KEKB Impedance Budget

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KEK Accelerator Division

June 7, 1995

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Outline of this talk

- Characteristics of KEKB
- Tools for Impedance Calculations
- Impedance of Various Beamline Components
  - ARES RF Cavities
  - Resistive-wall
  - Masks at Arc
  - Pumping Slots
  - BPMs
  - IP Chamber
  - IR Chamber + Recombination Chambers
  - Bellows
- Summary

1. Characteristics of KEKB

- The very large beam currents:
  - 2.6 A @ LER
  - 1.1 A @ HER
- However, the bunch currents are small:
  - 0.52 mA @ LER
  - 0.22 mA @ HER
- Consequently, single-bunch instabilities are moderate.
- Main concerns are on coupled-bunch instabilities due to
  - High -Q resonances such as cavity HOMs
  - Transverse resistive-wall instability

- The short bunch (σ_z=4mm) requires a close watch on the bunch lengthening
- Combination of the short bunch and the large beam currents makes the HOM power loss and the heating problem serious at
    - Be chamber at IP
    - IR chamber + Recombination chambers (crotches)
    - BPMs
- Where do wakes and HOM powers go?

2. Tools for Impedance Calculations

- 2.5-dimensional code
  - ABCI
    - Time domain
    - Computes wake potentials, loss factors, impedance and others
- 3-dimensional code
  - MASK30
    - Time domain
    - Computes wake potentials, loss factors, impedance and others
  - MAFIA
    - Time domain (T3) and Frequency domain (URMEL 3-D)
    - Computes wake potentials, loss factors, eigenmodes, impedance and others

- Analytic formulae for impedance of holes and slots derived by

    Kurennoy - Stupakov (Ref. Phys. Rev. E49, 794 (1994))

    Kurennoy - Chin (Ref. KEK Preprint 94-193 (1995))

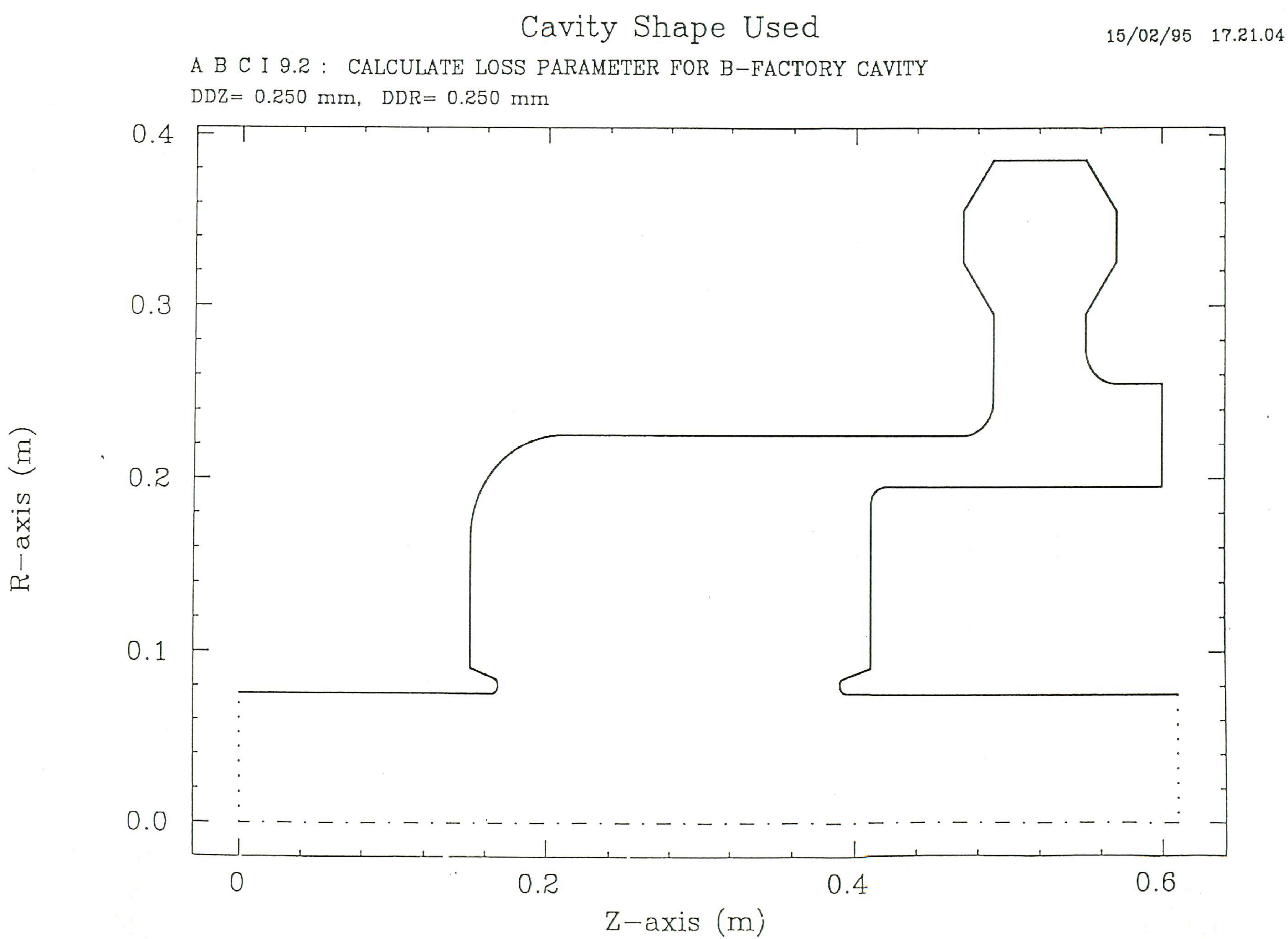
3-1. ARES RF Cavities

- 20 (40) ARES cavities in LER (HER).

k_L=0.529 V/pC per cavity

k_L=0.363 V/pC per taper (ϕ100 ↔ ϕ145 ↔ ϕ100)*

* There is a possibility of no taper used.

