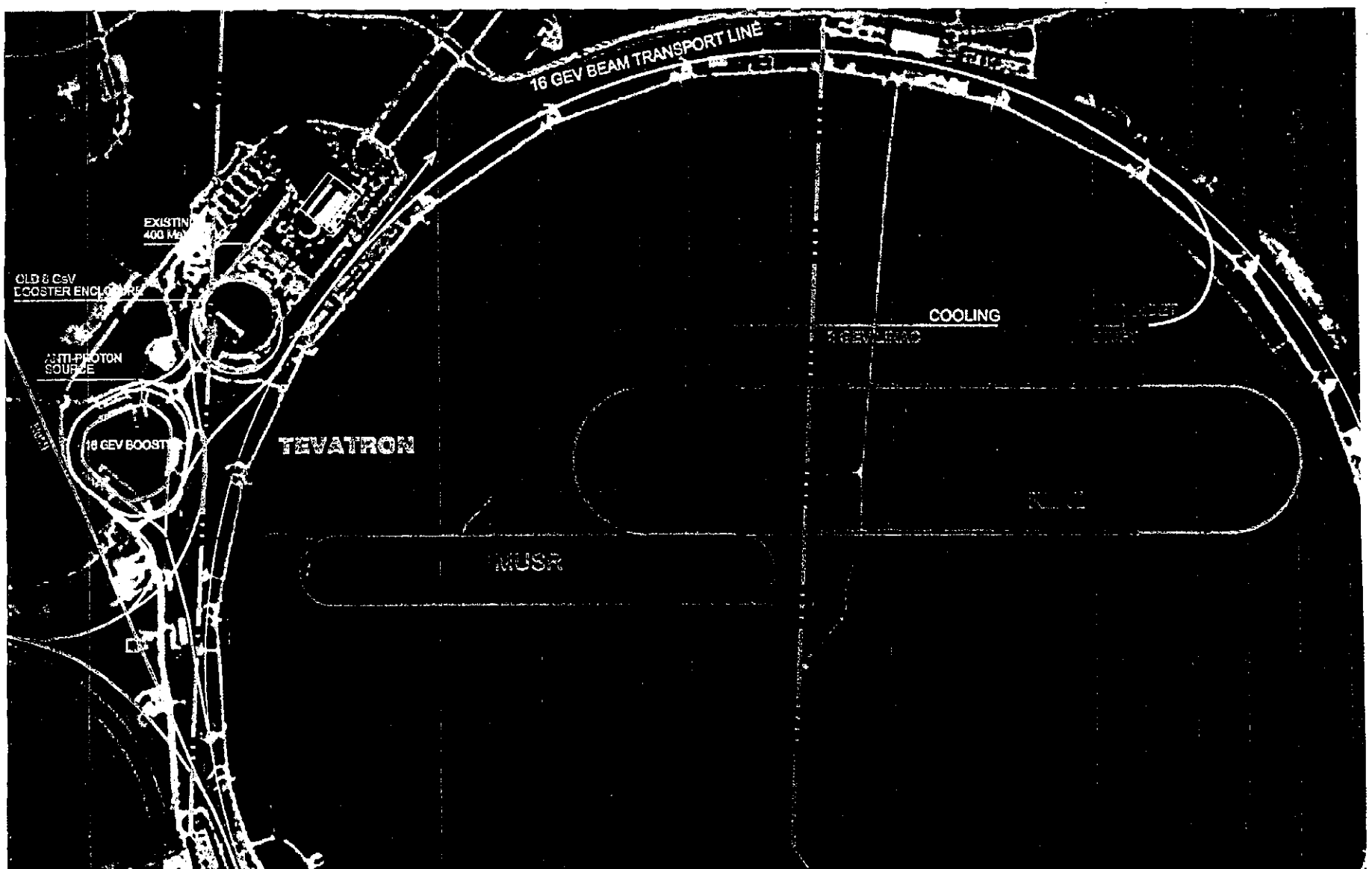
Fig. 1.4 Beam power to be achieved by the present project.

Table 1. High Beam Power Proton Machines

Machine	Protons per Cycle	Repetition Rate (Hz)	Protons per Second	Beam Energy (GeV)	Beam Power (kW)
Existing:					
RAL ISIS	2.5×10^{13}	50	1.25×10^{15}	0.8	160
BNL AGS	7×10^{13}	0.5	3.5×10^{13}	24	130 (50 kW on target)
LANL PSR	2.5×10^{13}	20	5×10^{14}	0.8	64
Planned:					
Fermilab MiniBooNE	5×10^{12}	7.5	3.8×10^{13}	8	50
Fermilab NUMI	4×10^{13}	0.5	2×10^{13}	120	400
Proton Driver	1×10^{14}	15	1.5×10^{15}	16	4000
Europe ESS	2.34×10^{14}	50	1.2×10^{16}	1.334	2500
ORNL SNS	2×10^{14}	60	1.2×10^{16}	1	2000
Japan JHF	3.2×10^{14}	0.3	1×10^{14}	50	780
CERN Proton Driver				2	4000

Phase I for ν-Fact. 1000 kW

NEUTRINO FACTORY



FESS - ENGINEERING - 1-25-00 J. SIMS

Proton Driver Sub-System Parameters (as of Jan 25, 2000)

1. H^- source and linac:

   - High brightness H^- source: 115 mA, 80 μs, 15 Hz, 0.5-1.0 π mm-mrad
   - RFQ: 100 mA, 60 keV – 2.235 MeV, 201.25 MHz
   - Modified Tank 1: 100 mA, 2.235 – 10 MeV, 1.4 π mm-mrad
   - 400 MeV linac upgrade: 80-100 mA, 80 μs, 1.5-2.0 π mm-mrad

2. Chopper:

   - 2 MHz, $\pm$4 kV, rise- and fall-time $<$ 30 ns, physical length 15 cm

3. 16 GeV ring lattice

   - No transition crossing
   - Acceptance $>$ 50 π mm-mrad, momentum aperture = $\pm$2.5%
   - Triangular shape with 3 zero-dispersion straights, C $\sim$ 700 m

4. RF

   - 2 MHz, 1.2 MV, 20 MW
   - Finemet-loaded cavity with cut core, copper disc cooling

5. Magnets

   - Dipole: total 54, 2 types, 1.5 T, gap 5" $\times$ 13", E = 8.9 MJ
   - Quad: total 102, 3 types, 8.9 T/m, Accumulator LQA design, E = 2.7 MJ

6. Power supplies

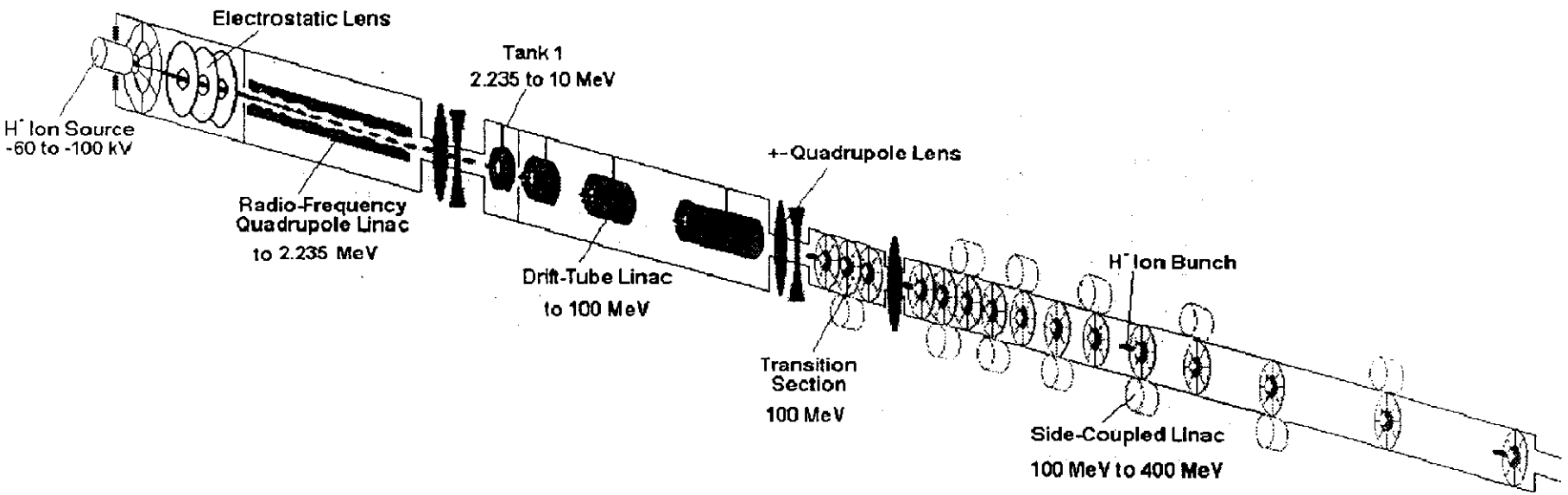
   - Resonant circuit at 15 Hz, with 12.5% 30 Hz component
   - 27 cells, 14.7 mH/cell, 7500 A, voltage-to-ground 3 kV
   - Trim coil power supply for tracking error correction

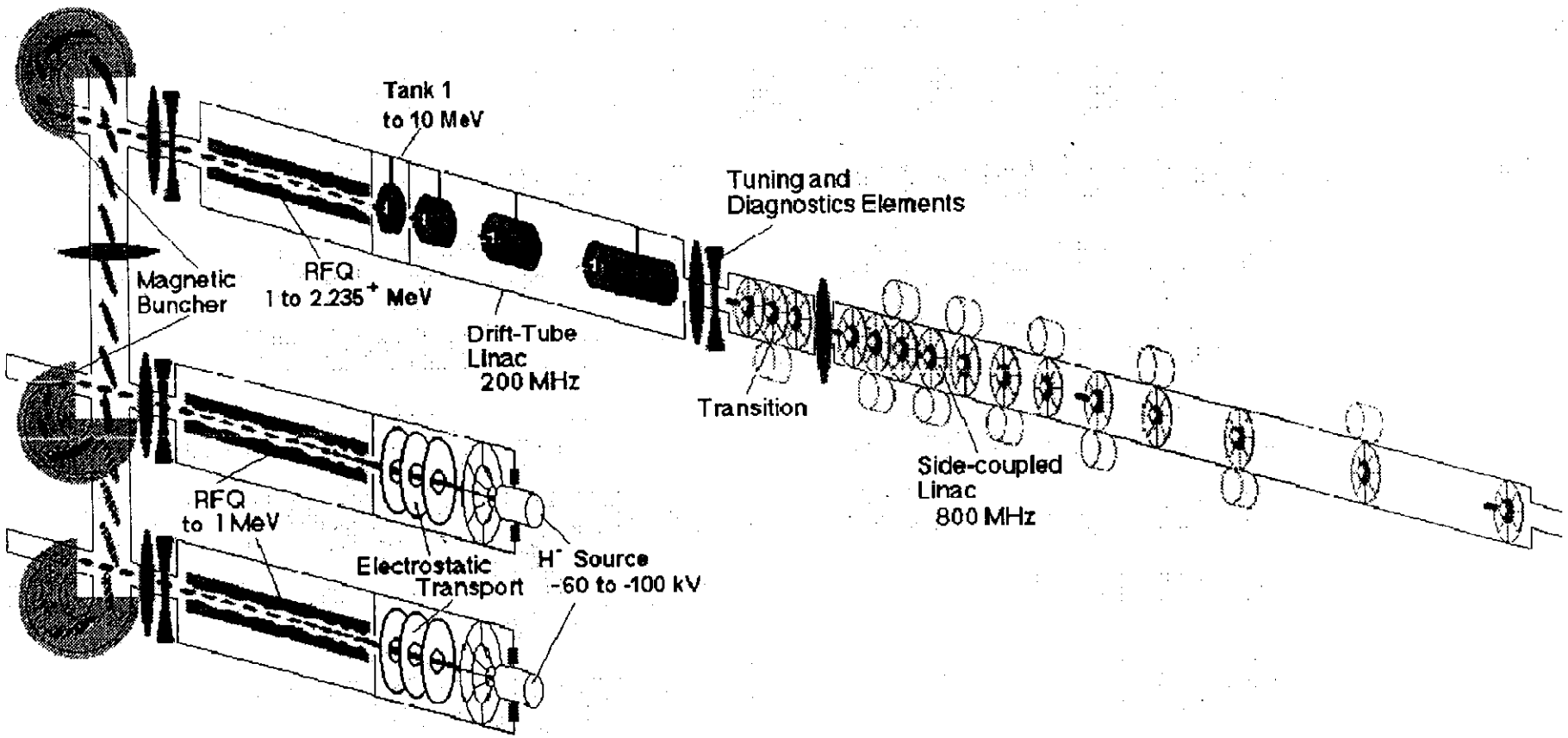
7. Vacuum pipe

   - Thin metallic pipe, 5" $\times$ 9", eddy current heat $\sim$ 8 kW/m

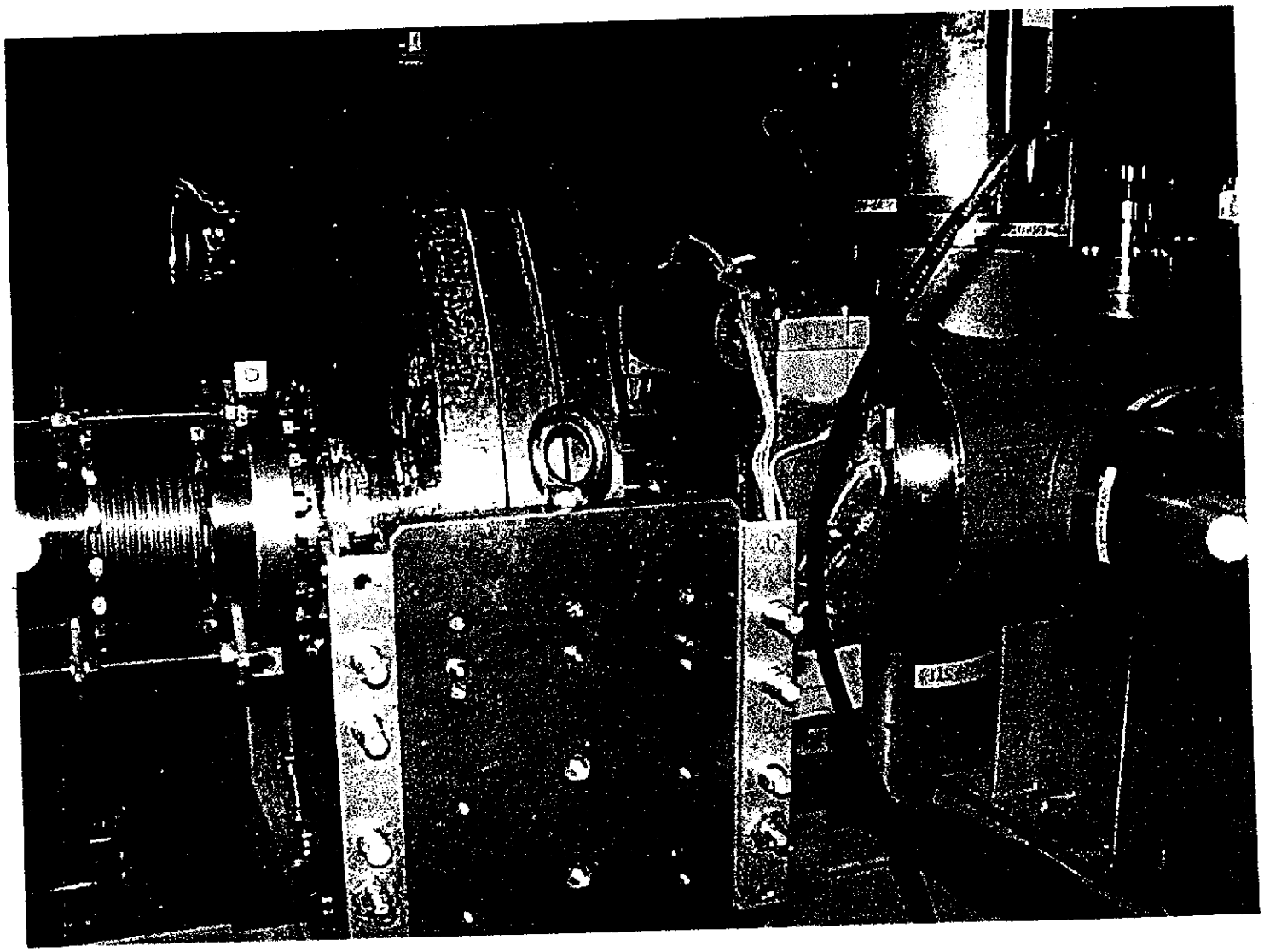
8. Collimators

   - 2-stage system, embedded in the injection straight
   - Designed for 10% loss at injection, 1% loss at top, efficiency $>$ 99%
   - Allowable loss in "quiet area" for hands-on maintenance: a few W/m


Electrostatic Lens
Tank 1
2.235 to 10 MeV
H⁻ Ion Source
-60 to -100 kV
+-Quadrupole Lens
Radio-Frequency
Quadrupole Linac
to 2.235 MeV
Drift-Tube Linac
to 100 MeV
H⁻ Ion Bunch
Transition
Section
100 MeV
Side-Coupled Linac
100 MeV to 400 MeV

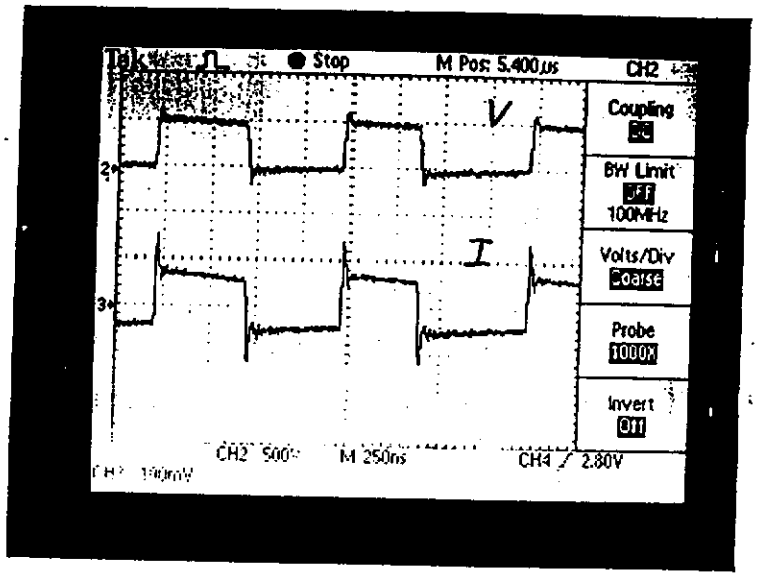

Tank 1
to 10 MeV
Tuning and
Diagnostics Elements
Magnetic
Buncher
RFQ
1 to 2.235+ MeV
Drift-Tube
Linac
200 MHz
Transition
Side-coupled
Linac
800 MHz
RFQ
to 1 MeV
Electrostatic
Transport
H- Source
-60 to -100 kV

Chopper installed
on the HIMAC linac

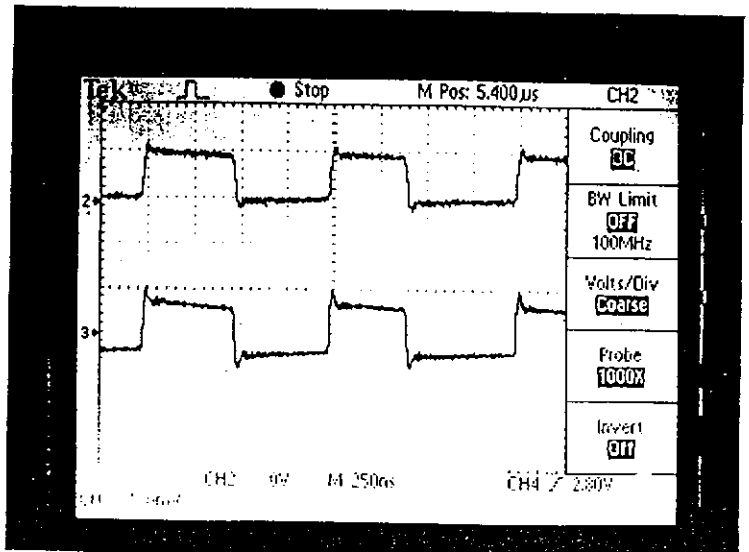


Dummy Load
(220 Ω)

$R_s = 5\,\Omega$
no snubber



$R_s = 10\,\Omega$
no snubber
$V_{pp} = 500\,V$
$I_0 = 3.5\,A$

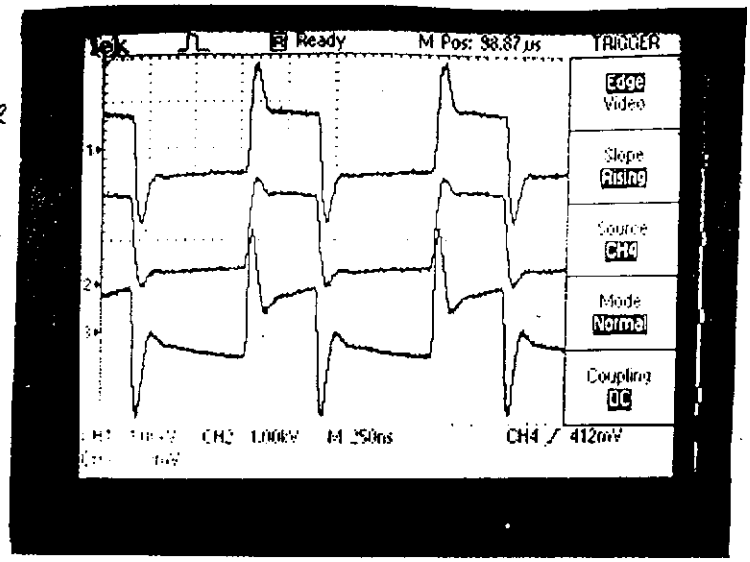


1.8 KV

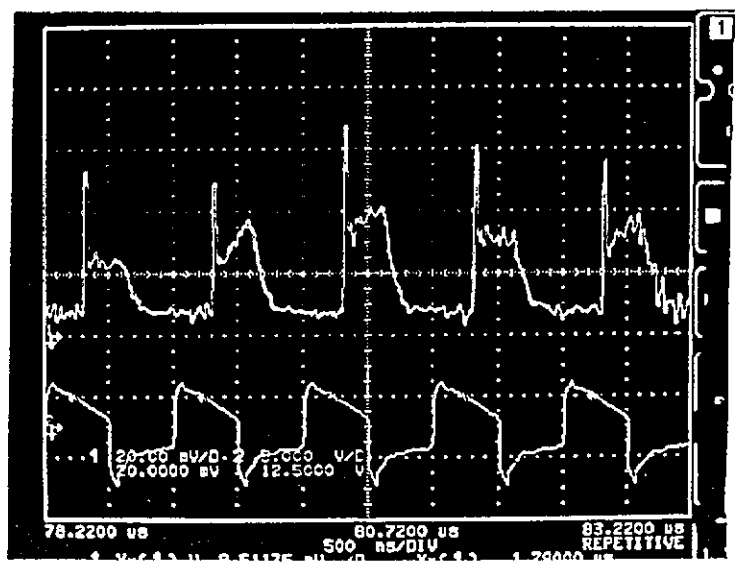
gap voltage

primary voltage

current

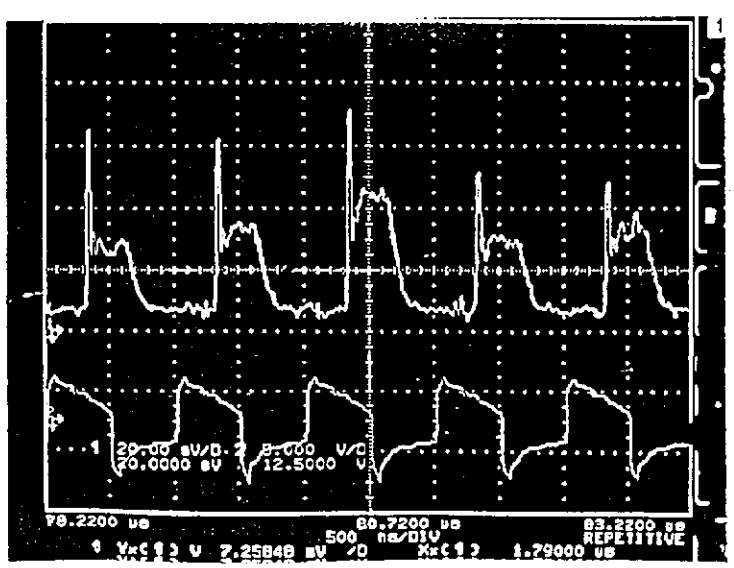


-5%

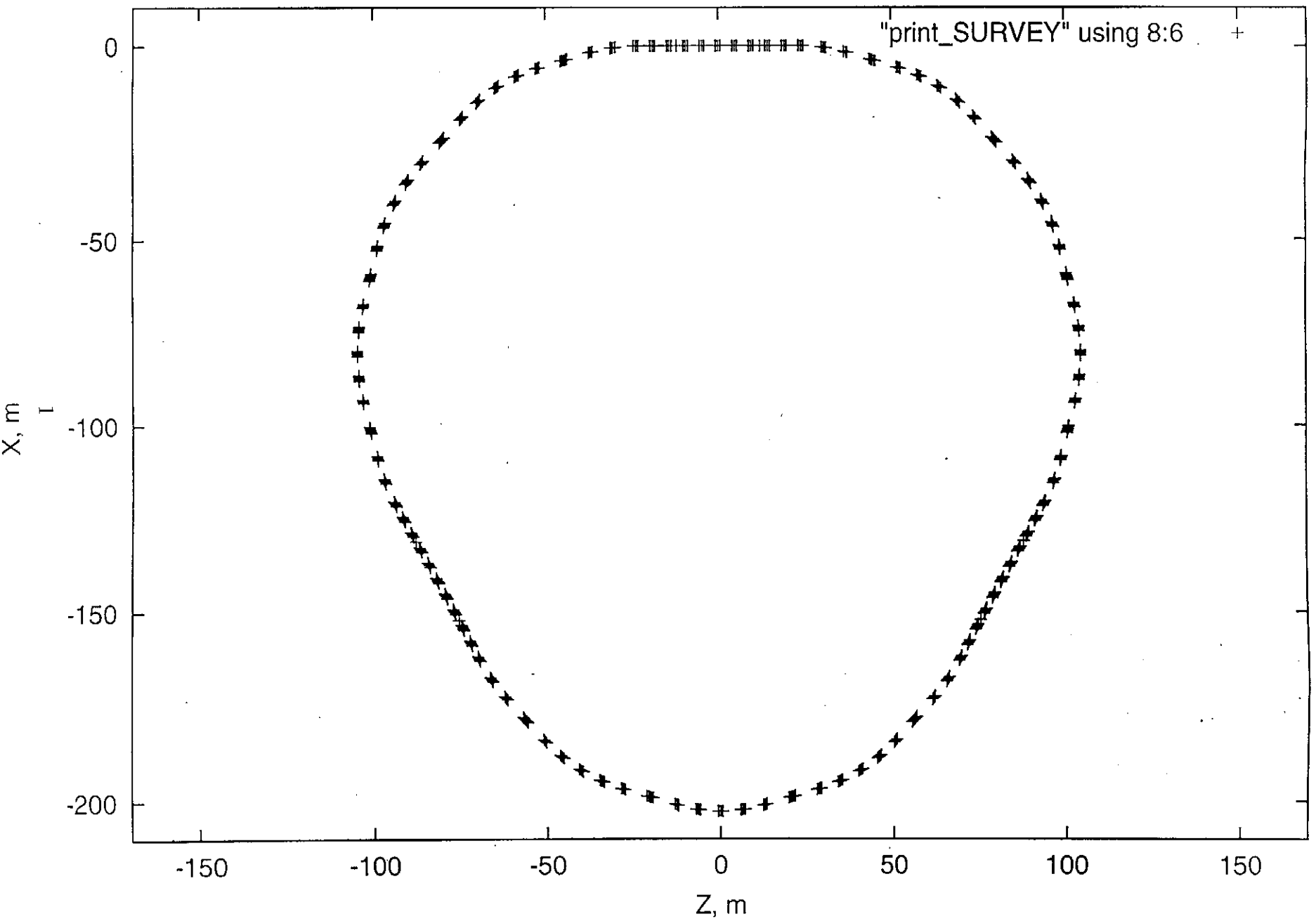


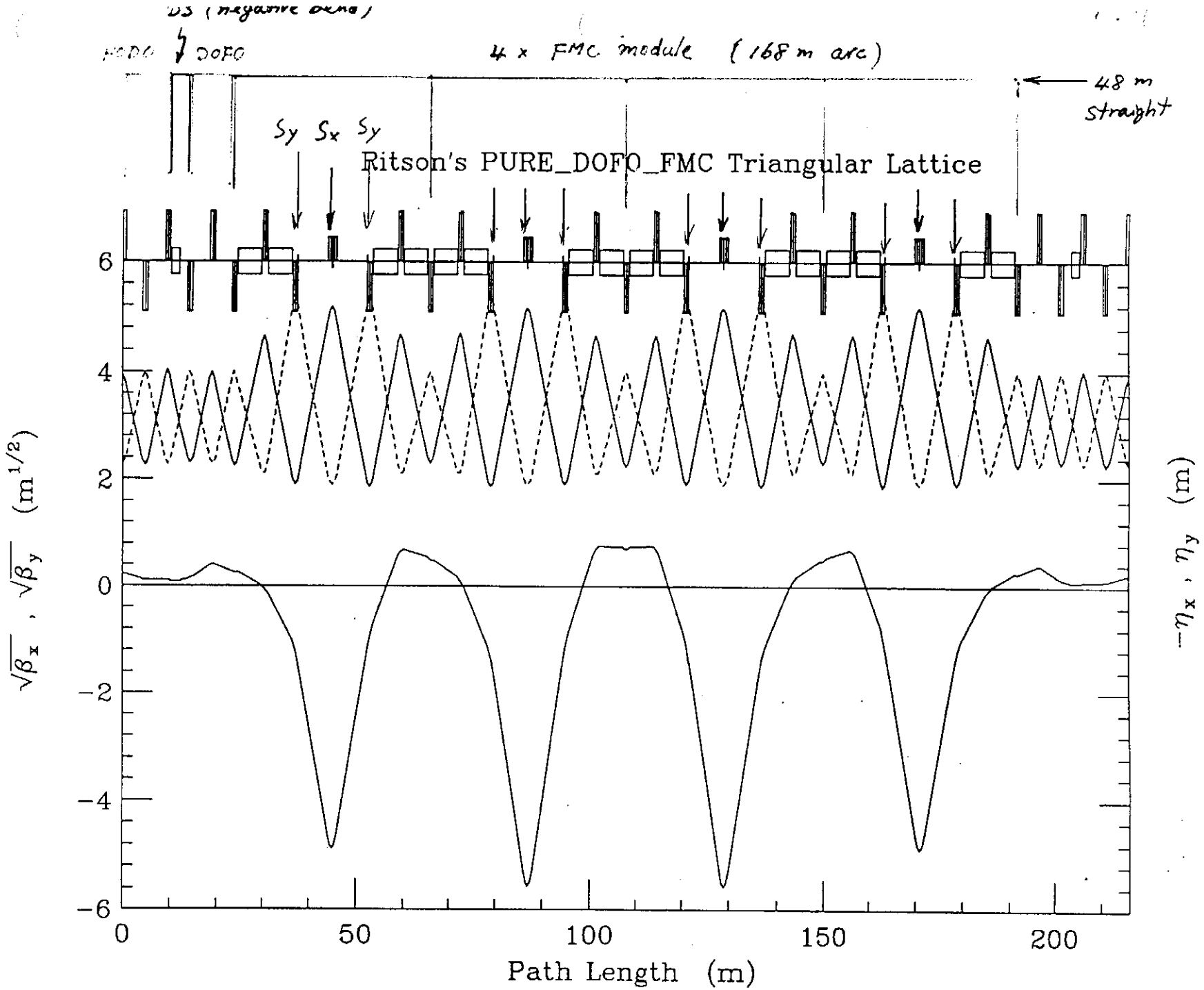
chopped beam

-6%



D. Ritson / A. Ozhedin




DS (negative bend)
DOFO
4 x FMC module (168 m arc)
48 m straight
Sy Sx Sy
Ritson's PURE_DOFO_FMC Triangular Lattice
6
4
2
0
−2
−4
−6
0
50
100
150
200
Path Length (m)
$\sqrt{\beta_x}$, $\sqrt{\beta_y}$ $(m^{1/2})$
$-\eta_x$, η_y (m)

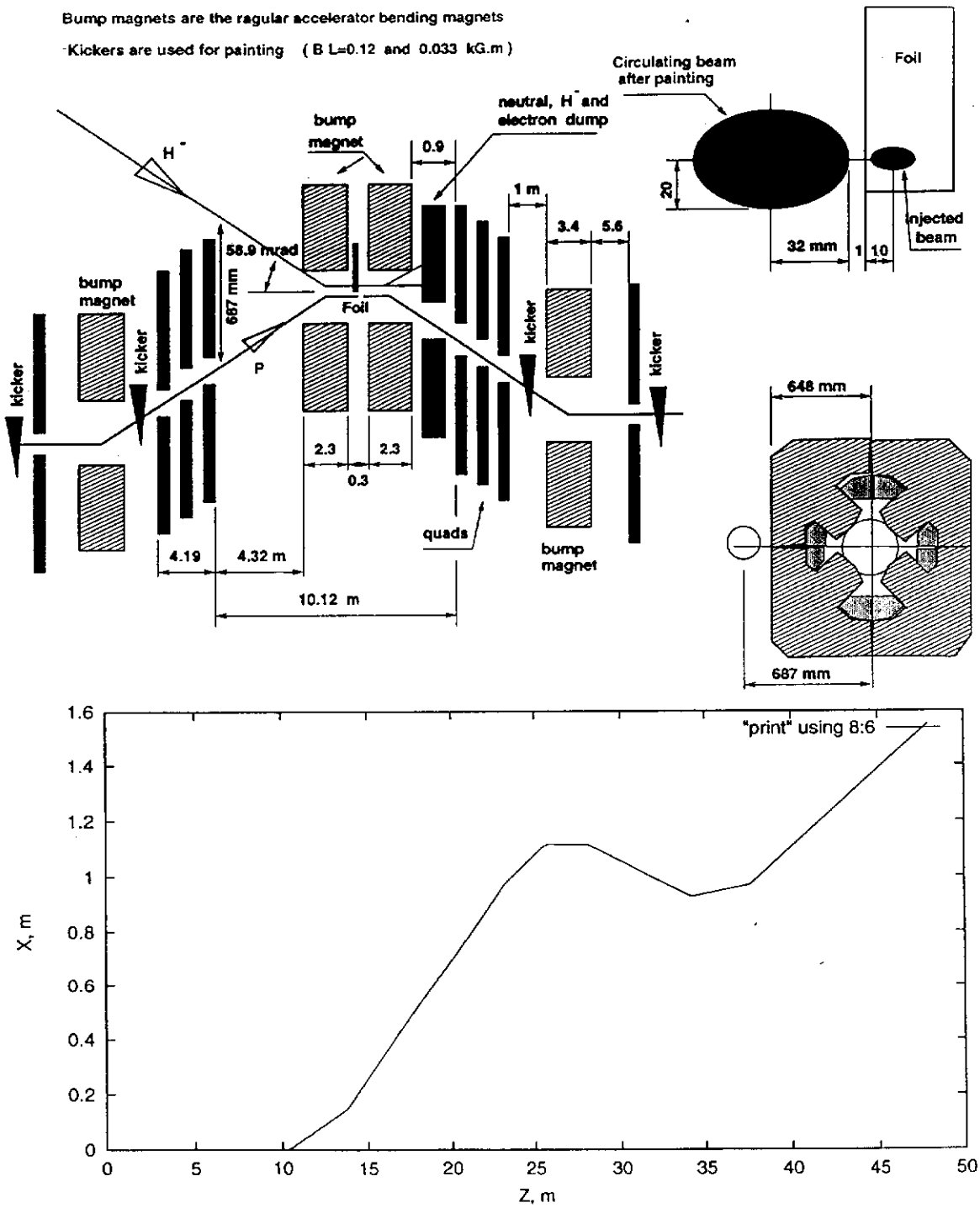


Figure 9: Beam painting scheme (top) and straight section geometry (bottom). Second version.