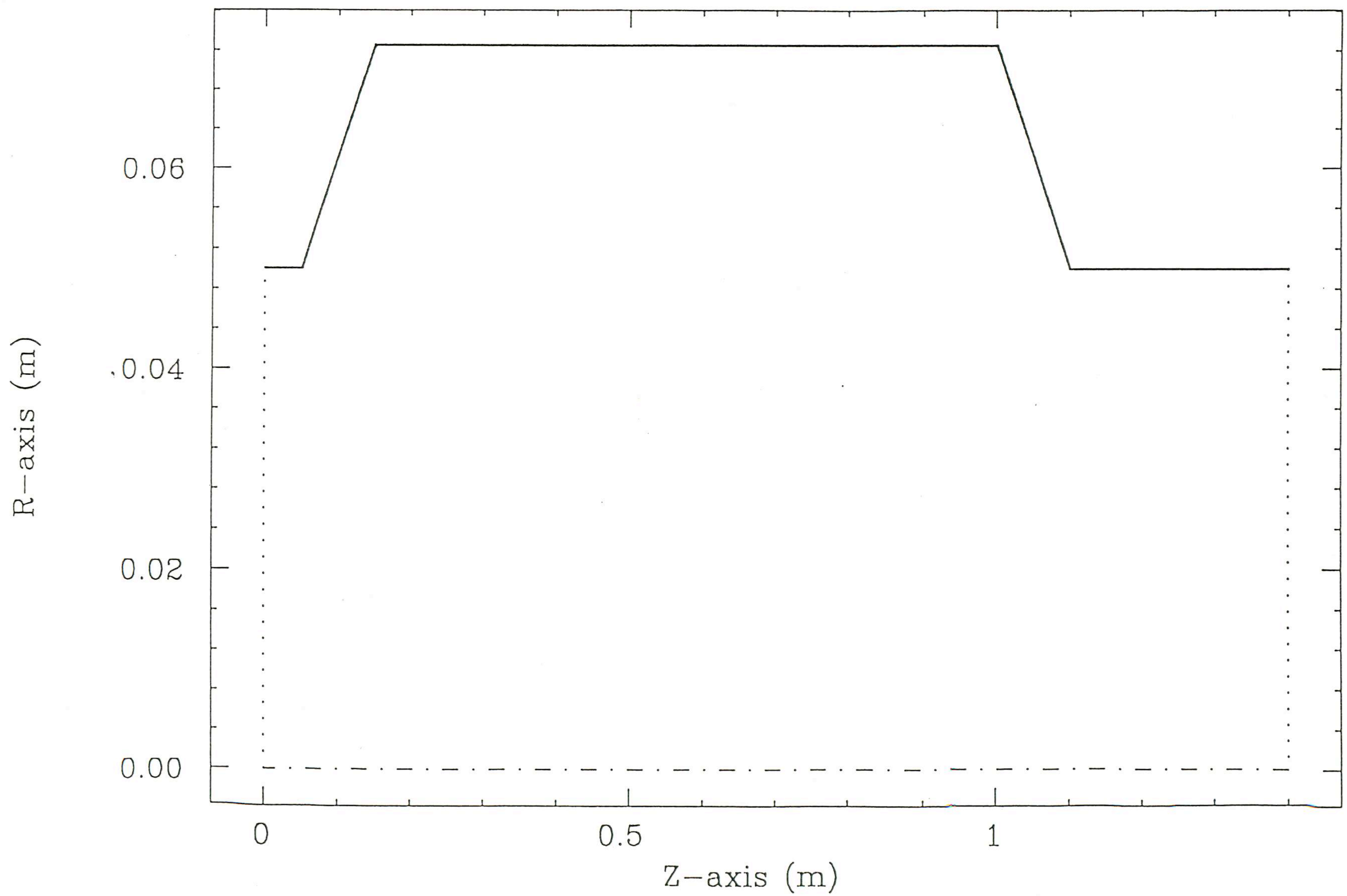

Cavity Shape Used
15/02/95 17.21.04
A B C I 9.2 : CALCULATE LOSS PARAMETER FOR B-FACTORY CAVITY
DDZ= 0.250 mm, DDR= 0.250 mm
R-axis (m)
0.4
0.3
0.2
0.1
0.0
0
0.2
0.4
0.6
Z-axis (m)

Cavity Shape Used

15/02/95 19.24.31

A B C I 9.2 : WAKE POTENTIAL FOR A TAPER OF A BEAM PIPE (100mm -> 145mm)

DDZ= 0.250 mm, DDR= 0.250 mm



3-2. Resistive-wall

- $Z/n = Z_0 \, (1-i)/2 \times \delta/b$

  δ: skin depth (e.g., $\delta = 1.4\mu$ at 2.3GHz)
  b: beam pipe radius (~50mm)
  $n = \omega_0/\omega$

- At KEKB,

  $Z/n = 0.788 \, (1-i)/n^{1/2}$

  $= 0.3 \, M\Omega$ at 100 kHz
  $= 2k\Omega$ at 2.3GHz

3-3. Masks at Arc

- There is a SR mask for every bellows on both sides of QM

  ~1000 masks in total

- Using a 3-D code MASK30,

$$\mathrm{Im}\,(Z/n) = 2.8 \times 10^{-3}\,\Omega$$

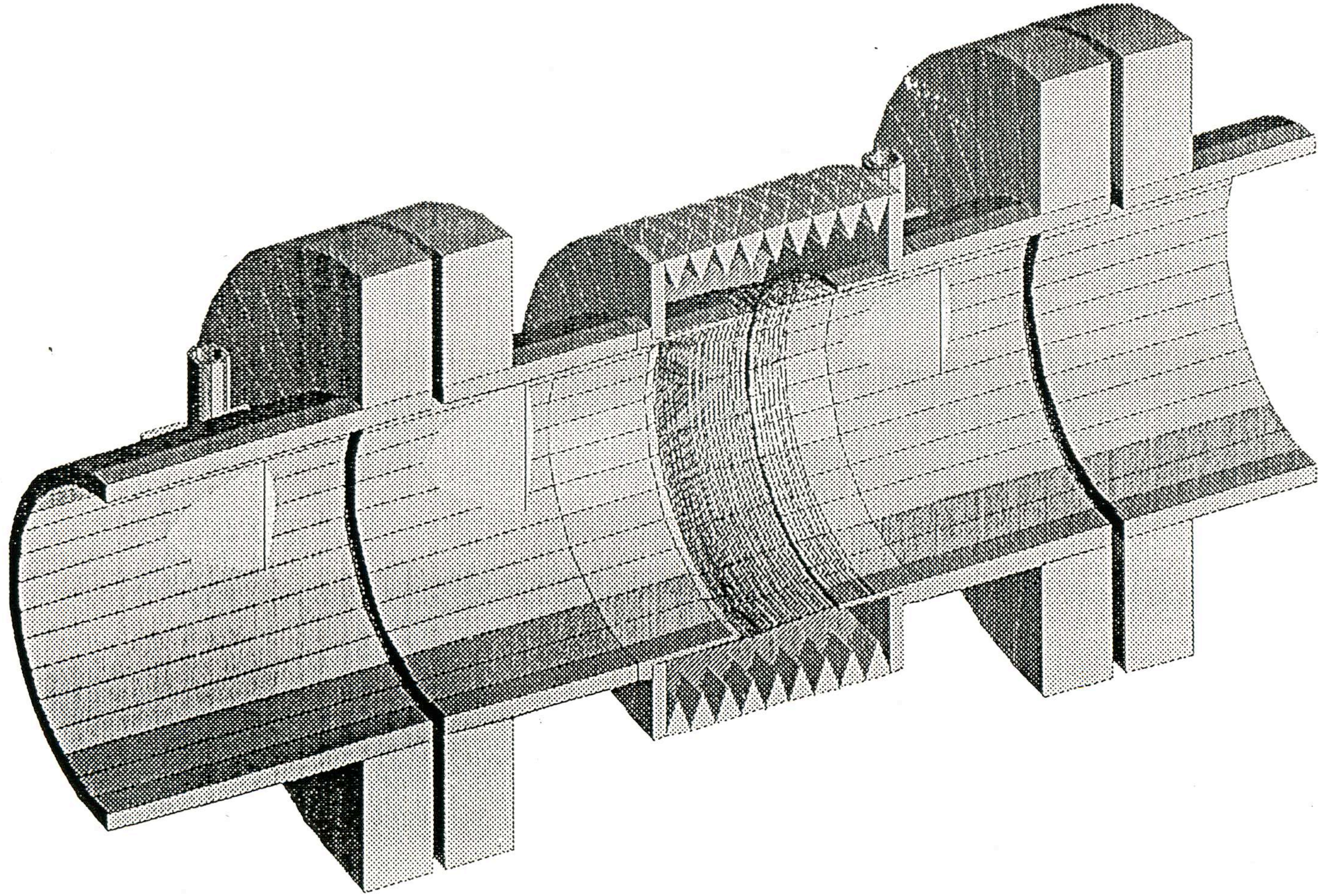
$$k_L = 4.6\ \mathrm{V/pC}$$

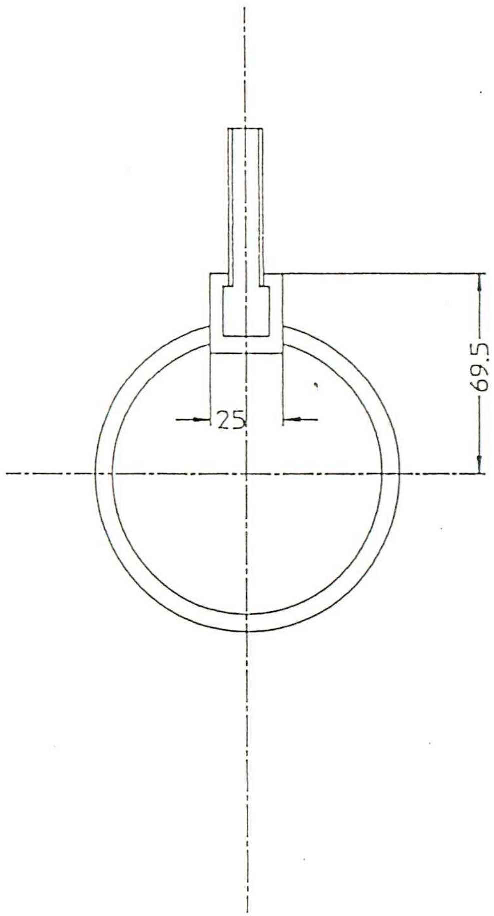
(HOM power loss = 62 kW in LER)