16 GeV Proton Driver Beam Injection and Extraction

A. Drozhdin

February 14, 2000

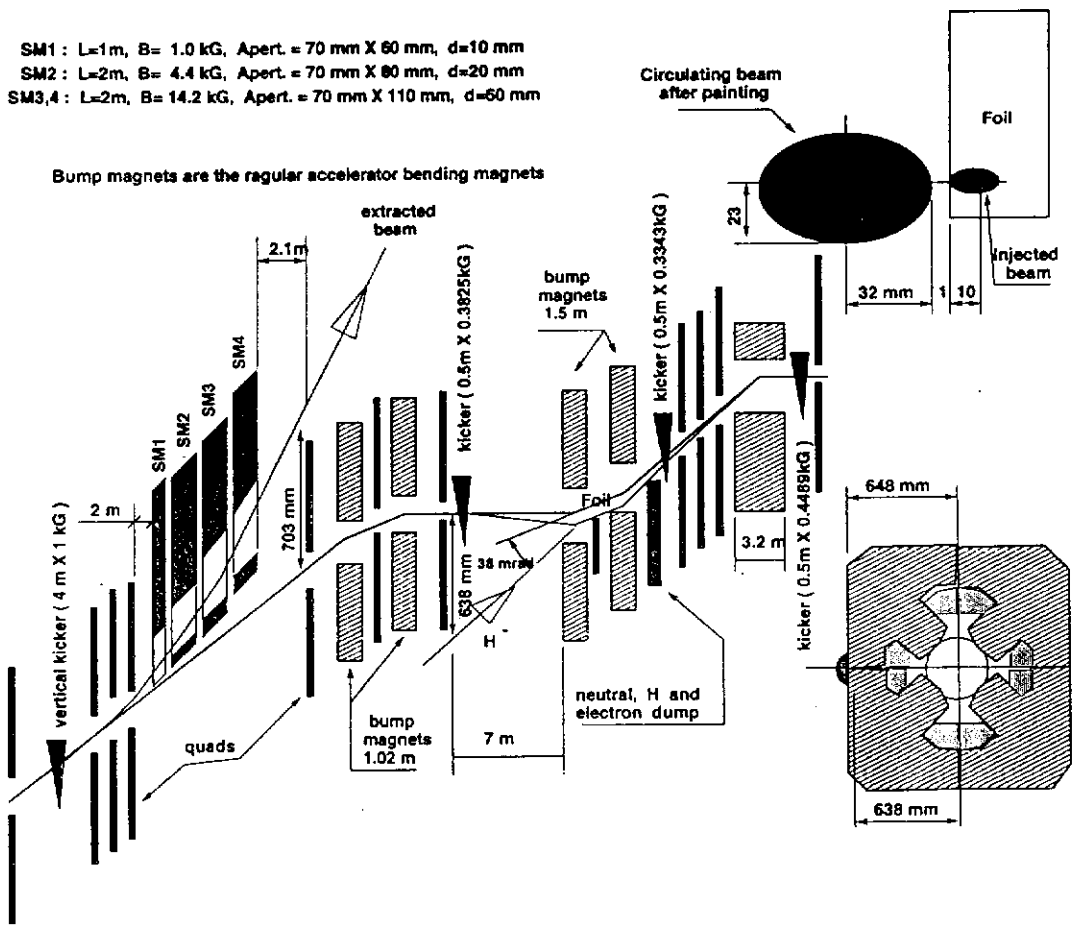
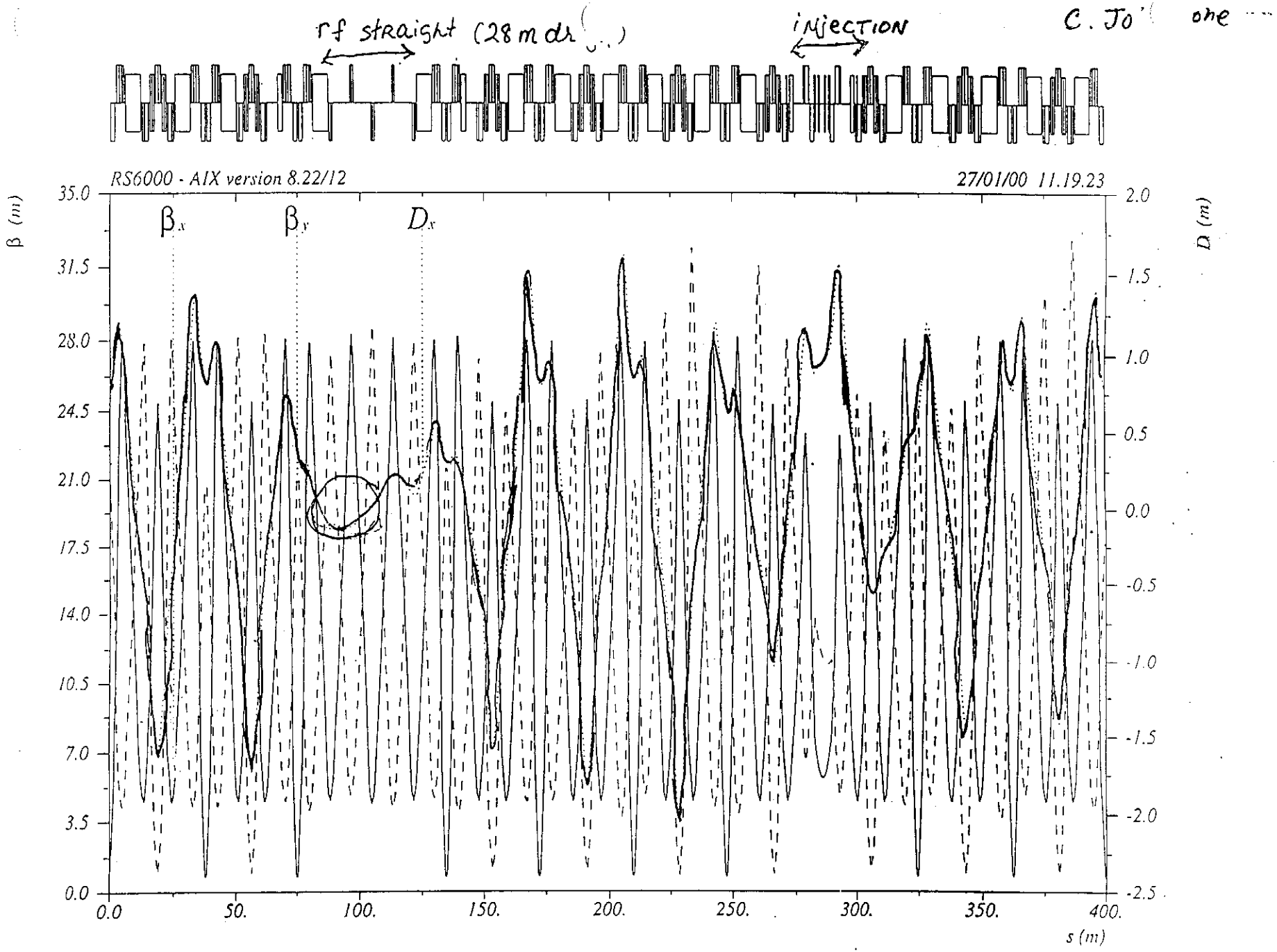


Figure 1: Beam extraction and beam painting schemes.

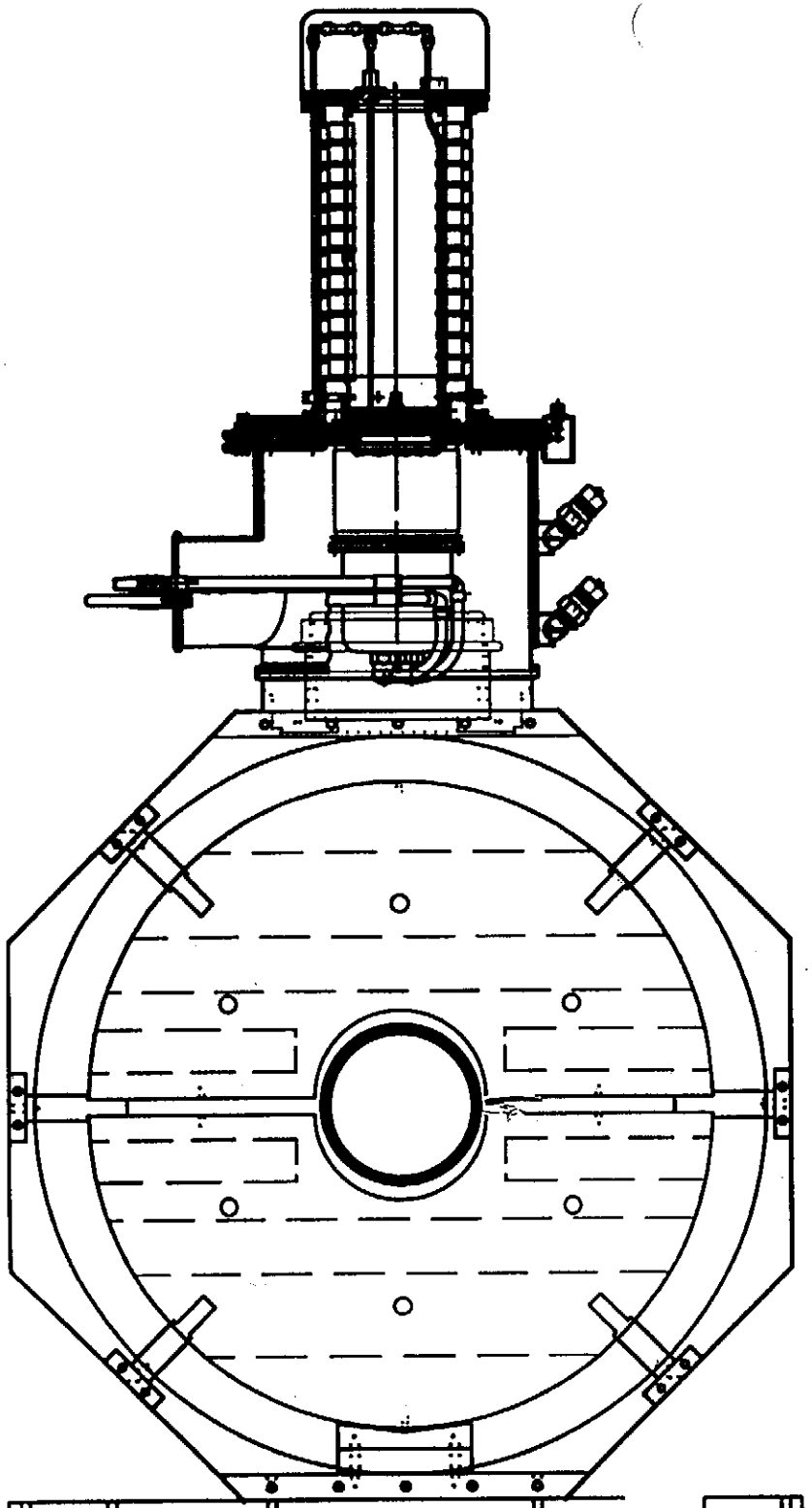


$\delta p/p_{nc}$ = 0.

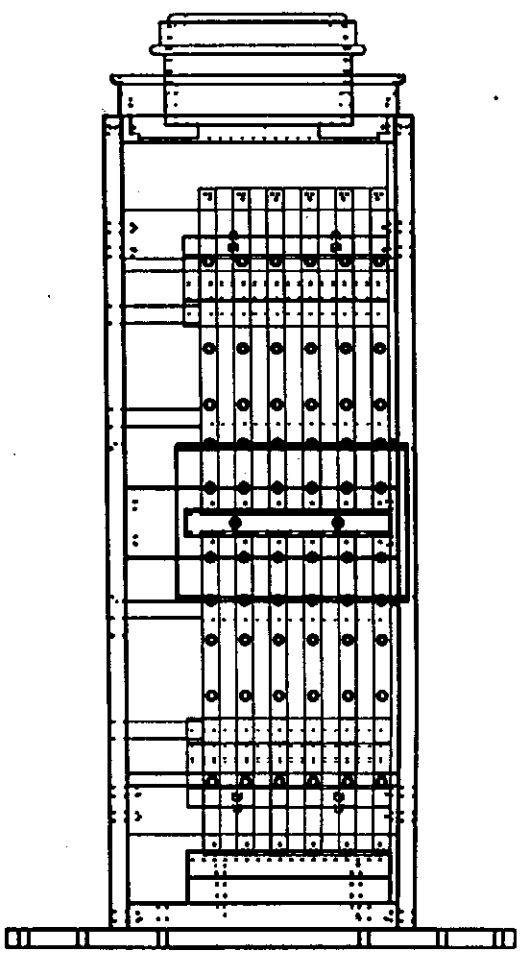
Table name = TWISS

Half Ring (PERIODICITY OF 2)

[Small Dispersion Wave due to adjustment of dipoles to close ring after matching.



D. WILDMAN and J. DEY
September 16, 1999



$B_{max} = 1.5\ T$ (16 GeV)

$B_{min} = 0.0846\ T$ (400 MeV)

$I_{peak} = 152\ KA$

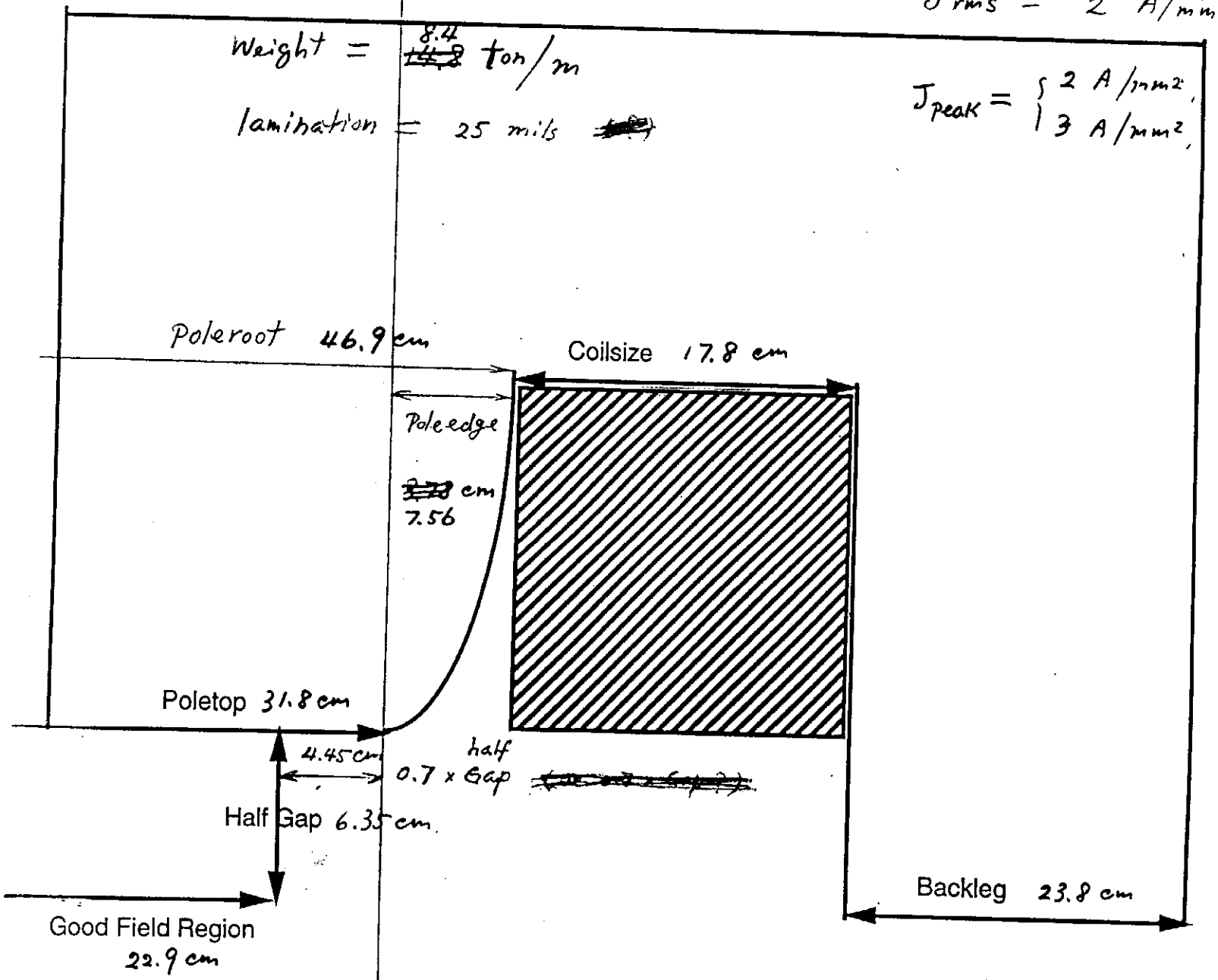
$I_{rms} = 127\ KA$

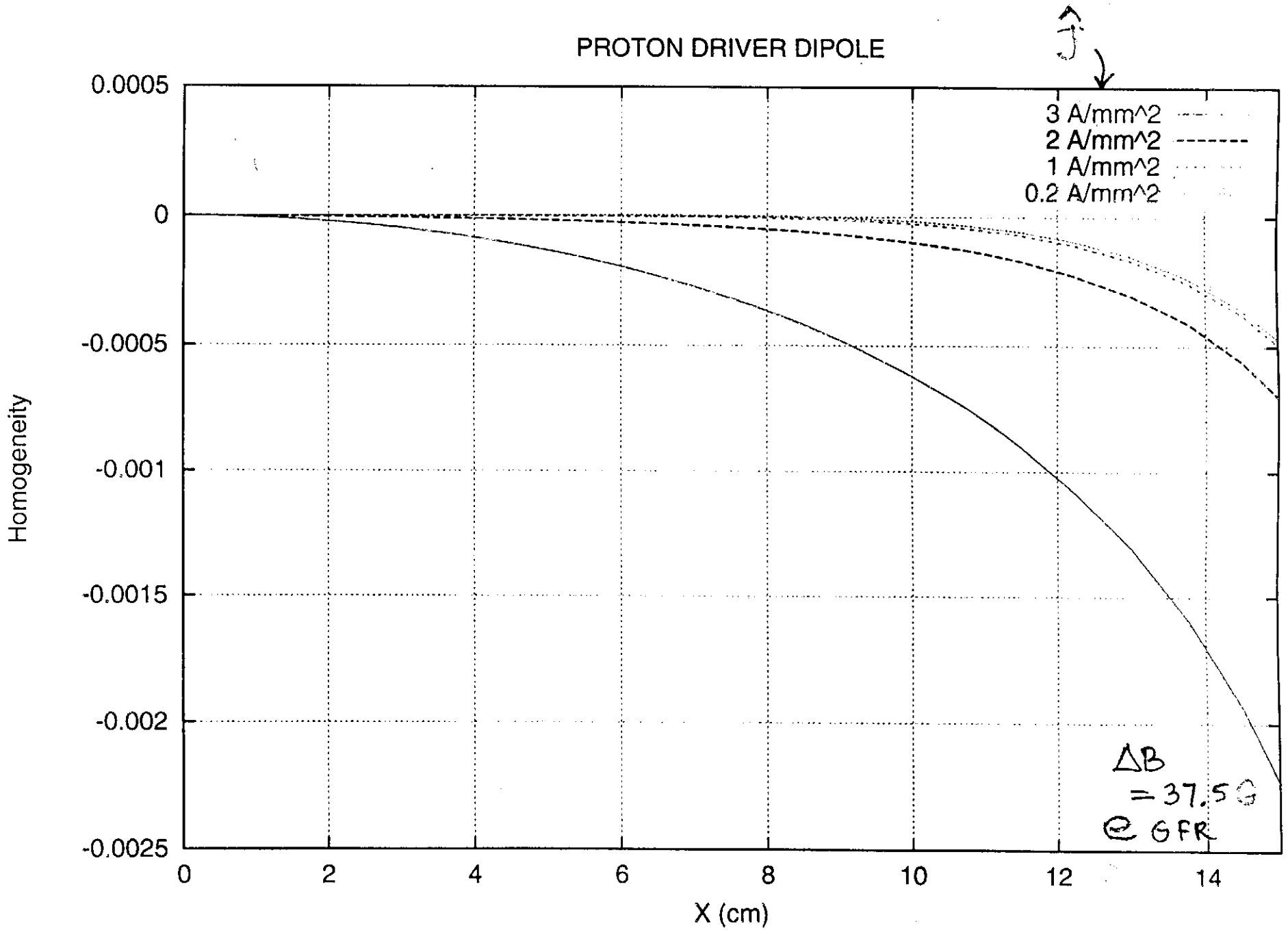
$J_{rms} = 2\ A/mm^2$

Weight = ~~14.8~~ 8.4 ton/m

lamination = 25 mils

$J_{peak} = \begin{cases} 2\ A/mm^2, & B = 1.17\ T \\ 3\ A/mm^2, & B = 1.54\ T \end{cases}$




PROTON DRIVER DIPOLE
$\hat{j}$
3 A/mm^2
2 A/mm^2
1 A/mm^2
0.2 A/mm^2
0.0005
0
-0.0005
-0.001
-0.0015
-0.002
-0.0025
Homogeneity
0
2
4
6
8
10
12
14
X (cm)
ΔB
= 37.5 G
@ GFR

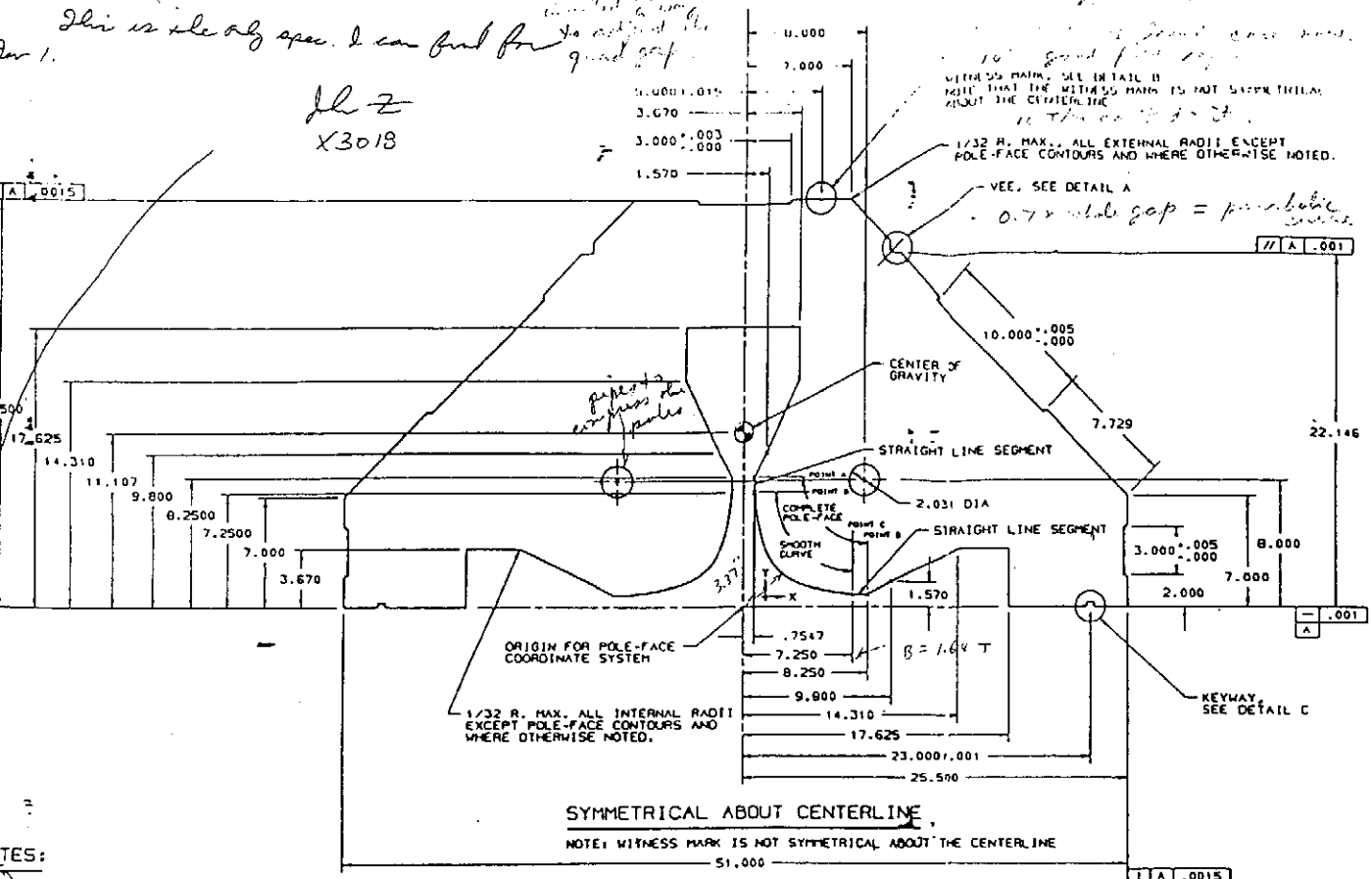
Jack Jaffe

LGB

accumulator

This is the only spec. I can find for

X3018



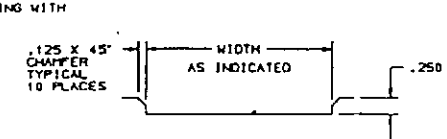
SYMMETRICAL ABOUT CENTERLINE

NOTE: WITNESS MARK IS NOT SYMMETRICAL ABOUT THE CENTERLINE

TES:

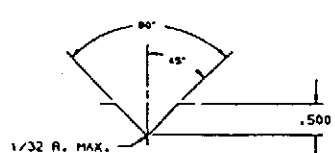
1. STEEL DESCRIPTION: COMMERCIAL QUALITY 1008 COLD ROLLED DRAWING QUALITY ASTMA 619-75 CLASS 1, 16 GUAGE .0598 ± .005" (AISI STANDARD) THICKNESS. MASTER COIL CROWN SHALL BE .003" OR LESS OVER THE FULL WIDTH BEFORE SLITTING. THIS STEEL SHALL HAVE AN IRON PHOSPHATE COATING WITH WITH A COATING WEIGHT BETWEEN 30-60 MG. PER SQUARE FT.
2. HARDNESS: HARDNESS WILL BE MEASURED ON THE ROCKWELL B SCALE. A MINIMUM OF 20 AND A MAXIMUM OF 45 WILL BE SET AS REJECTION LEVELS.
3. TEST SPECIMENS: VENDOR SHALL PROVIDE FERMILAB WITH SAMPLES FOR EPSTEIN TESTS, CONSISTING OF 20 PARALLEL AND 20 TRANSVERSE STRIPS 1.181" X 12" AS SHEARED. THESE SAMPLES WILL BE LABELLED WITH THE HEAT AND COIL NUMBERS APPLIED TO EACH STOCK CARD. THESE SAMPLES WILL BE DISTRIBUTED THROUGHOUT THE HEAT.
4. THE LAMINATIONS, AND THE STEEL BEFORE STAMPING, MUST BE HANDLED CAREFULLY SO AS NOT TO CAUSE DAMAGE BY BENDING, OR SCRATCHING.
5. EDGE BURR SHALL NOT EXCEED .003
6. VARIATION BETWEEN PARTS SHALL NOT EXCEED ±.0005
7. PIECE PART SHALL BE FLAT WITHIN .250 (B)
8. USE TABLE TO LOCATE POINTS FOR POLE-FACE SURFACES. SURFACES SHALL BE SMOOTH CURVES WHERE INDICATED.

LAMINATION PERIMETER: 192.26 INCHES
LAMINATION AREA: 801.01 SQUARE INCHES



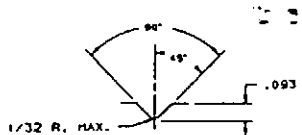
TYPICAL RECTANGULAR NOTCH

FULL SIZE



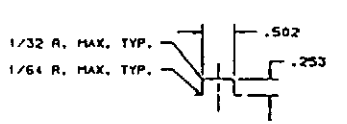
TYPICAL VEE NOTCH

DETAIL A FULL SIZE



WITNESS MARK

DETAIL B 3X SCALE



TYPICAL KEYWAY

DETAIL C FULL SIZE

COORDINATES FOR 1/2 OF THE LAMINATION

X	Y	
0.0000	25.5000	
0.0000	17.6250	
3.6700	17.6250	
3.6700	14.3100	
1.5700	9.8000	
.7547	8.2500	POINT A
.7547	7.2500	POINT B
.7680	7.1250	
.7818	7.0000	
.7960	6.8750	
.8108	6.7500	
.8261	6.6250	
.8421	6.5000	
.8586	6.3750	
.8778	6.2500	
.8957	6.1250	
.9144	6.0000	
.9338	5.8750	
.9541	5.7500	
.9754	5.6250	
.9975	5.5000	
1.0207	5.3750	
1.0450	5.2500	
1.0705	5.1250	
1.0973	5.0000	
1.1254	4.8750	
1.1550	4.7500	
1.1862	4.6250	
1.2192	4.5000	
1.2540	4.3750	
1.2909	4.2500	
1.3300	4.1250	
1.3716	4.0000	
1.4158	3.8750	
1.4630	3.7500	
1.5135	3.6250	
1.5675	3.5000	
1.6256	3.3750	
1.6881	3.2500	
1.7556	3.1250	
1.8288	3.0000	
1.9083	2.8750	
1.9950	2.7500	
2.0900	2.6250	
2.1945	2.5000	
2.3100	2.3750	
2.3423	2.3423	
2.3750	2.3100	
2.5000	2.1945	
2.6250	2.0900	
2.7500	1.9950	
2.8750	1.9083	
3.0000	1.8288	
3.1250	1.7556	
3.2500	1.6881	
3.3750	1.6256	
3.5000	1.5675	
3.6250	1.5135	
3.7500	1.4630	
3.8750	1.4158	
4.0000	1.3716	
4.1250	1.3300	
4.2500	1.2909	
4.3750	1.2540	
4.5000	1.2192	
4.6250	1.1862	
4.7500	1.1550	
4.8750	1.1254	
5.0000	1.0973	
5.1250	1.0705	
5.2500	1.0450	
5.3750	1.0207	
5.5000	.9975	
5.6250	.9754	
5.7500	.9541	
5.8750	.9338	
6.0000	.9144	
6.1250	.8957	
6.2500	.8778	
6.3750	.8586	
6.5000	.8421	
6.6250	.8261	
6.7500	.8108	
6.8750	.7960	
7.0000	.7818	
7.1250	.7680	
7.2500	.7547	POINT C
8.2500	.7547	POINT D
9.8000	1.5700	
14.3100	3.6700	
17.6250	3.6700	
17.6250	0.0000	
25.5000	0.0000	
25.5000	7.0000	
7.0000	25.5000	
0.0000	25.5000	

A	[illegible]	[illegible]
B	[illegible]	[illegible]

NOTIONAL COORDINATES DESCRIBE THE REST OF THE LAMINATION, BUT NOT THE NOTCHES OR KEYWAY.

60 mil. lami. (dc)

COORDINATES FOR COMPLETE POLE-FACE

TOL. ±.001

SEE NOTE 8.0

ITEM	PART NO.	DESCRIPTION OR SIZE

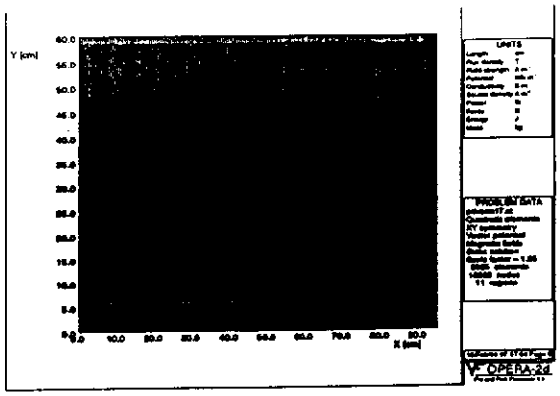
PARTS LIST

UNLESS OTHERWISE SPECIFIED	ORIGINATOR	J. HEIM 1/1
FRACTIONS DECIMALS ANGLES	DRAWN	J. R. BISHOP 10/
± 1/64 ± .002 ± 1°	CHECKED	S. C. SHOWDEN
1. BREAK ALL SHARP EDGES 1/32 MAX.	APPROVED	F. C. MILLS 1/1
2. DO NOT SCALE DRAWING.	USED ON	
3. DIM. TO BE AVG VALUE		
4. MAX. DIA. PARAL. SURFACES	MATERIAL	SEE NOTES

FERMI NATIONAL ACCELERATOR LABORATOR
UNITED STATES DEPARTMENT OF ENERGY

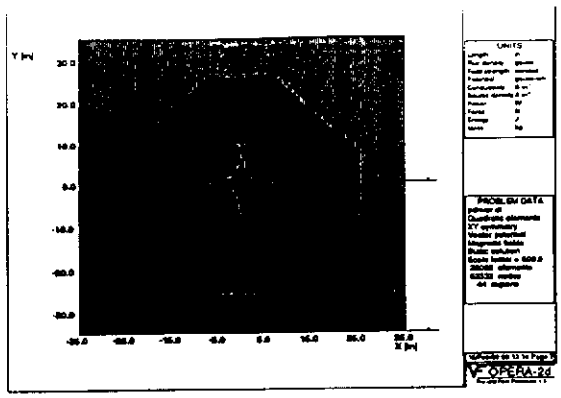
TEVATRON I LARGE APERTURE QUAD LAMINATION

SCALE	FILENAME	DRAWING NUMBER
1/4		8020-MD-176020



PROTON DRIVER DIPOLE CONCEPT

Bmax (16 Gev)	1.5188	T
Bmin (400 MeV)	0.0846	T
Gap	12.7	cm
Physical Aperture(H)	31.8	cm
Good Field Region	22.9	cm
Length	1.81/5.1128	m
Excitation	2.0	A-turns
No of turns	TBD	
J (RMS)	2.0	A/mm^2
Inductance	$0.0195 \times N^2$	mH/m
Steel (SiFe)	M17	
Lamination thickness	0.025	in
Volume	3.21	m^3
Weight	25.3	Tons

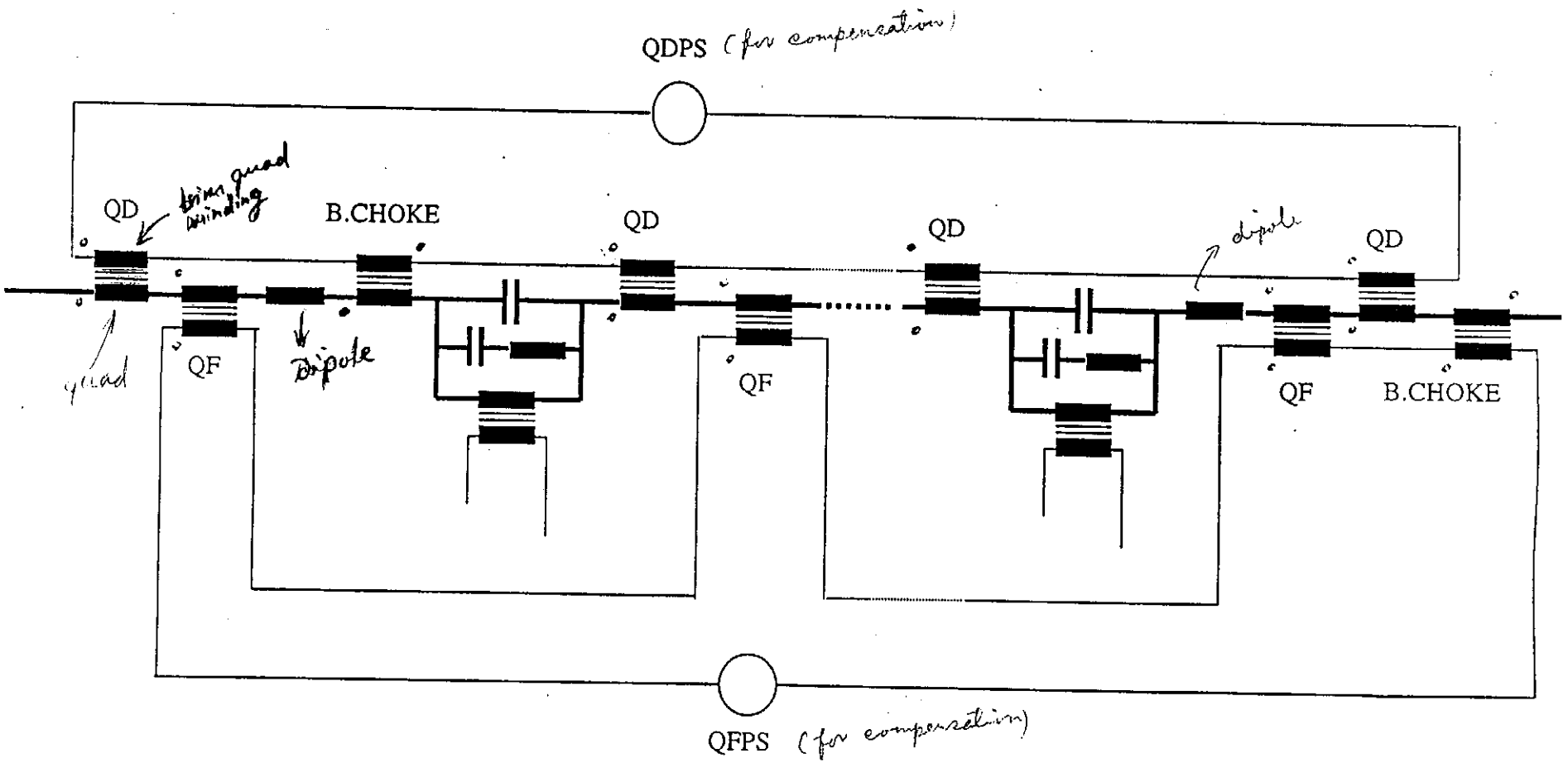


PROTON DRIVER QUADRUPOLE CONCEPT

Gradient	8.9000	T/m
Max Physical Aperture (H/V)	8.250	in
Pole Tip Radius	2.3423	in
Length	1.349/1.343/1.492	m
Steel (SiFe)	M17	
Lamination thickness	0.025	in
Excitation	25650	A-Turn/pole
J (RMS)	7.8	A/mm^2
No of turns	TBD	
Inductance	$0.0152 \times N^2$	mH/m