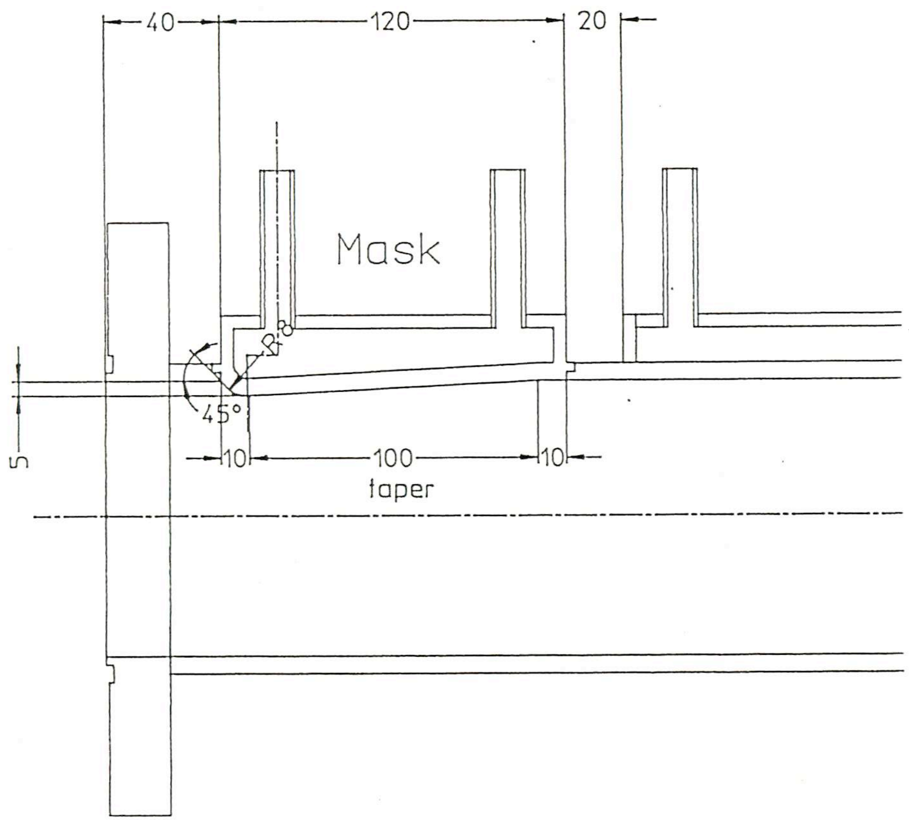
SRマスクの構造について

12/8 末次

ベローズ付近のマスク配置案



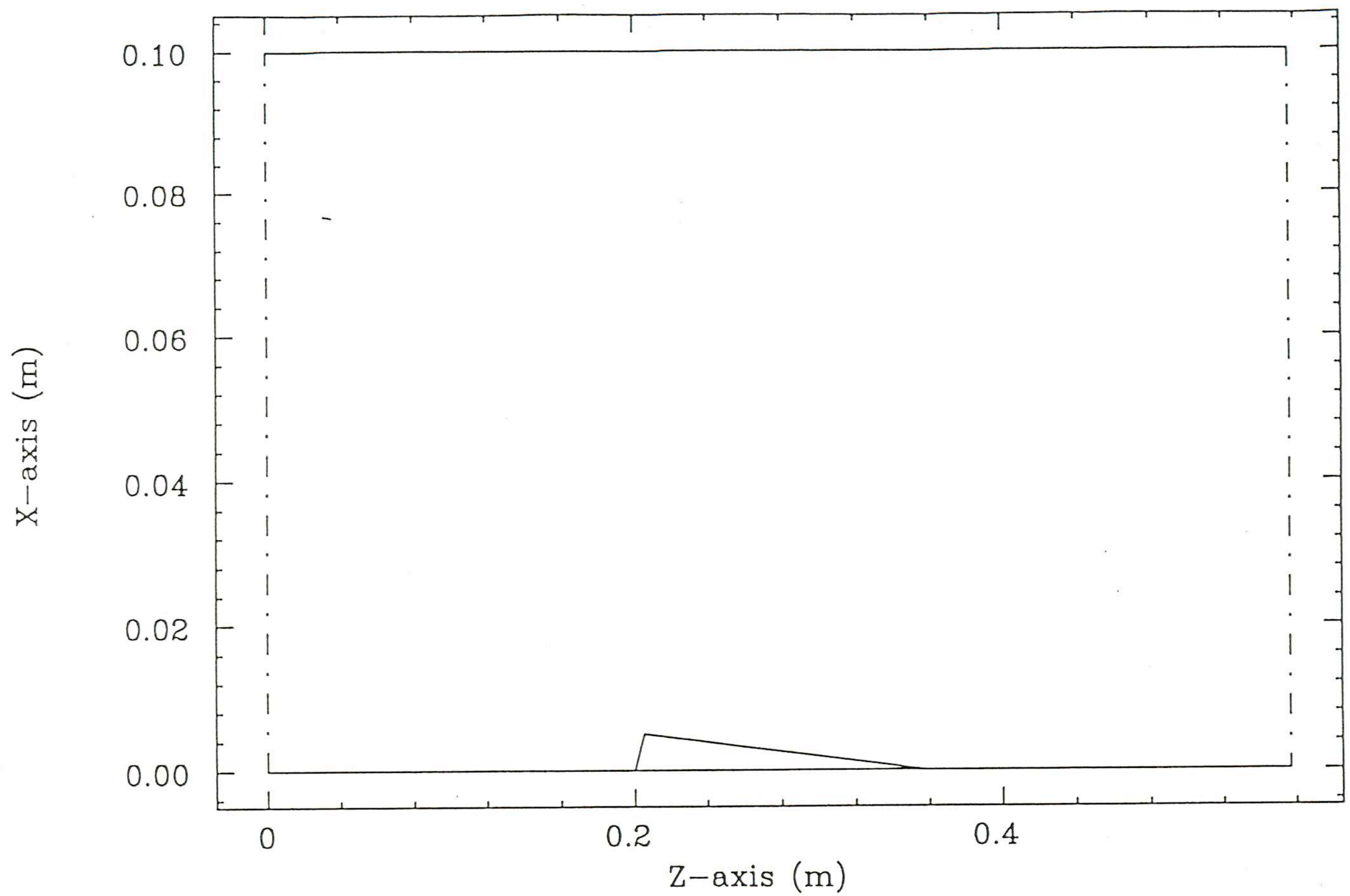

25
69.5


40
120
20
Mask
R8
45°
5
10
100
10
taper

Cavity Shape Input

M A S K 2.0 : LER 5MM HIGH MASK (with 20cm long beam pipes)

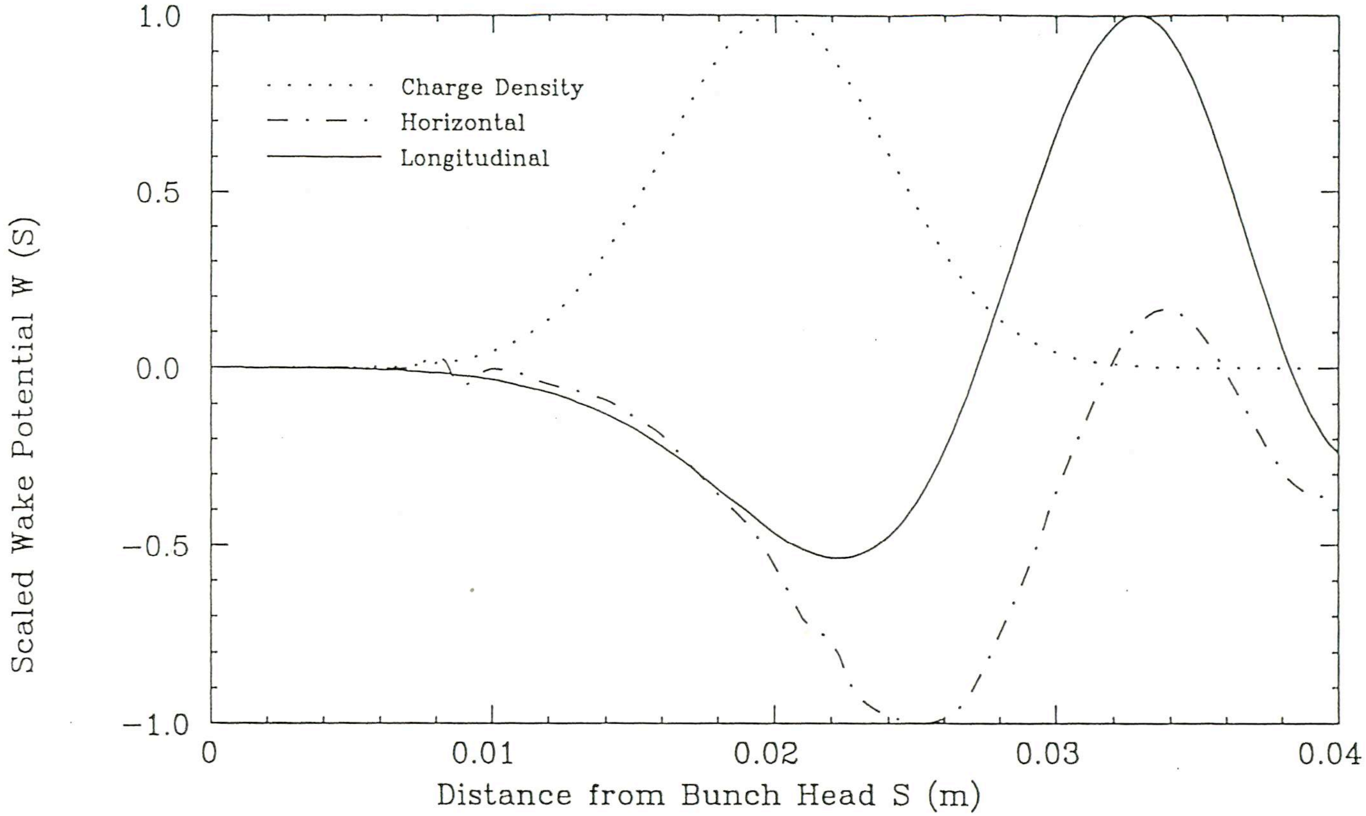
DDZ= 1.000 mm, DDR= 1.000 mm



Wake Potentials

M A S K 2.0 : LER 5MM HIGH MASK (with 20cm long beam pipes)