(I)

Quadrupole Correction Diagram (Saturation and Tuning) – 1/3 of the Ring



PROTON DRIVER 16 GEV RING POWER SUPPLIES

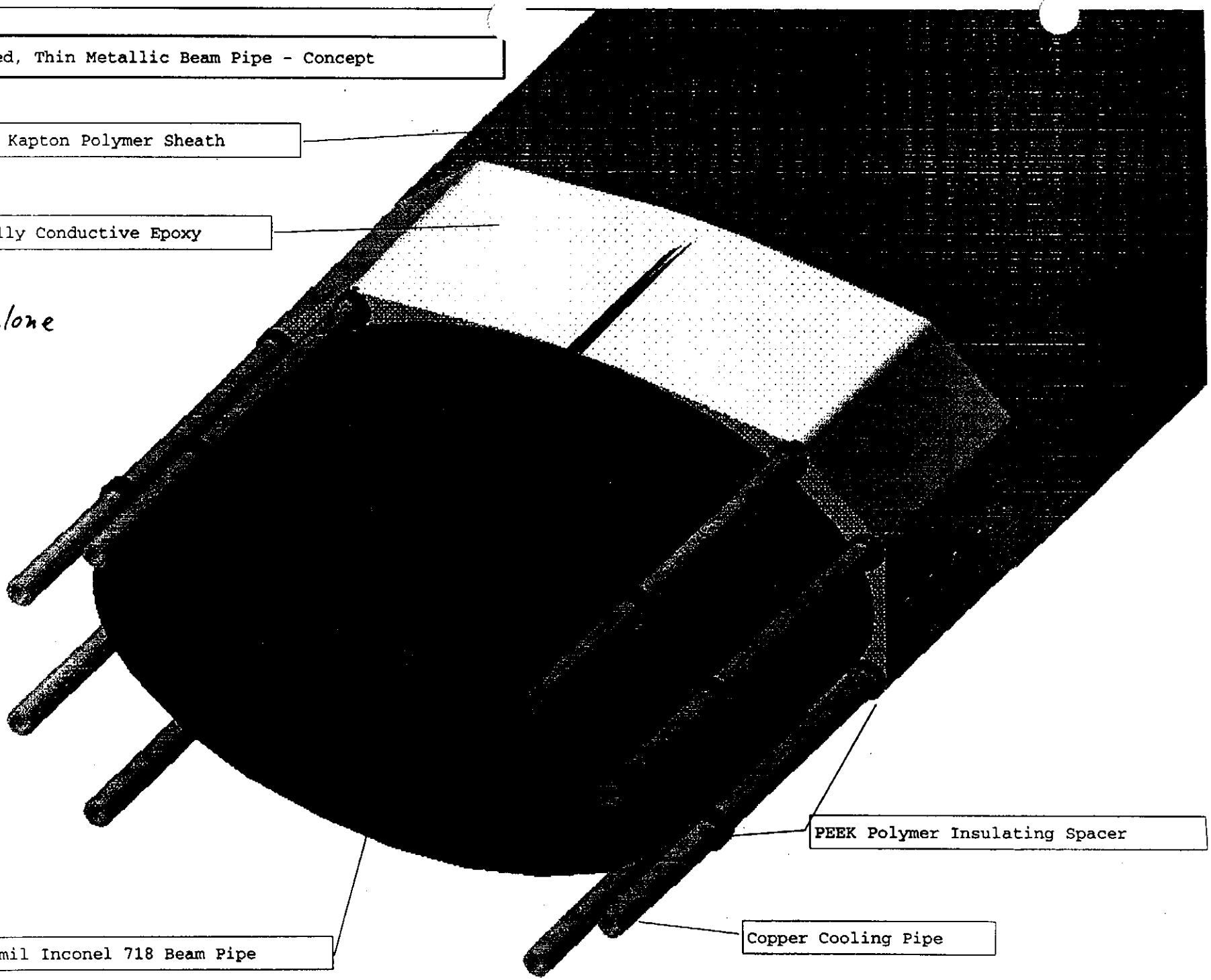
Main dipole and quadrupole power supply system:

Magnet Current	
- peak	7,500 A
- dc component	3,960 A
- ac component, 15 Hz, peak	3,540 A
- ac component, 30 Hz, peak	440 A
Number of resonant cells	27
Equivalent cell magnet inductance	14.7 mH
Cell choke inductance	18.6 mH
Cell cap bank capacitance	8.6 mF
Trap choke inductance	14.8 mH
Trap cap bank capacitance	3.0 mF
Magnet peak stored energy, total	11.2 MJ
Voltage to ground, peak	3,100 V
Resonant circuit loss, total	14 MW
DC bus loss	0.5 MW
Beam pipe loss	1.5 MW
Total loss	16 MW
Power supply rating	30 MVA

2. Quadrupole (D&F) tracking and correction system:

Dipole-Quad tracking error, max	1.5%
Tune shift correction, max	+/- 2%
Quadrupole main/trim turns ratio	4:1
Bucking choke peak stored energy	73.3 kJ
Number of bucking chokes	6
Bucking choke main/trim turns ratio	47:32
Power supply minimum bandwith	210 Hz
Power supply rating	400 kVA
Number of power supplies	6

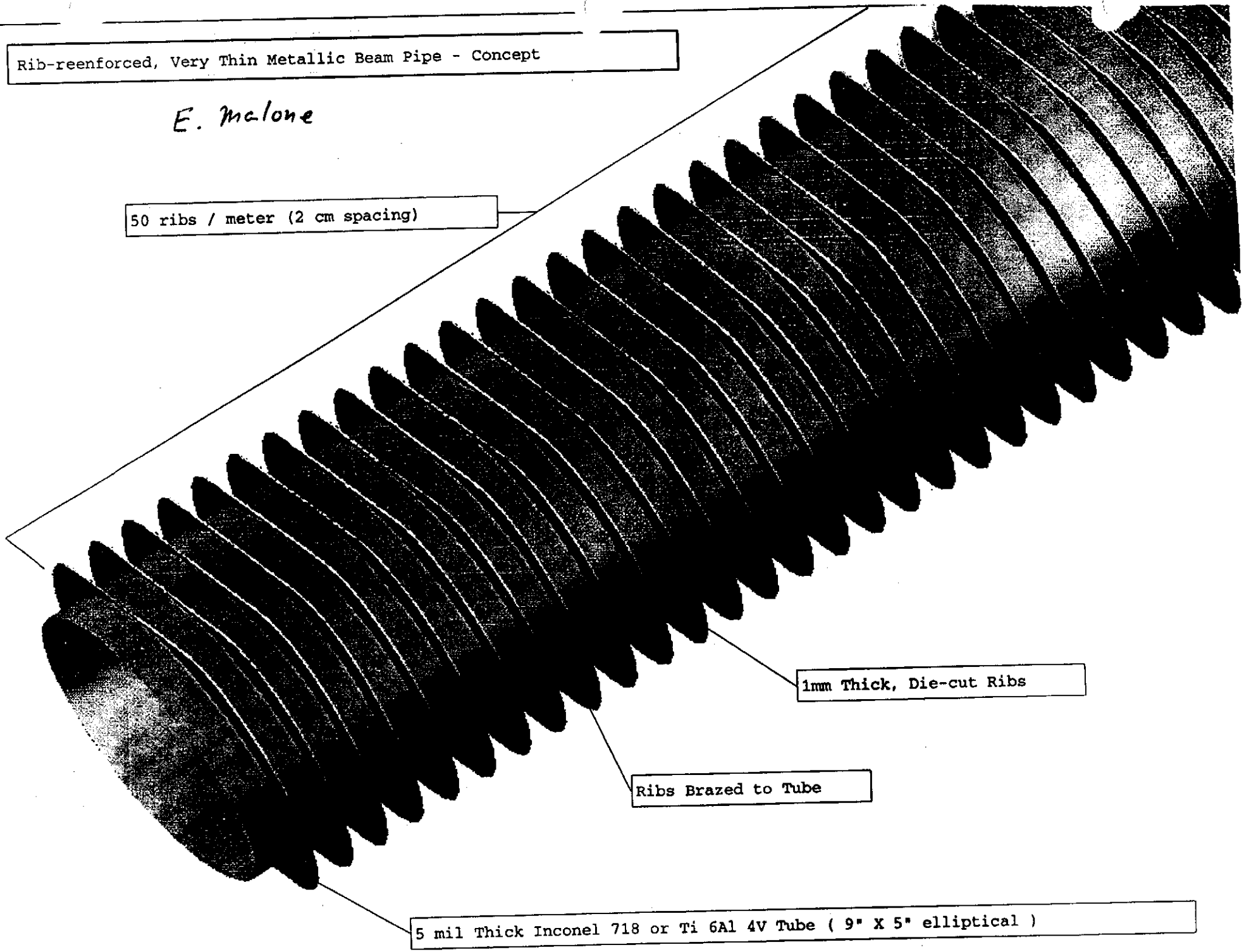
Water-Cooled, Thin Metallic Beam Pipe - Concept

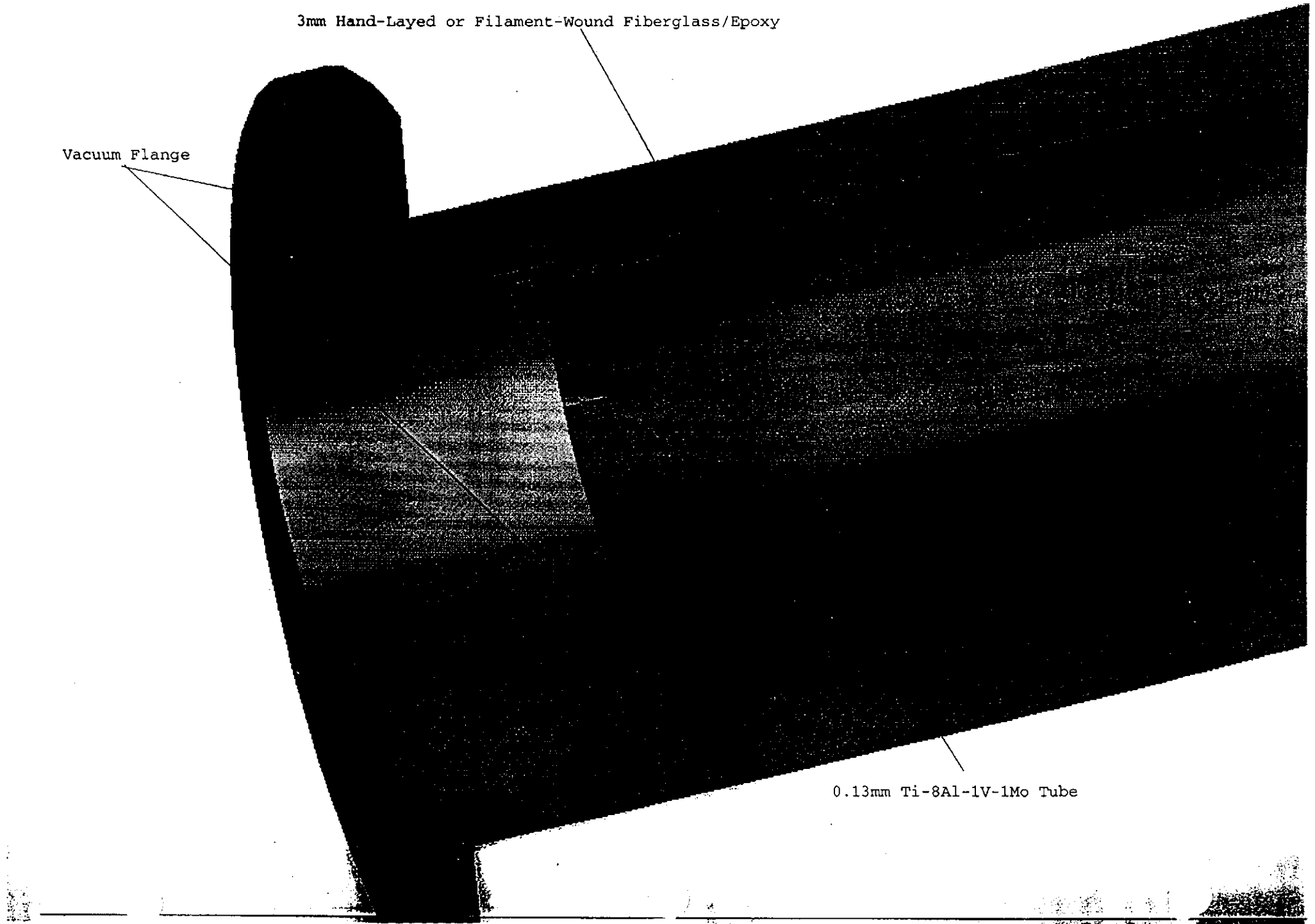


E. Malone

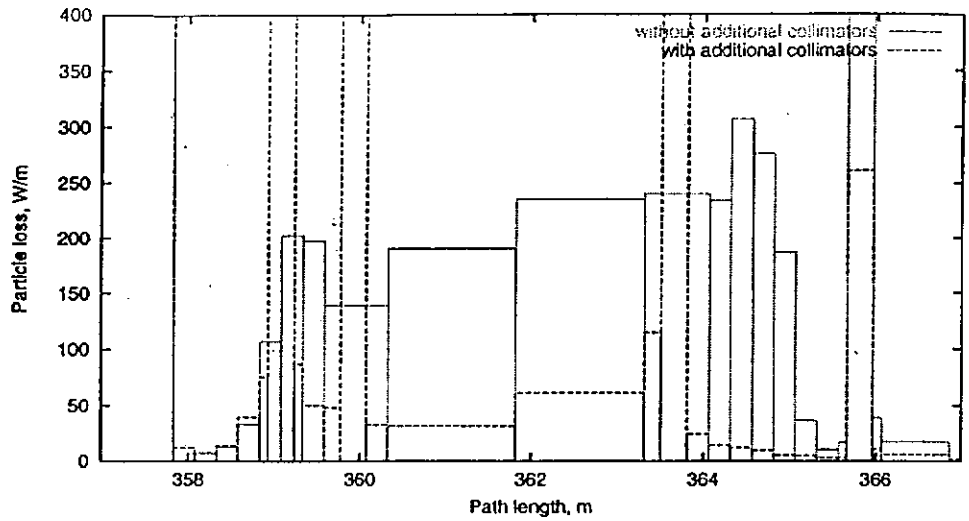
Rib-reenforced, Very Thin Metallic Beam Pipe - Concept

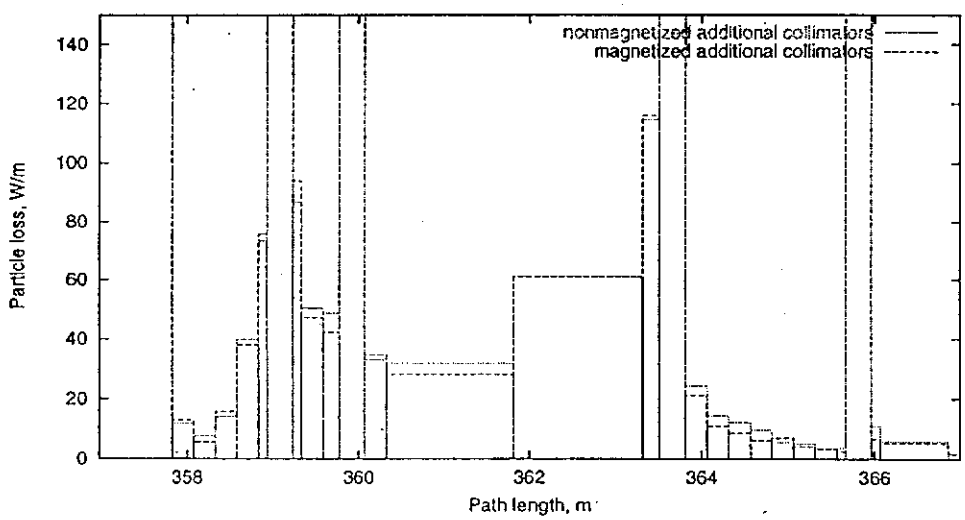
E. Malone




3mm Hand-Layed or Filament-Wound Fiberglass/Epoxy
Vacuum Flange
0.13mm Ti-8Al-1V-1Mo Tube

3 additional collimators





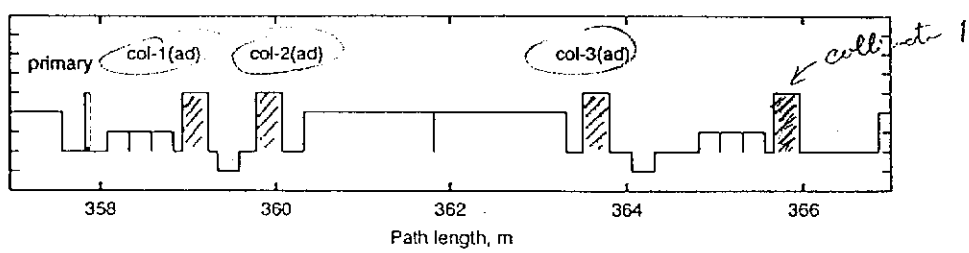


Figure 10: Beam losses at injection behind the primary collimator for the system without additional collimators and with additional collimators at 3 mm from the beam (top), Effect of additional collimators magnetization (bottom).

Technical Design Issues

- Unique feature of this machine - High longitudinal brightness N_b/ϵ_L.
  - High beam power, a few bunches $\longrightarrow$ large N_b
  - Short bunch length $\longrightarrow$ small ϵ_L
- How to preserve longitudinal emittance: (ICFA mini-Workshop, Mar 7-10, CERN)
  - Avoid transition (lattice design)
  - Avoid microwave instability
    - Always below transition
    - Keep resistive wall impedance small
  - Avoid coupled bunch instability (low Q cavity)
  - Inductive insert for compensating space charge
  - Longitudinal damper
- How to perform high intensity bunch rotation:
  - Instability
  - Beamloading
  - Effect of higher order momentum compaction α_1
  - Effect of space charge tune spread
- How to get large momentum as well as dynamic aperture in a FMC lattice.
- How to compensate beamloading of an intense short bunch (hundreds amperes peak current).
- How to collimate the beam so that the tunnel activation level would allow hands-on maintenance.
- How to do injection when the power supply is dual harmonic.
- How to do painting.
- How to correct tracking errors in a resonant synchrotron using separated function magnets.