SIG= 0.400 cm, DDZ= 1.000 mm, DDR= 1.000 mm



Horizontal Wake	Min/Max= −2.622E−03/ 4.262E−04 V/pC ,	Loss Factor= −1.447E−03 V/pC
Vertical Wake	Min/Max= −1.111E−04/ 3.460E−05 V/pC ,	Loss Factor= −2.903E−05 V/pC
Longitudinal Wake	Min/Max= −7.133E−03/ 1.332E−02 V/pC,	Loss Factor= −4.574E−03 V/pC

3-4. Pumping Slots

- Rounded edge ⟶ Impedance reduced
- Impedance is insensitive to the length of slot
  ⟶ a long slot better ?
- Magnetic fields are easy to leak out if a slot is long
  ⟶ a hole better ?

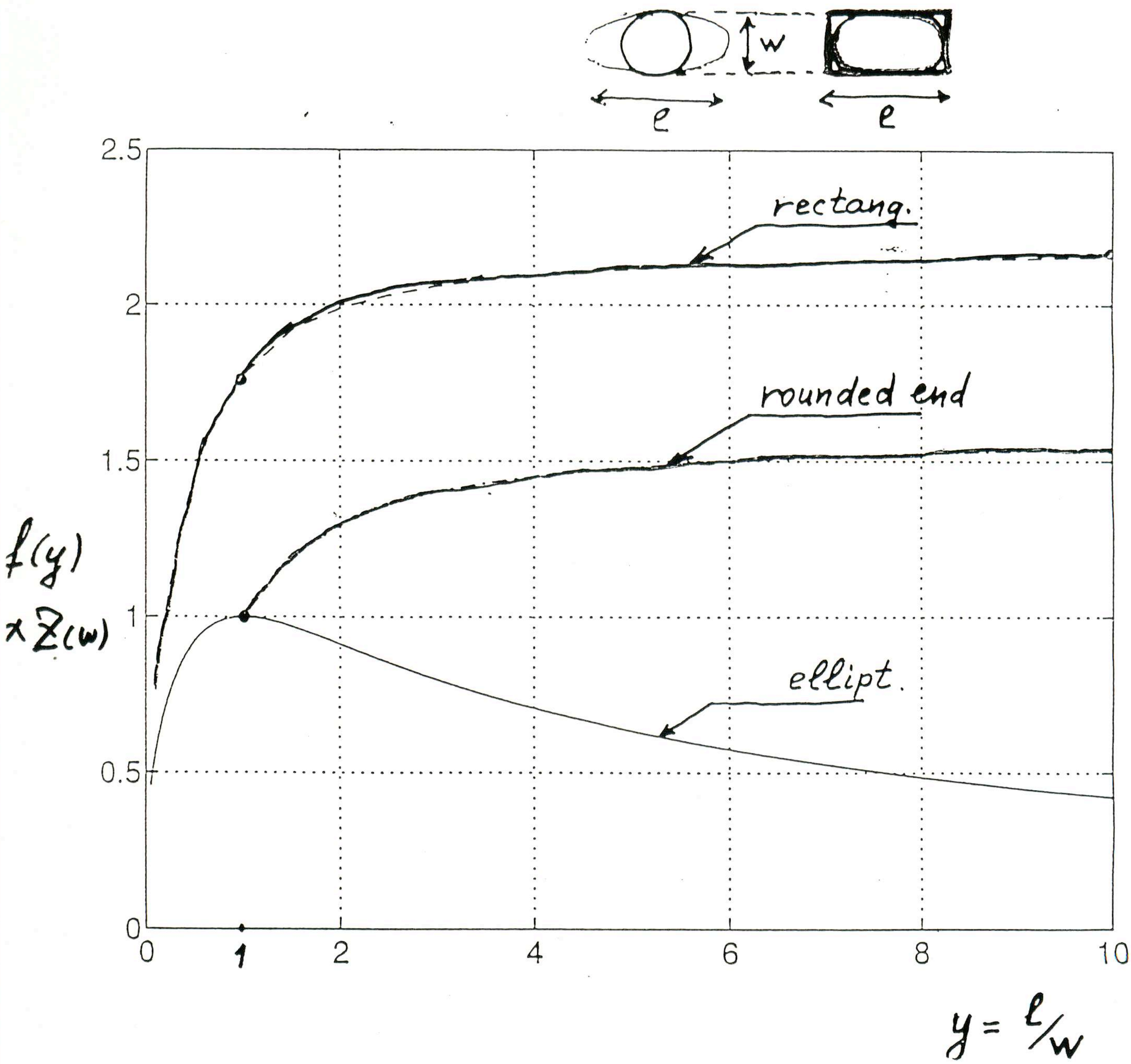
↓

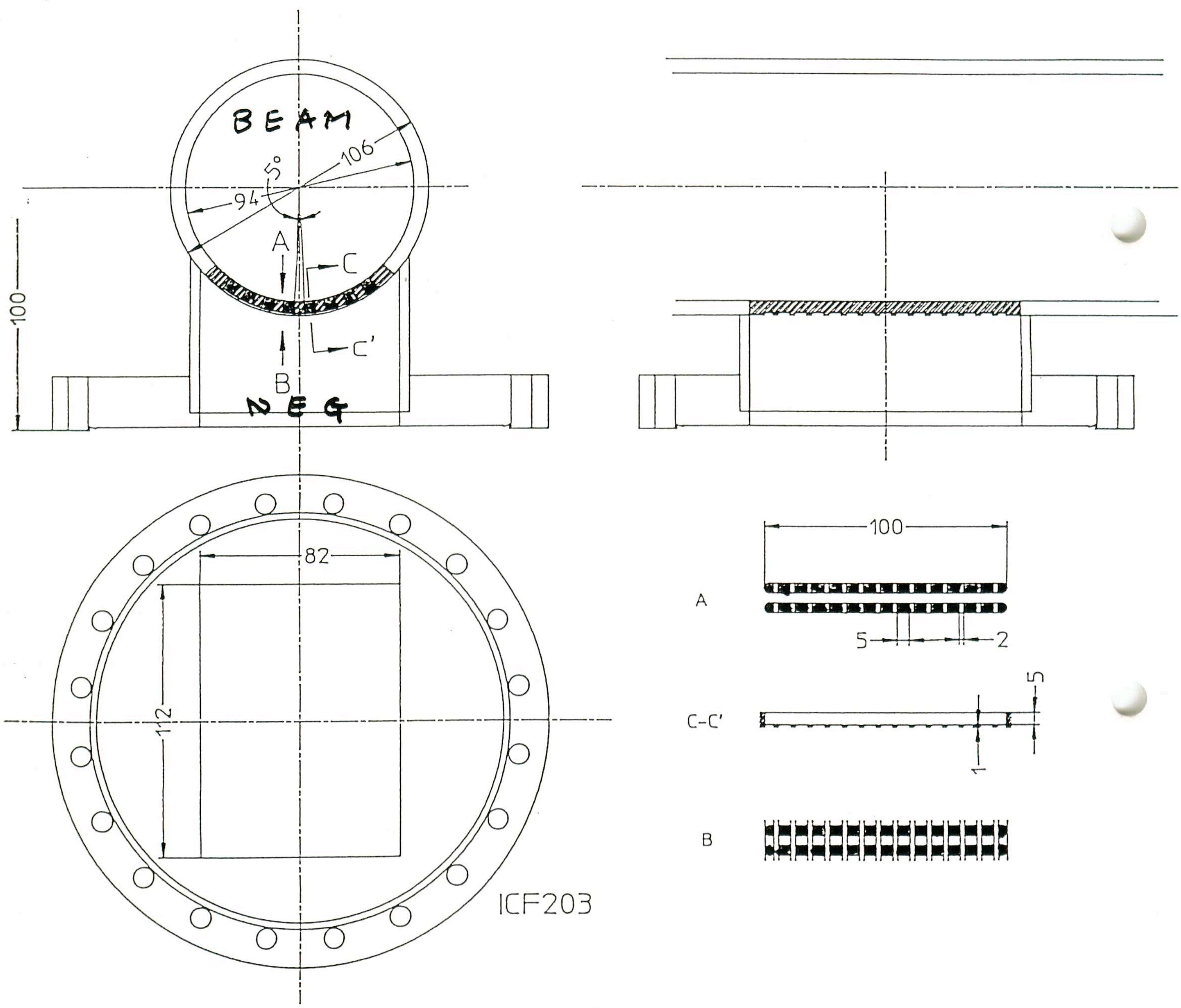
Hidden holes or grooved holes
(a long slot patched with a rectangular grid from the pumping chamber side to prevent the μ-power to leak out)