- How to design and fabricate high gradient rf cavity.
- How to design and fabricate thin metallic pipe carrying heavy eddy current induced heat load and field error.
- How to design and test high brightness H^- source.
- How to design and test RF chopper.
- How to design, fabricate and test large magnets requiring big good field region.
- *etc.*

Beam physics issues

Longitudinal beam dynamics

1. HIGH LONGITUDINAL PHASE SPACE DENSITY – KEEP ϵ_L SMALL

Machine	E_{max} (GeV)	N_{tot} (10^{12})	N_b (10^{12})	ϵ_L (eV-s)	N_b/ϵ_L (10^{12}/eV-s)
Existing:					
CERN SPS	450	46	0.012	0.5	0.024
FNAL MR	150	20	0.03	0.2	0.15
KEK PS	12	3.6	0.4	2	0.2
FNAL Booster	8	4	0.05	0.1	0.5
PETRA II	40	5	0.08	0.12	0.7
DESY III	7.5	1.2	0.11	0.09	1.2
FNAL Main Inj	150	60	0.12	0.1	1.2
CERN PS	14	25	1.25	0.7	1.8
BNL AGS	24	63	8	4	2
PSR	0.797	23	23	1.25	18
ISIS	0.8	25	12.5	0.6	21
Planned:					
Proton Driver	16	100	25	2	12.5
Japan JHF	50	200	12.5	5	2.5
AGS for RHIC	25	0.4	0.4	0.3	1.3
PS for LHC	26	14	0.9	1.0	0.9
SPS for LHC	450	24	0.1	0.5	0.2

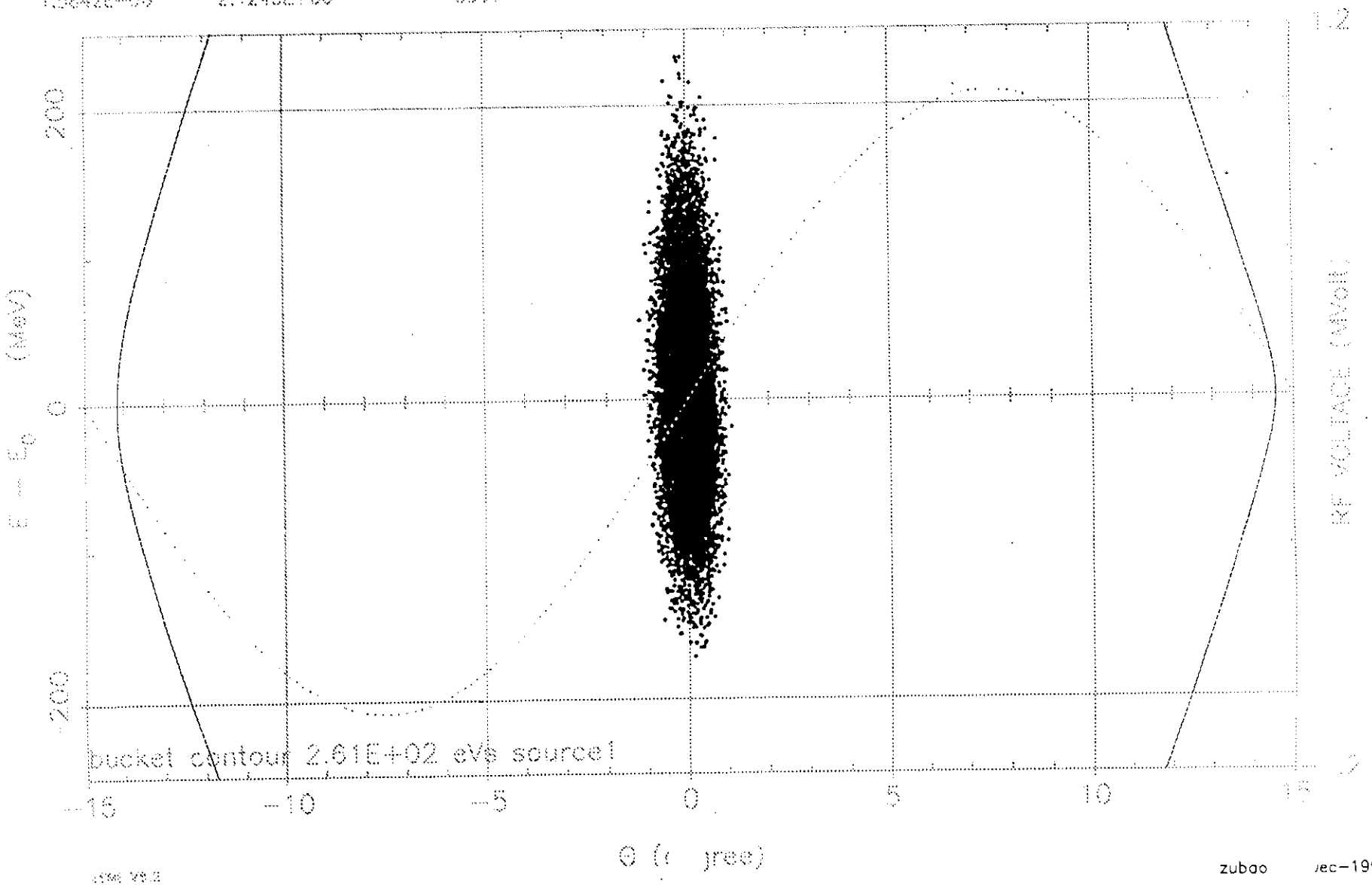
(Phase I: 3.8)

- Avoid transition crossing. (see lattice design)
- Avoid microwave instability:
  - Always below transition
  - Keep resistive wall impedance small
- Avoid coupled bunch instability. (see rf design)
- Inductive insert for space charge compensation (see expt.)
- Longitudinal damper

D ter

TURN 79750 6.637E-02 sec

H_0 (MeV)	S_0 (eV s)	E_0 (MeV)	h	V (MV)	ψ (deg)
7.8301E+02	2.8073E+02	1.8938E+04 (16 GeV)	12	1.000E+00	0.000E+00
ν_s (turn^{-1})	pdot (MeV s^{-1})	η			
4.0755E-04	0.0000E+00	-1.4686E-03			
τ (s)	S_b (eV s)	N			
1.5842E-05	2.1240E+00	9997			



zubao ec-1998 08:40

$$\alpha = \frac{\Delta L/L}{\Delta P/P}$$

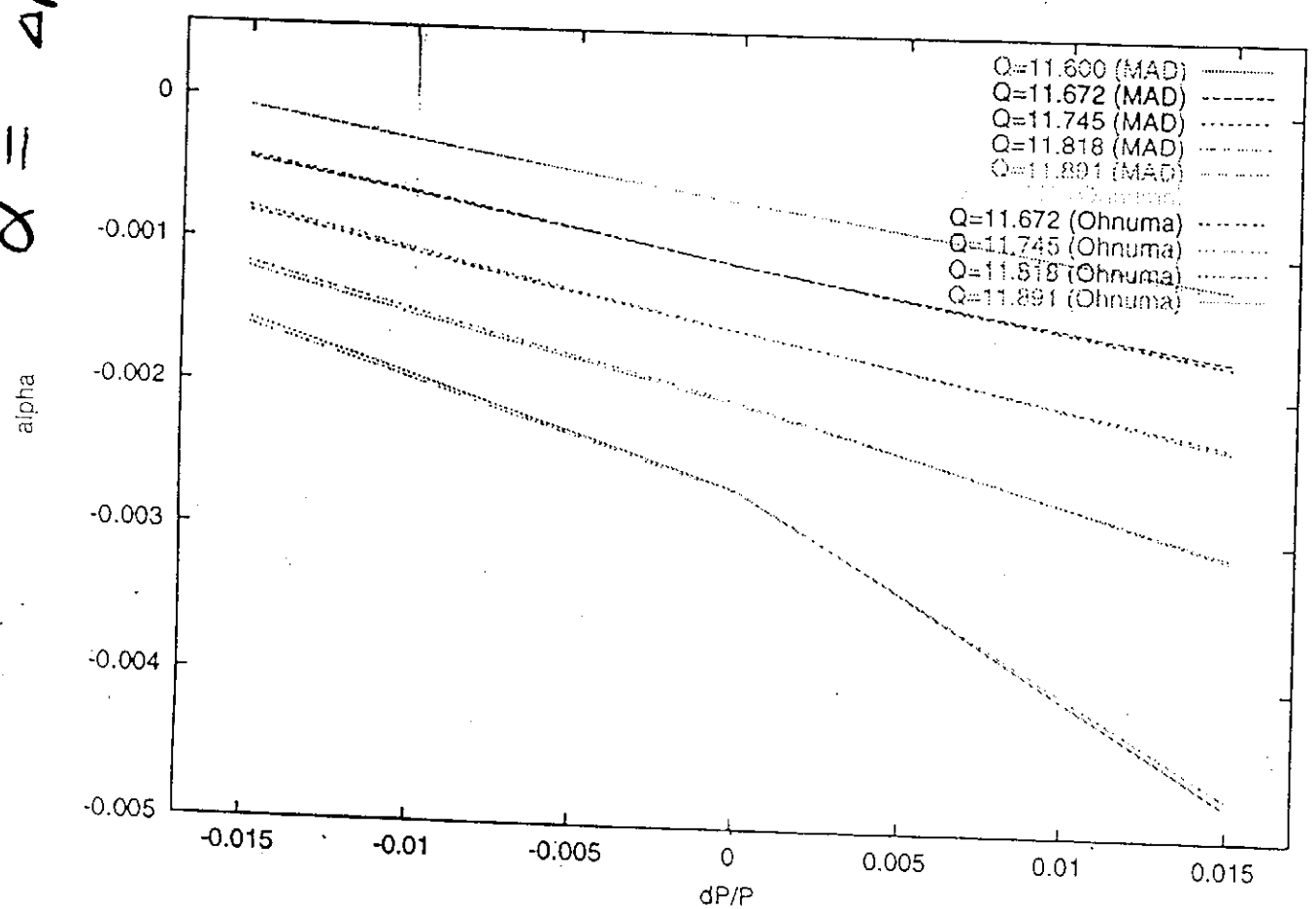
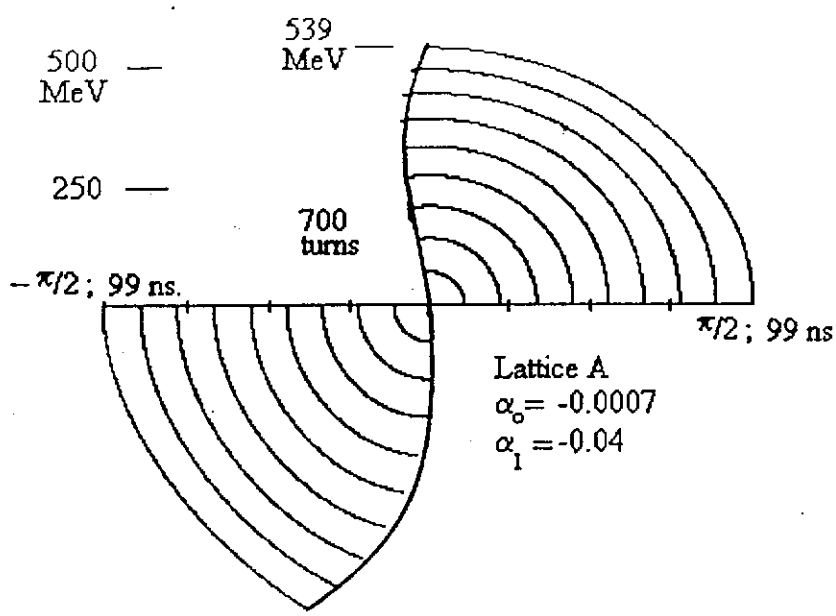
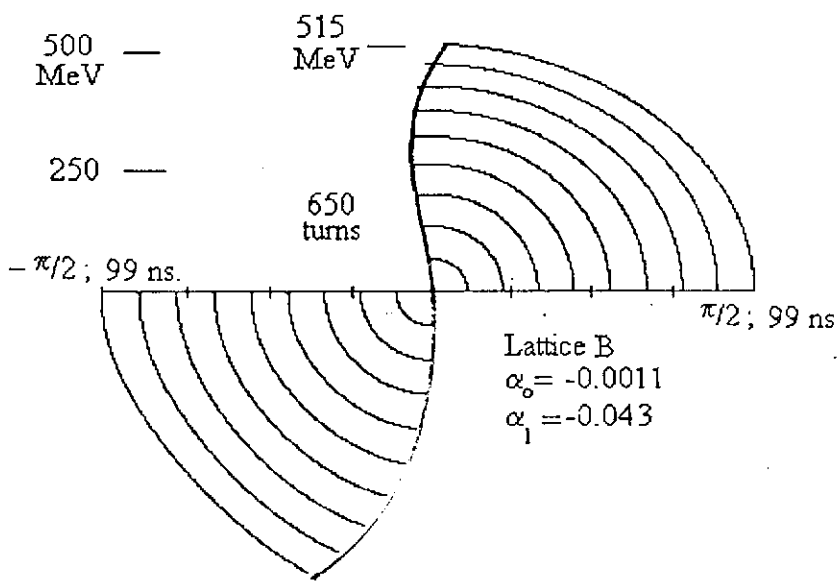


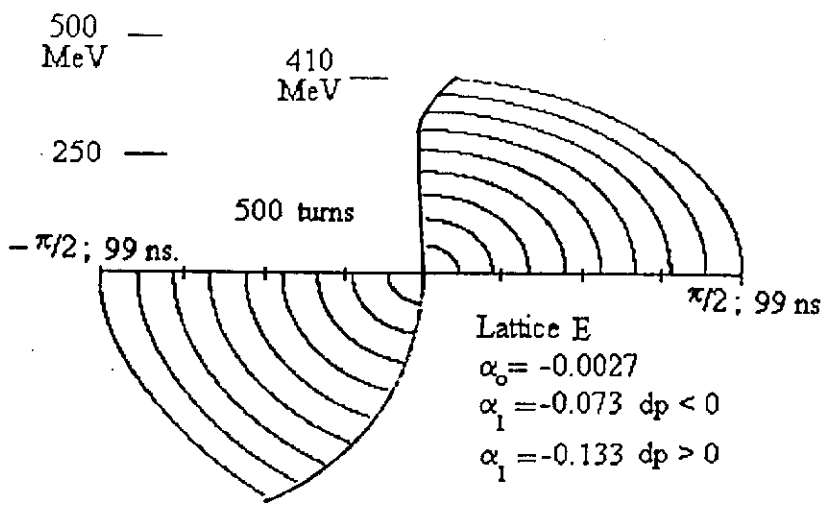
Figure 11: Ritson's (No negative bend, RBEND) 16 GeV Proton Driver lattice (No.2). "Alpha" dependence on dP/P.

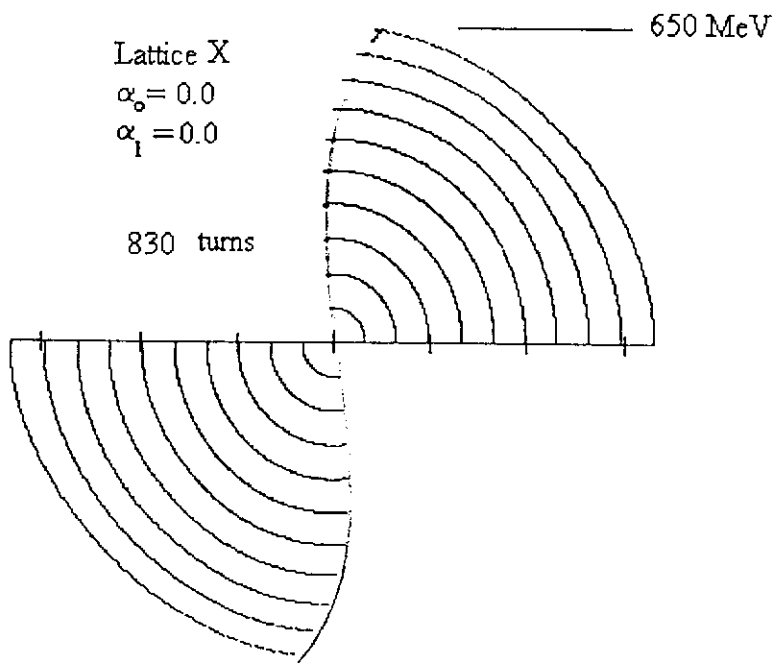
2-13-2000
J. Griffin





2-13-2000
J. Griffin





R&D Program for FY00-01

- Hardware R&D

  1. High gradient rf cavity prototyping
  2. Beamloading compensation
  3. Thin metallic beam pipe prototyping
  4. 53 MHz booster rf cavity modification
  5. RF chopper
  6. Linac front end test station

- Machine experiments

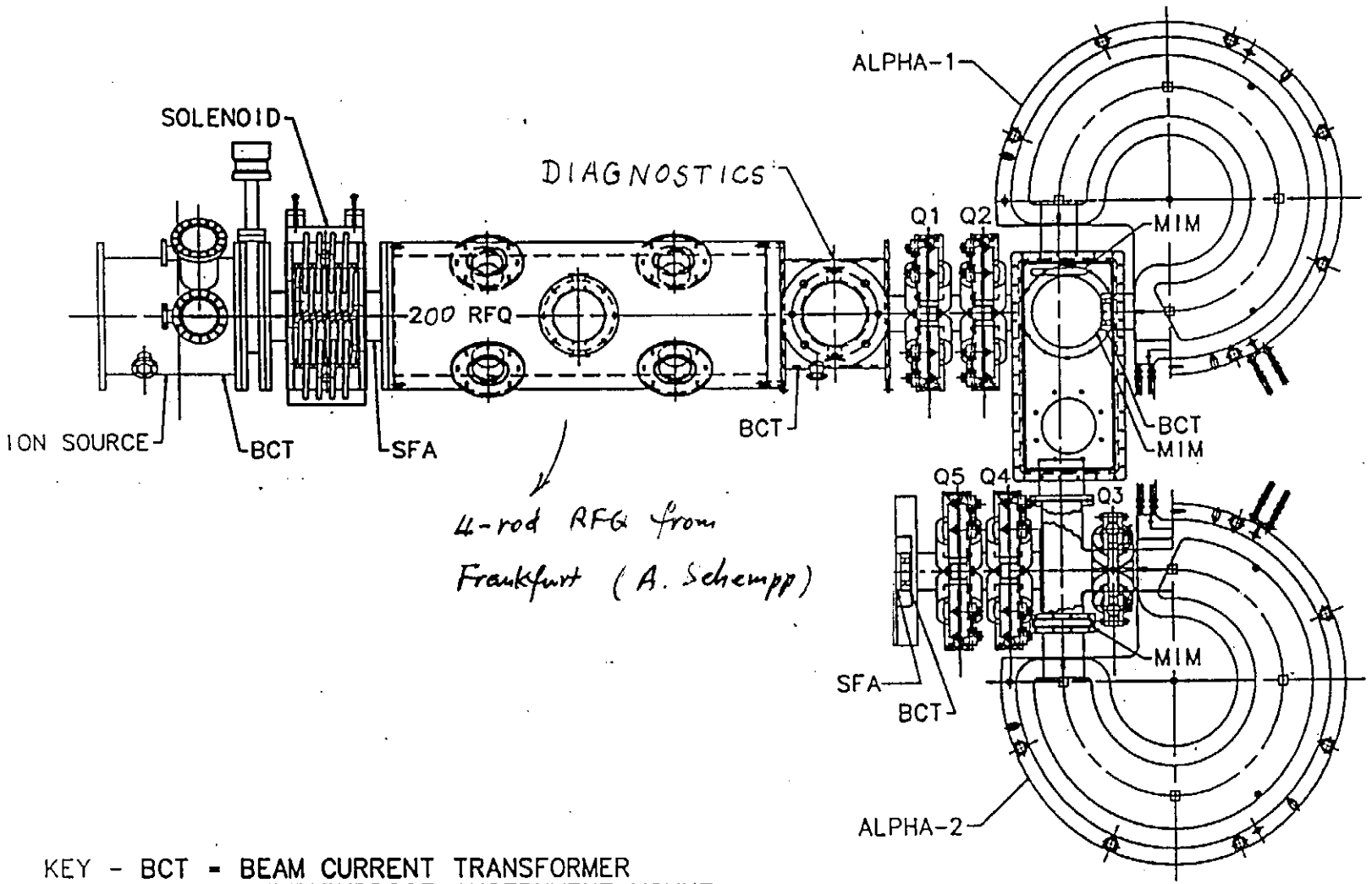
  1. Beam test of Finemet cavity (Fermilab/MI, BNL/AGS)
  2. Inductive insert (LANL/PSR, ANL/IPNS)
  3. 6-lab "contest" on intense short bunch production:

     Six labs (BNL, KEK, Fermilab, CERN, Indiana U. and GSI) are to carry out experiments on (i) bunch compression and (ii) μ-wave instability below γ_t. The competing items are:

     - Max I_{peak}
     - Max N_b/eV-s
     - Max compression ratio

Linac Front End Test Station

BEAM INSTRUMENTATION LAYOUT



KEY - BCT = BEAM CURRENT TRANSFORMER
- MIM = MULTIPURPOSE INSTRUMENT MOUNT
- SFA = SEGMENTED FARADAY APERTURE

To: J. Marriner

From: Proton Driver TDR Team Weiren Chou x 5489
Proton Source Department Bob Walker 1/14/00

Date: January 12, 2000

Subject: A joint proposal for Booster cavity modification

Cc: P. Martin, F. Lange, R. Pasquinelli

We propose to modify a present Booster rf cavity to achieve two goals: (1) to enlarge the aperture from 2.25" to 5", (2) to increase the cavity voltage by 20%.