sℓ

$t = 0$

$$f(y) = \frac{Z(y)}{Z_{circ.}} \quad , \quad w \text{ is fixed.}$$



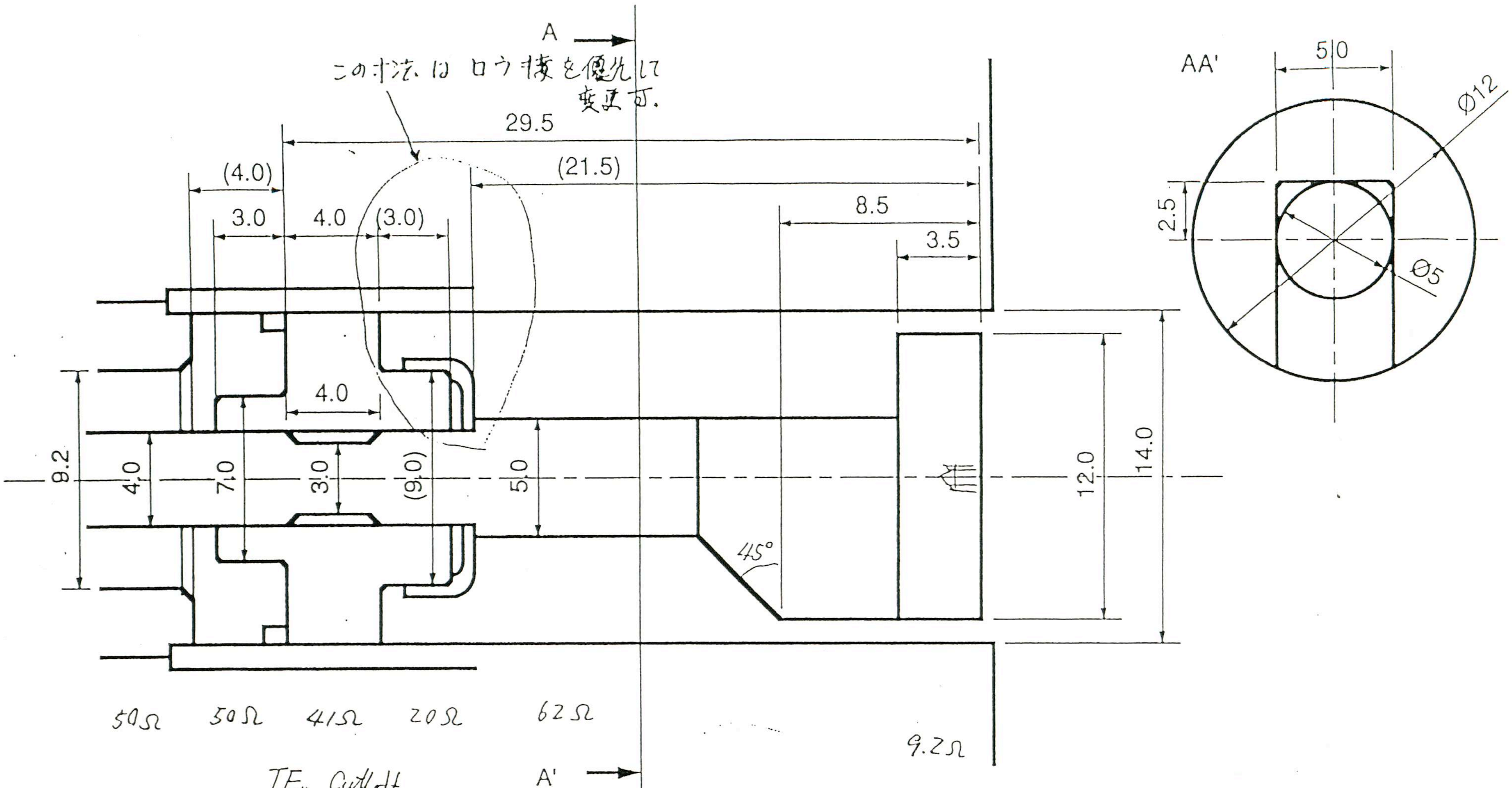

BEAM
5°
106
94
A
C
C'
B
NEG
100
82
112
ICF203
100
A
5
2
C-C'
5
1
B

3-5. BPMs

- A Shintake BPM-type has been considered (an asymmetric inner electrode structure to convert TE modes into TM modes and extract them from the coaxial cable).

- Both simulations (T3 code of MAFIA) and measurements show that the TE mode at f=7.10 GHz decays quickly by radiating its power into the beam pipe.

Q_{sim} =43 (Q_{mea}~40) ⟶ τ = 230 ms >> τ_{rad} =20 ms
R_{sim}=2.9 Ω



TE_{11} Cutoff

$\lambda_c^* \sim 37.7$ mm

TE_{110} 7.5GHz

$$k_0^2 = k_r^2 + k_z^2$$

$$= \left(\frac{2\pi}{\lambda_c}\right)^2 + \left(\frac{2\pi}{2l}\right)^2$$

$$\lambda_0^* = 7.8 \text{ mm}$$

$$f_0 = \frac{c/\sqrt{\varepsilon}}{\lambda_0} = 12. \text{[illegible]}$$

N型電極
修正案

KEK:新竹
Jan. 30. 1995

MAFIA	FRAME: 8	07/03/95 - 09:27:43	VERSION[V320.0]	BBPHTE.DRD
	FREQUENCY/HZ	7.29781923531O6E+09		3D MODEL OF BPM FOR KEKB
	MAXIMUM ERROR OF CURLCURL-E	[redacted]		
	MEAN ERROR OF CURLCURL-E	2.4000302093410E-13		
	MAXIMUM ERROR OF DIVERGENCE-D	9.8872081730166E-16		TIME HARMONIC ELECTRIC FIELD IN V/M

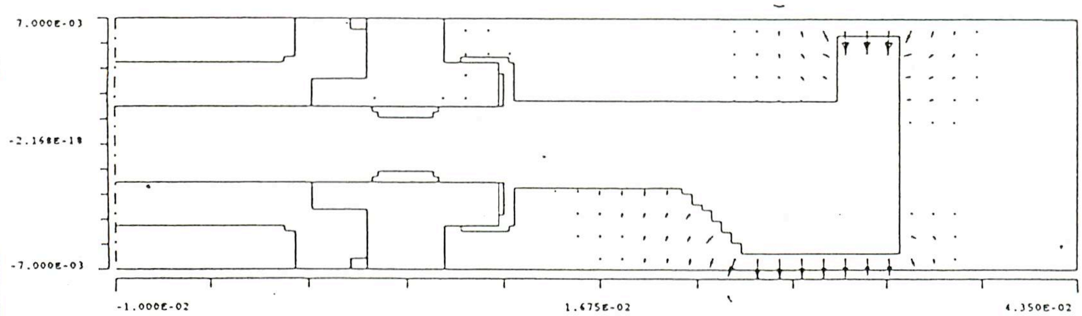
P--:3.20

D

#ARROW

COORDINATES/M
FULL RANGE / WINDOW
X[.0000, .0070000]
[.0000, .0000]
Y[-.0070000, .0070000]
[-.0070000, .0070000]
Z[-.0100000, .0435000]
[-.0100000, .0435000]

SYMBOL = E_5
X-MESHLINE: 1
CUT AT X/M: .00000E+00
INTERPOLATE.= 1
LOGSCALE....= .00000E+0
MAX ARROW = 4537.0



Y
-X
Z

MAFIA	FRAME: 9	07/03/95 - 09:27:43	VERSION[V320.0]	BBPHTE.DRD
	FREQUENCY/HZ	7.8852640804942E+09		3D MODEL OF BPM FOR KEKB
	MAXIMUM ERROR OF CURLCURL-E	1.6516006439991E-11		
	MEAN ERROR OF CURLCURL-E	1.1895840306366E-12		
	MAXIMUM ERROR OF DIVERGENCE-D	7.8481452675163E-16		TIME HARMONIC ELECTRIC FIELD IN V/M