1. Motivation:

   - Proton Driver
     One application of the proton driver is to serve as a new high intensity booster for the Main Injector. In this scenario, the present booster rf cavity (53 MHz) could be reused, which would be a significant cost-saving measure. Previous studies show that, with appropriate upgrades, the MI could take 2.5×10^{13} protons from each booster cycle, a number consistent with the proton driver Phase I design. However, the present booster cavity aperture (2.25") is too small and has not enough accelerating voltage (55 kV per cavity). This modification would increase the aperture to 5" and voltage to 66 kV to meet the proton driver design goal.
   - Present Booster
     Installation of dogleg magnets around the extraction septa and improved gradient magnet alignment in recent years has increased the useful aperture of the Booster. These efforts have been successful to the point that the rf cavities now represent the next level of aperture limits in the machine. The rf power amplifiers, sitting atop the cavities, are the highest maintenance items in the Booster. Already the cavities are among the highest residual radiation points in the Booster apart from the injection and extraction components. Enlarged cavity aperture, while leading to only fractionally small increases in beam intensity, will certainly reduce radiation levels at the cavities themselves. PA and cavity maintenance will become a critical issue as Booster duty cycle and proton throughput are increased an order of magnitude from present operation for MiniBooNE and NUMI experiments. Cavity aperture improvements will greatly facilitate this maintenance from a radiation safety perspective and result in increased beam up time. Booster operation at higher average pulse rates will lead to more wear and tear on the amplifiers and most likely more frequent failure. Increased cavity voltage will provide a greater margin of available rf voltage, permitting operation to continue in spite of several station failures. This will reduce the number of unscheduled operational interruptions for PA maintenance.

To: J. Marriner, P. Martin

From: Proton Driver TDR Team

Date: January 10, 2000

Subject: Proposal for coalescing and beamloading compensation experiments in the Main Injector using a Finemet cavity

Cc: S. Holmes

We propose to install a 7.5 MHz Finemet cavity in the Main Injector for two experiments: (1) beam coalescing for 132 ns bunch spacing, (2) beamloading compensation using a digital system.

1. Motivation:
   As part of the US-Japan collaboration, the proton driver TDR team is building a 7.5 MHz rf cavity using Finemet cores. This cavity is about 0.5 m long and will produce about 16 kV gap voltage. It can be used for a future multi-megawatt proton driver. It can also be used in the Main Injector for beam coalescing to obtain 132 ns bunch spacing, which is required by the Tevatron in Run II. In addition, a digital beamloading compensation system is under design. It will use the same cavity to compensate the transient beamloading voltage. The proposed experiments will test both the cavity and the compensation system.

2. Steps and and schedule:

   (a) Cavity assembly: The Finemet cores, copper cooling disks, case and power tube are in place. Various parts of the power amplifier are being fabricated in the machine shop. The assembly should be completed by February.

   (b) High power test (200 kW): This will be done from February to March in the MI-60 building.

   (c) Cavity installation: The cavity will be installed at 630E of the MI-60 straight section in the tunnel. This work is planned for the March-April period when E-835 is running.

   (d) Coalescing experiment: April and May.

   (e) Beamloading compensation experiment: The system should be ready by June. The experiment will be done during the summer.

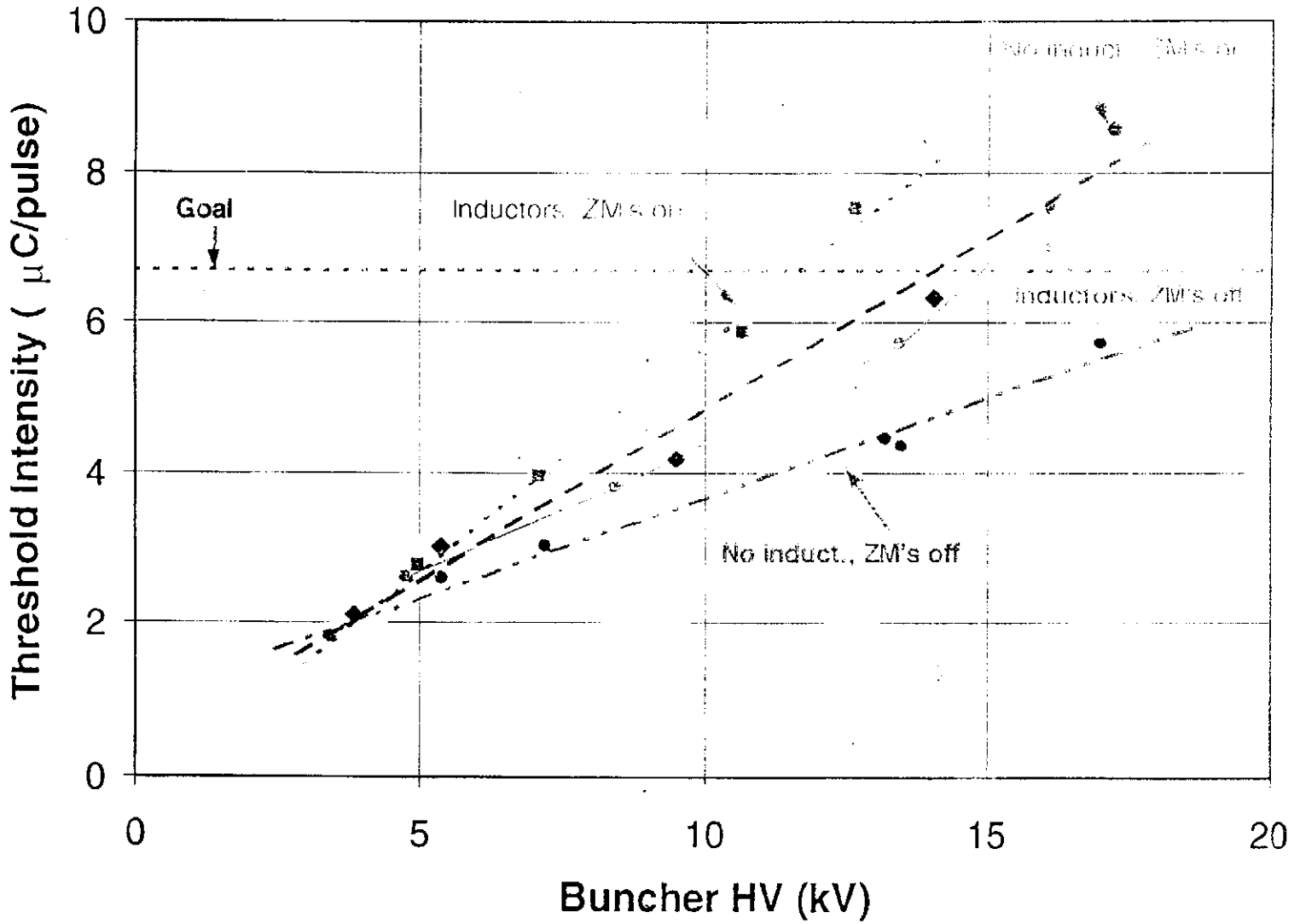
   Some details about (d) and (e) can be found in the appendices by D. Wildman and J. Steimel.

3. Required resources:

   (a) We need to borrow the following equipments:

   - One spare MI modulator

1999 Results from inductor



LANSCE
Los Alamos Neutron Science Center

Q: How to obtain 1 bunch?
(How to do coalescing?)

PROPOSAL FOR MEASURING MW INSTABILITY IN MI

I. Kourbanis
1/4/2000

Purpose:

Search for "microwave instabilities" below transition energy in the Main Injector (γ_{tr}=21.6, E_{tr}=20.3 GeV).

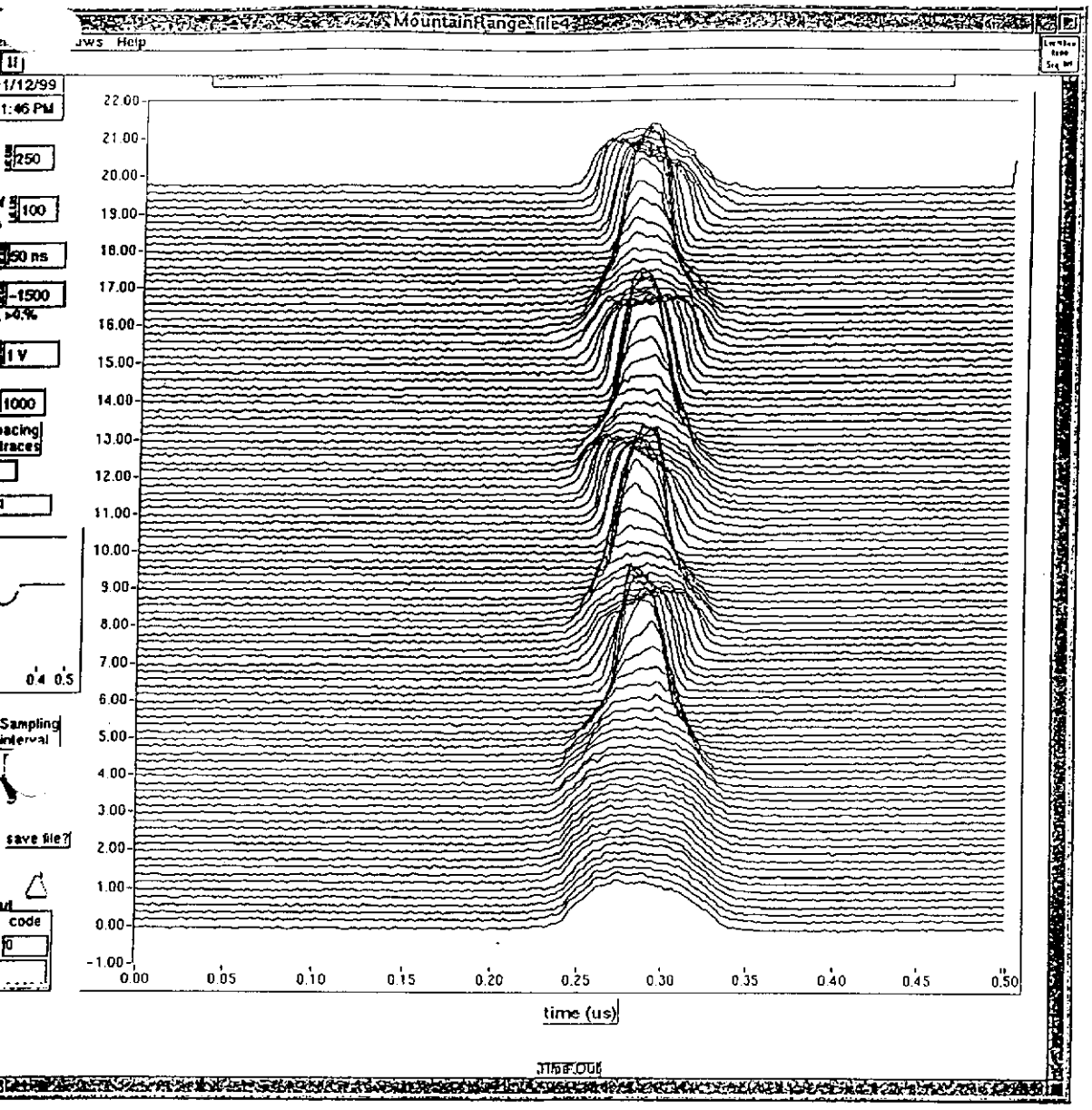
Experimental setup:

We will use a $2E Main Injector cycle with a 0.5 sec long front porch close but ABOVE transition (E=23.5 GeV, $\eta=5.5\times10^{-4}$). Ideally we would like to accelerate one high intensity bunch from the Booster to the front porch turn the rf off and observe any instability signals (2-3 GHz) during the debunching. Since it is very difficult to accelerate 1 bunch we will inject and accelerate 3-5 bunches. Alternatively we can coalesce 3-5 bunches at the front porch before we turn the rf off.

We will repeat the above experiment with a front porch close but BELOW the transition energy (E=18 GeV, $\eta=-5.7\times10^{-4}$) .

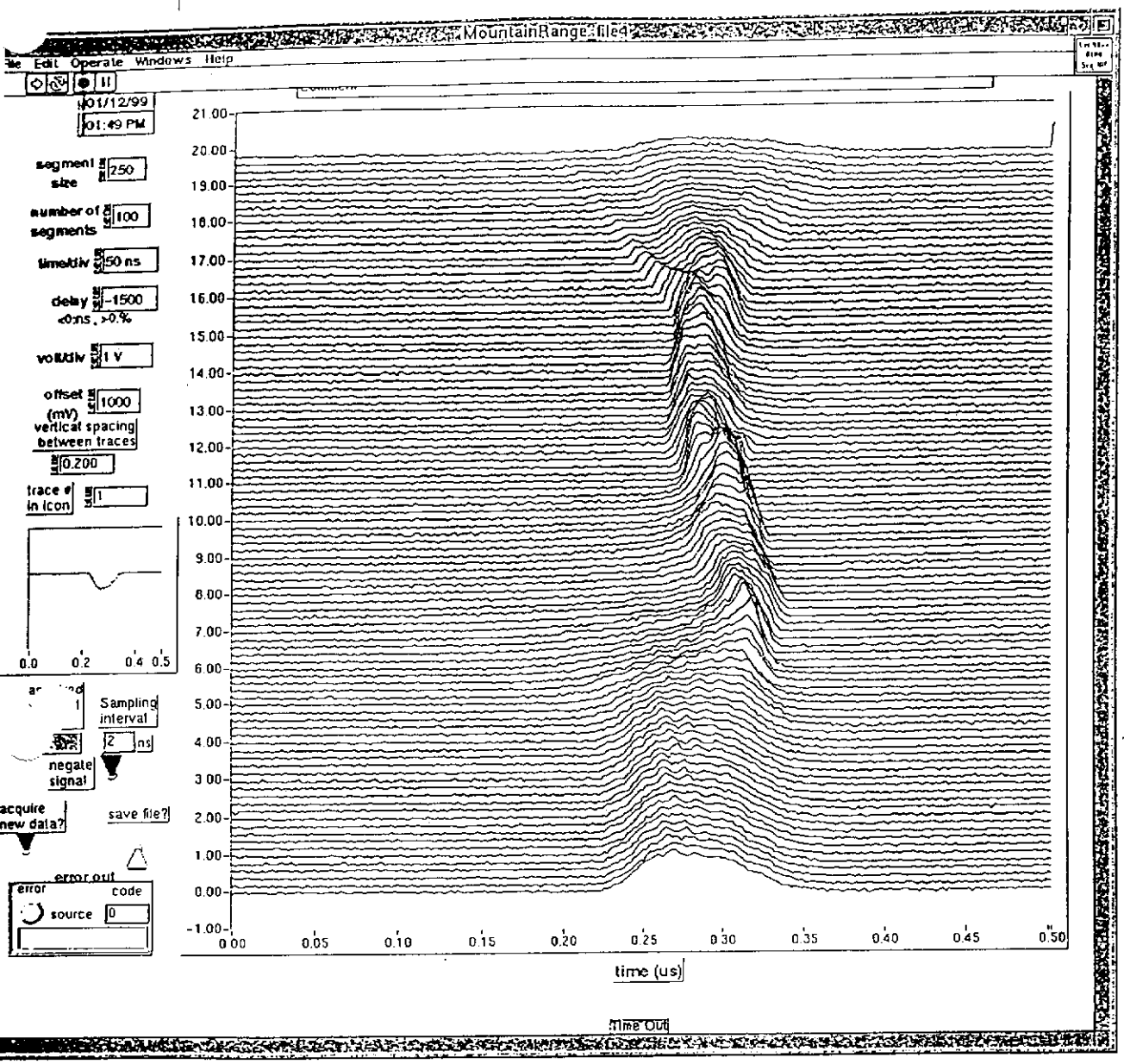
People and shifts:

3-4 shifts with 2-3 people per shift will be required. The study can be done parasitically to the MI operations.



STP

20KV/T
||
Vrf (min)



5 Tp

10 KV/T

Vrf (minimum

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510
630-840-3211 FAX 840-2939

Director's Office

January 25, 2000

Ms. Jane L. Monhart
Fermi Group Leader
U.S. Department of Energy
P.O. Box 2000
Batavia, Illinois 60510

Dear Ms. Monhart:

SUBJECT: Conference Request

Fermilab proposes to sponsor an **ICFA Workshop on High Intensity High Brightness Hadron Beams** to be held 2–6 October 2000 at Fermilab. I support this Workshop and request approval pursuant to DOE Order 110.3 and have enclosed the required information necessary for the approval.