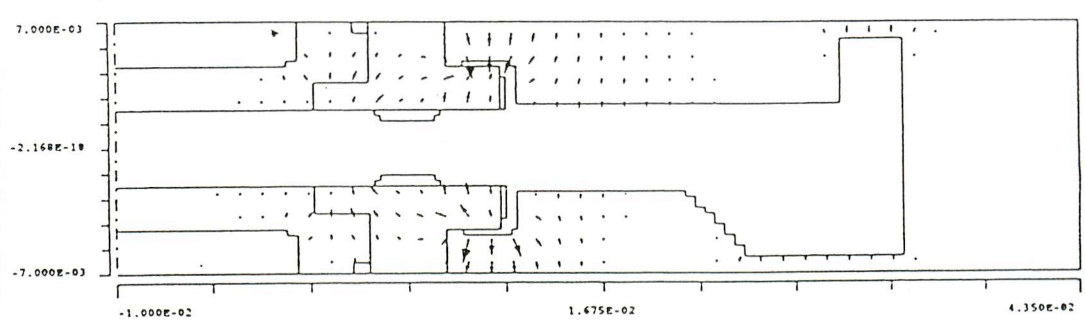
P--:3.20

D

#ARROW

COORDINATES/M
FULL RANGE / WINDOW
X[.0000, .0070000]
[.0000, .0000]
Y[-.0070000, .0070000]
[-.0070000, .0070000]
Z[-.0100000, .0435000]
[-.0100000, .0435000]

SYMBOL = E_6
X-MESHLINE: 1
CUT AT X/M: .00000E+00
INTERPOLATE.= 1
LOGSCALE....= .00000E+0
MAX ARROW = 2514.2



Y
-X
Z

6

MAFIA

FRAME: 6 01/06/95 - 14:38:28 VERSION[V320.0]

BBPM.DRD

3D MODEL OF BPM FOR KEKB LER

CUT PLOT OF THE MATERIAL DISTRIBUTION IN THE MESH

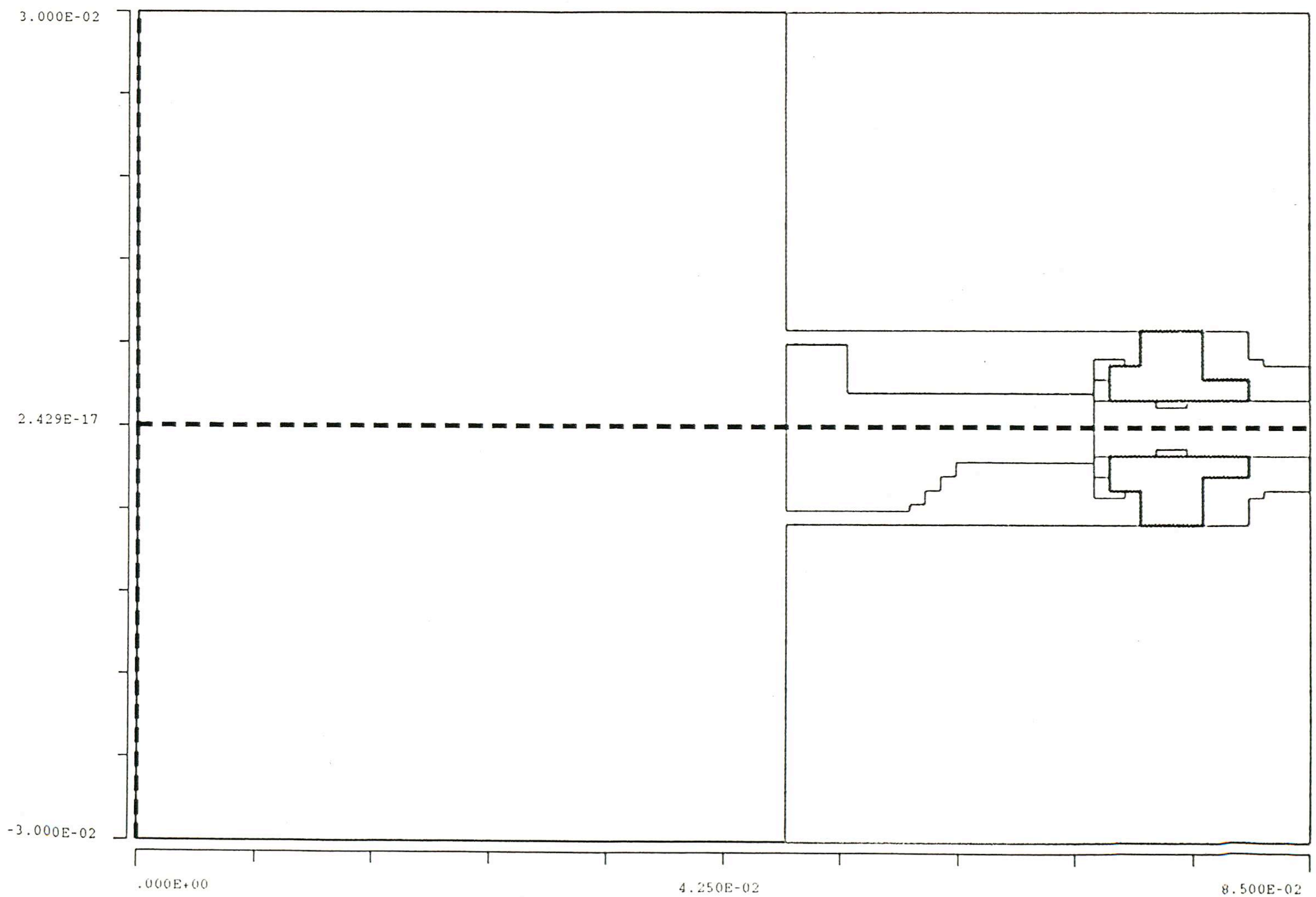
#2DPLOT

COORDINATES/M
FULL RANGE / WINDOW

X[	.0000,	.085000]
[	.0000,	.0000]
Y[	.0000,	.085000]
[	.0000,	.085000]
Z[	-.030000,	.030000]
[	-.030000,	.030000]