Sincerely,

K. C. Stanfield /for

Michael Witherell
Director

cc: K. Stanfield
B. Chrisman
C. Sazama
W. Chou

Schedule

- April 2000: Internal review of the proton driver design.
- October 2-6 2000: ICFA workshop on high intensity high brightness hadron beams.
- December 2000: A complete TDR.

- Under consideration - One-day workshop to discuss possible physics program using the proton driver (sometime this summer).

R&D List in a Five-Year Plan (FY00-04)

(30 KV/m, a few MHz)

- High gradient, low frequency rf in CW operation
- Beamloading compensation
- Thin metallic pipe
- RF chopper
- Inductive inserts
- Intense short bunch experiment
- Linac front end test station

(0.5 ~ 1 MV/m, a few MHz)

- High gradient, low frequency rf in burst mode operation
- High brightness H^- source
- High current RFQ
- Collimators (including bent crystal as the primary)
- FMC lattice
- Tracking error correctors
- Power supply using new technology (dual-resonance, dual-frequency, IGBT, *etc.*)
- Fast rise- and fall-time kicker
- Passive and active feedback systems
- Large aperture magnets (including end effects)

Table 1. Parameters of Three Cavity Designs

	Ferrite loaded	Ceramic loaded	Vacuum cavity
Frequency (MHz)	5	4	5
Aperture radius (cm)	30	30	30
Average gradient (MV/m)	0.5	0.42	0.5
Cavity length (m)	1	1.2	3.08
Cavity diameter (m)	1.66	3.12	2.3
Shunt impedance (kΩ/m)	25.6	52	175
Quality factor	100(?)	8400	11933
Peak power (MW/m)	5	1.7	1.4

2. Dielectric material loaded:
   This is suggested by J. Griffin. A low loss ceramic cylinder is placed in the center of the cavity. It has a dielectric constant $\epsilon = 9.5$ and gives a capacitance of about 5000 pF. The main concern of this design is the dielectric strength of the ceramic. The present commercial alumina products may not be able to withstand the rquired 13 MV/m.

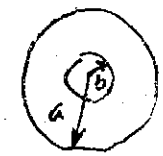
3. Vacuum cavity:
   There is such a cavity at the CERN Antiproton Collector. The problem of this type of cavity is its huge size. In order to reduce it, one may introduce electrodes with large surface area, as suggested by Y. Iwashita, A. Moretti and Z. Qian. The main concern is possible vacuum sparking. Although calculation shows the peak electric field is below the Kilpatrick's limit, it is still a question how valid is the scaling law with respect to the gap size and pulse length. Furthermore, the large surface area and the existence of a magnetic field (from the solenoid) would increase the probability of sparking.

Table 1 lists some cavity parameters. Each design has its advantages and concerns. It is too early to draw any conclusion at this moment. Theoretical calculation and numerical simulation (Superfish and Mafia) are under way. Hardware R&D is also in plan.

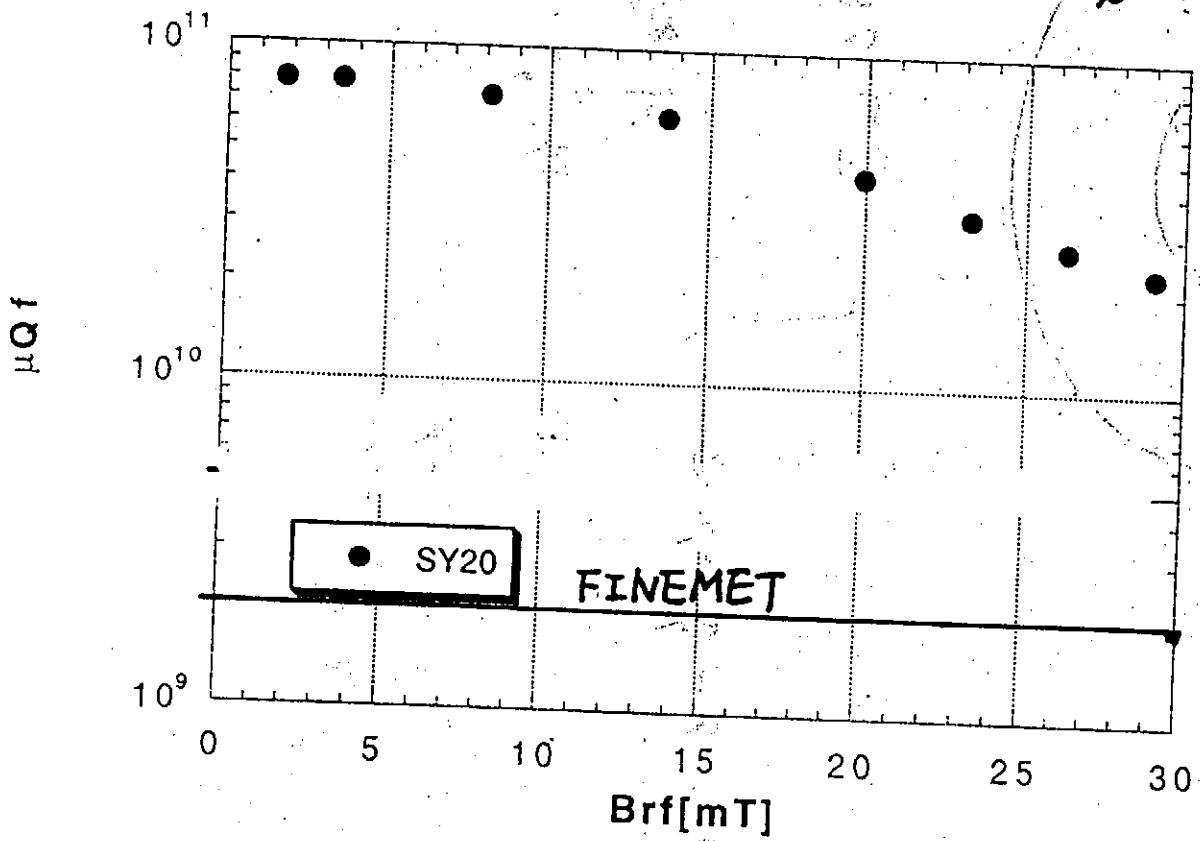
4 Discussion

Koba

SY20 core:



$$B_{rf} = \frac{V}{\omega S}$$



Goal: $V = 0.5\ MV/m$

@ $f = 5\ MHz$

$B_{rf} = 0.03\ T$

Design:

$$S = \frac{V}{B\omega} = \frac{5\times10^5}{2\pi\times5\times10^6\times0.03}$$

$$= 0.53\ m^2$$

$L = 1\ m$

$$b-a = \frac{S}{L} = 0.53\ m$$

Let $b = 0.3\ m$

then $a = 0.83\ m$

$$R_{sh} = \mu_0 \times L \times \ln\frac{a}{b} \times \mu Qf$$

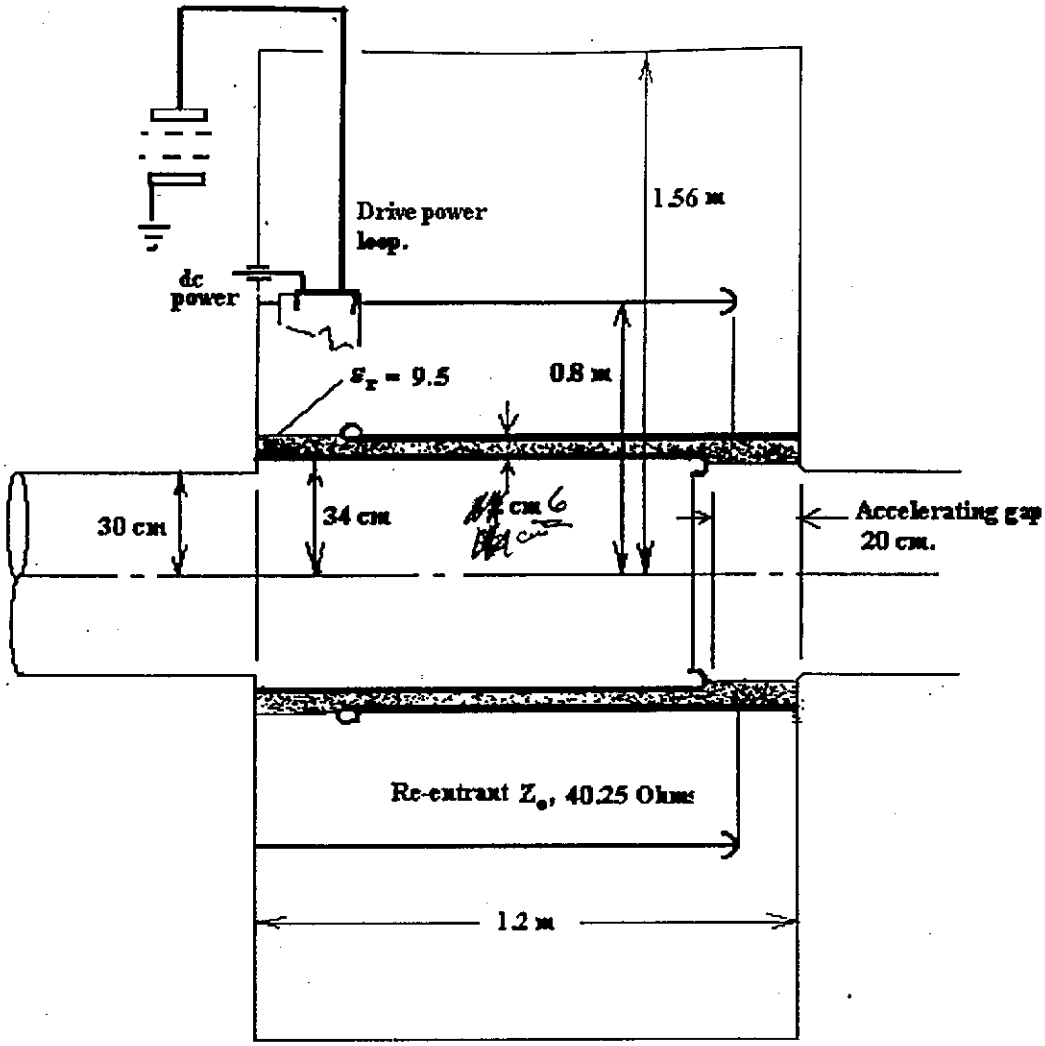
$$= 4\pi\times10^{-7}\times1\times\ln\frac{0.83}{0.3}\times2\times10^{10}$$

$$= 25.6\ K\Omega$$

$$P_{peak} = \frac{V^2}{2R_{sh}} = \frac{5^2\times10^{10}}{2\times25.6\times10^3}$$

$$= 4.9\ MW$$

J. Griffin



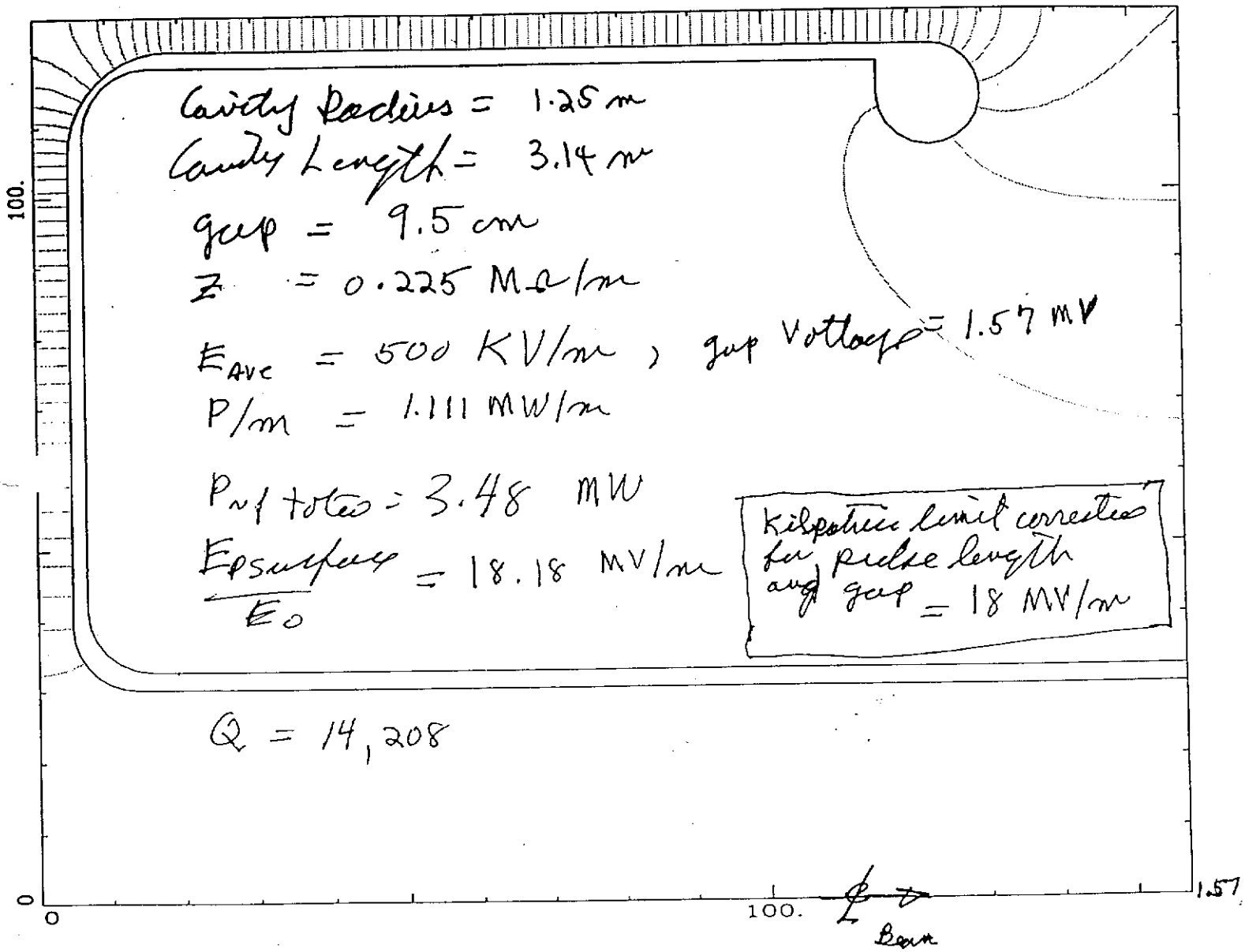
$f = 4\,MHz, \quad E = 420\ kV/m$

$R_{sh} = 62.5\ K\Omega, \quad Q = 8400$

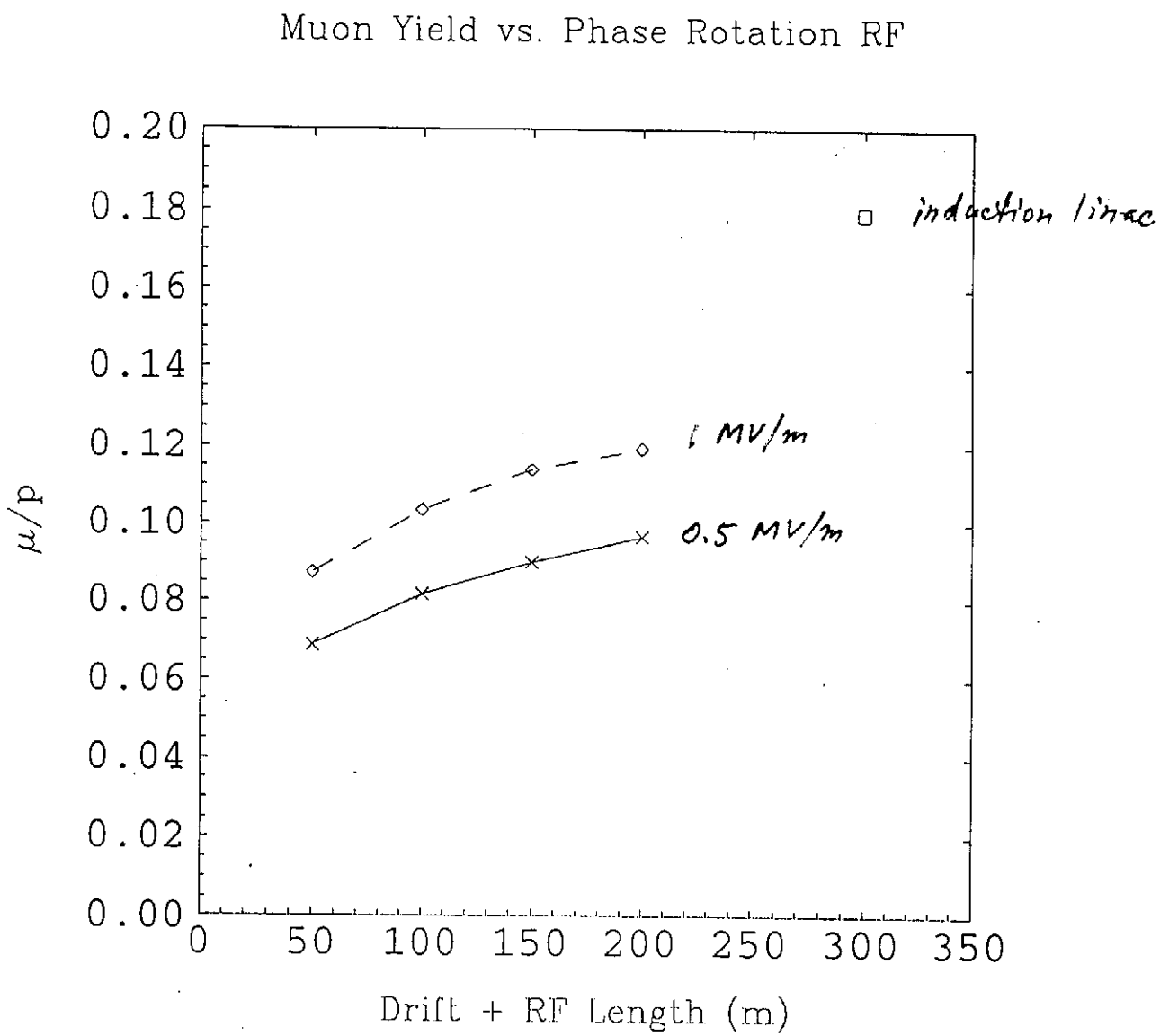
$P = 2\ MW$ (ceramic: 0.3 MW, copper: 1.76 MW)

$E_p = 13.2\ MV/m$

all.53 HIGH GRADIENT CaVITY ; Resonant frequency= 5.003



Tubes
CPI 4CM2500KG (~$100K)
Burd 7835 (~$25K)


Muon Yield vs. Phase Rotation RF
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
μ/p
0
50
100
150
200
250
300
350
Drift + RF Length (m)
induction linac
1 MV/m
0.5 MV/m