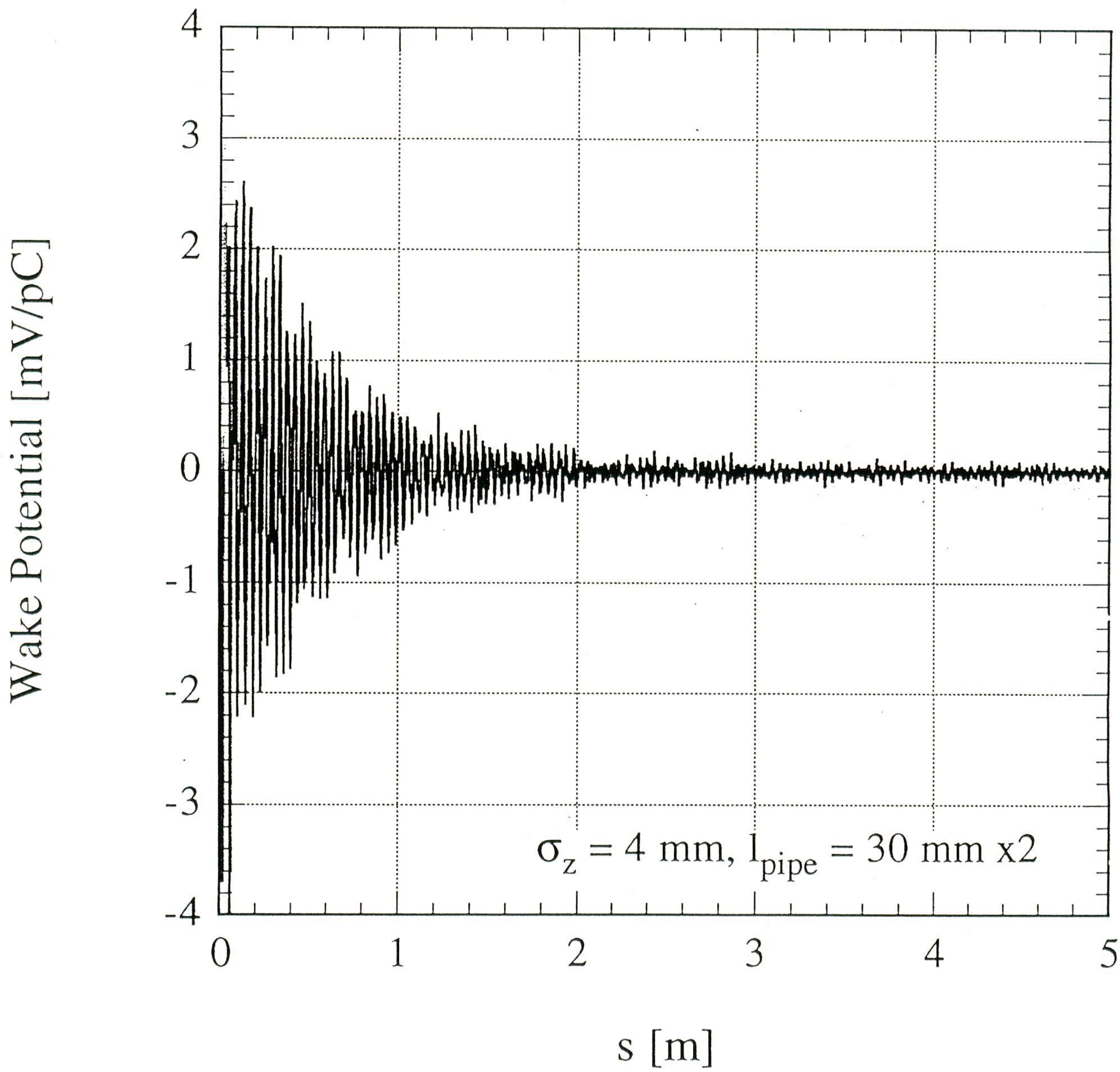
MATERIALS: 0,

X-MESHLINE= 1
CUT AT X/M= .0000E+00
Y,Z-CUT

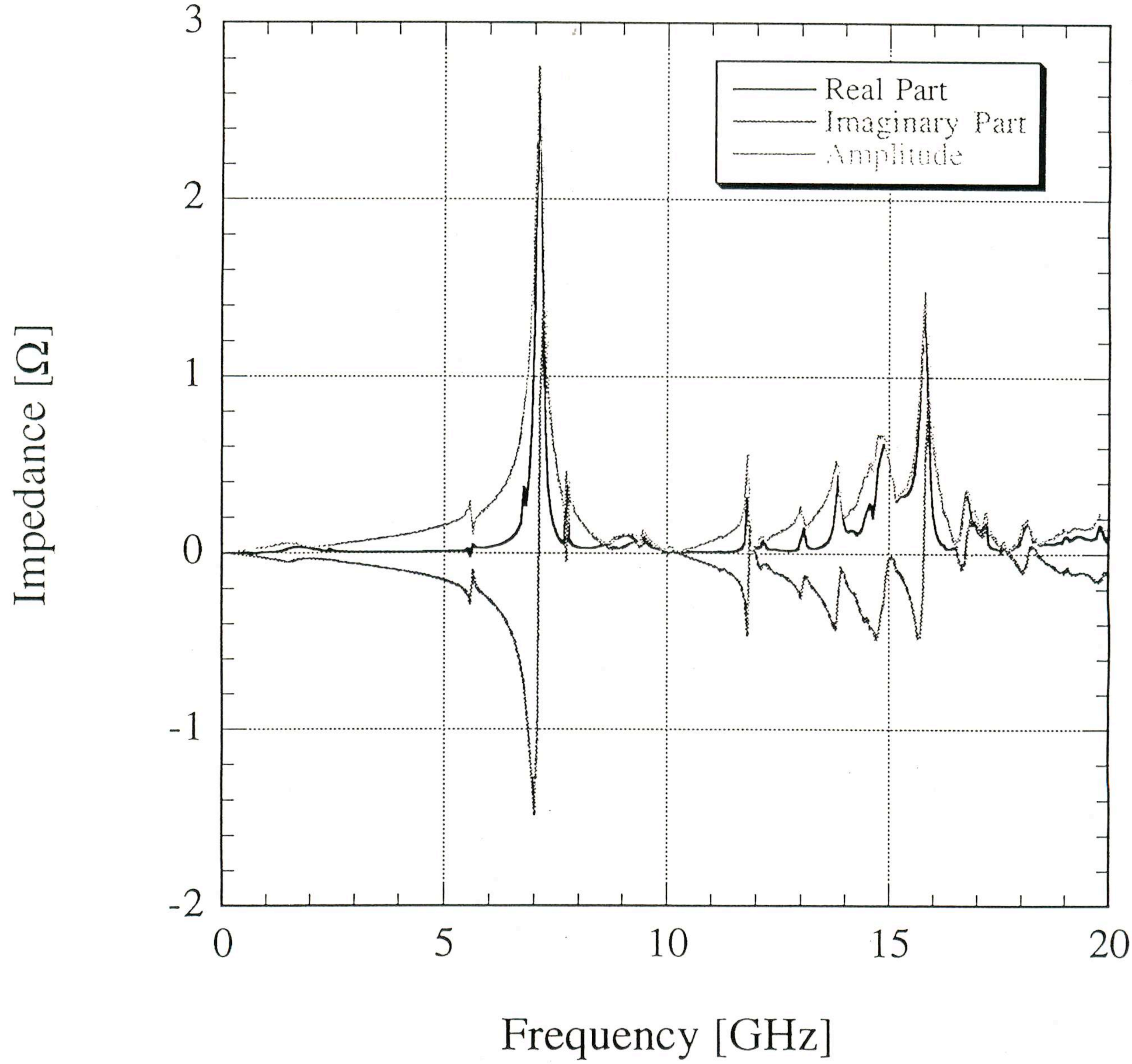


Z
Y

Wake Potential for KEKB BPM (LER)



Longitudinal Impedance of KEKB BPM



Impedance for LER of KEKB BPM

Tow large peaks below 2GHz

f [GHz]	f/f_{rf}	Rs [Ω]	Q
7.10	13.96	2.9	43
15.80	31.04	<1.36	<82

If only one mode exists, growth time of longitudinal coupled bunch instability will be

230 ms (m=4621)	for 7.10 GHz
>250 ms (m=579)	for 15.80 GHz

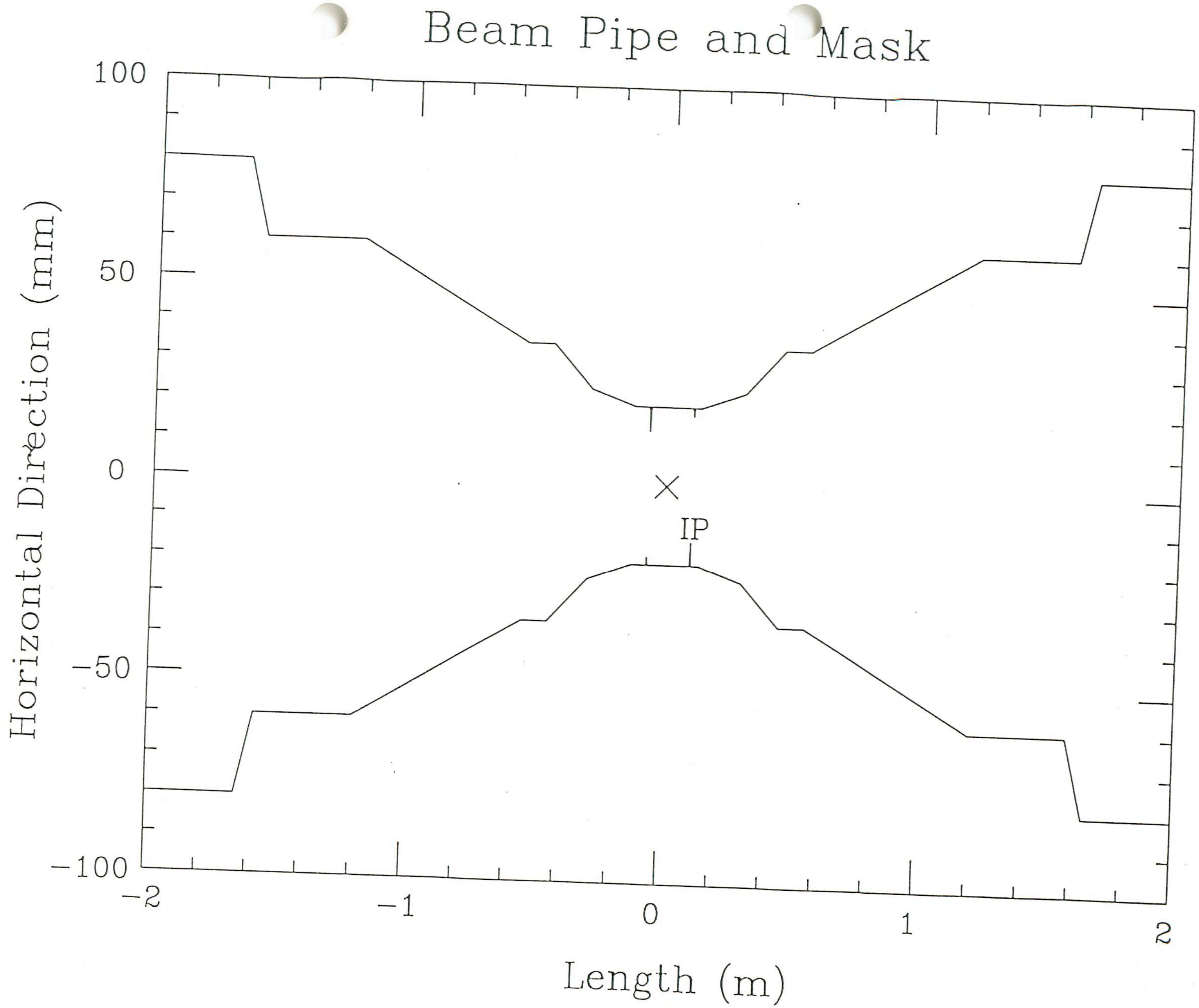
for 400 BPMs.

3-6. Trapped Modes and Power Loss in Be Chamber

- Two cutoff frequencies f_c:
  - f_c = 6.36 GHz at b=20 mm
  - f_c = 8.20 GHz at b=14 mm
- The power loss between these two frequencies was found to be (from MASK30)

  0.0084 V/pC x (2.6+1.1) A x (5.23+2.22) nC = 240 W

  > Be chamber tolerance=200W
- Are all of these modes really trapped ?

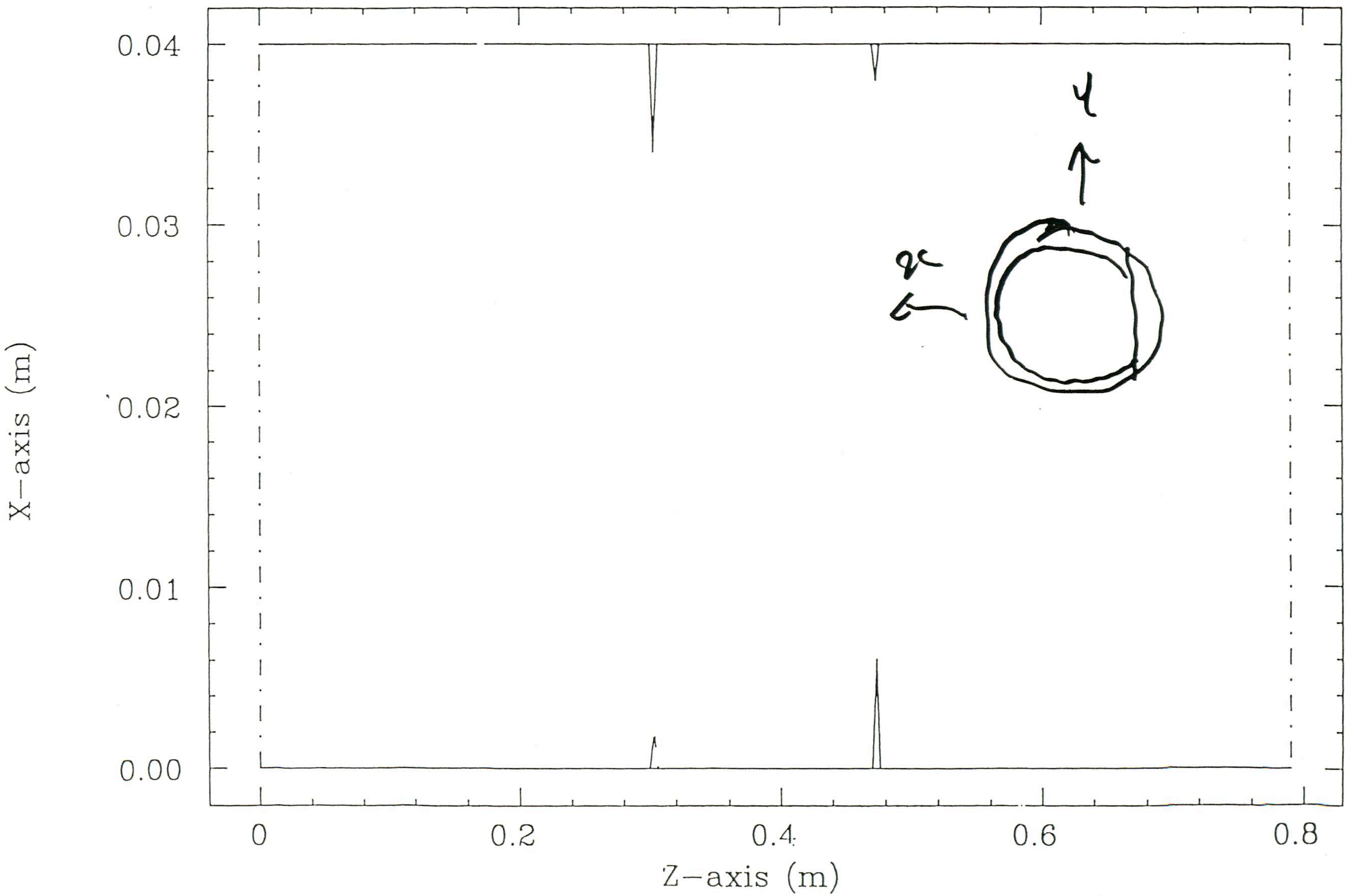


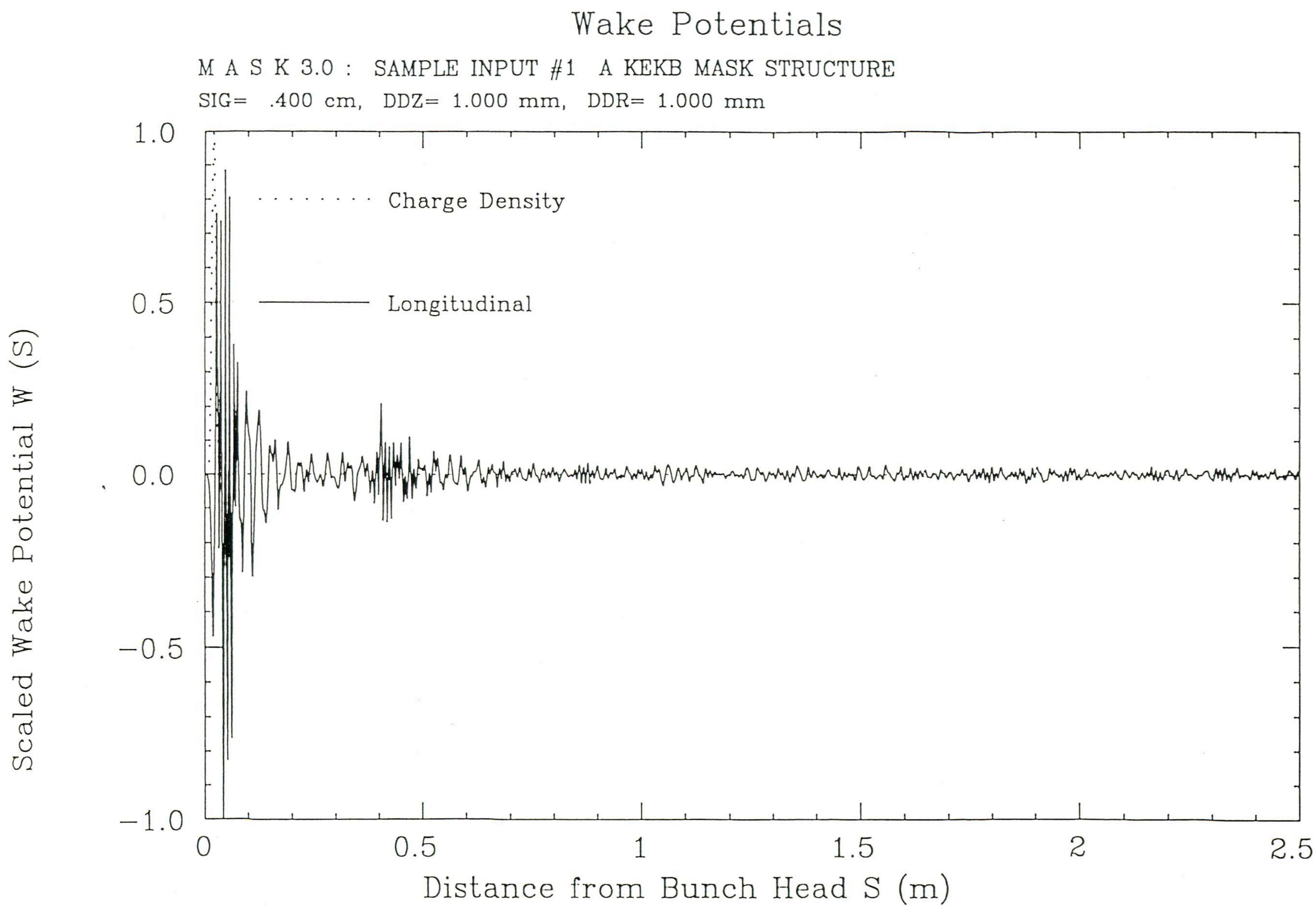
Beam Pipe and Mask
100
50
0
−50
−100
Horizontal Direction (mm)
IP
−2
−1
0
1
2
Length (m)

Cavity Shape Input

M A S K 3.0 : SAMPLE INPUT #1 A KEKB MASK STRUCTURE

DDZ= 1.0^0 m, DDR= 1.000 mm





Horizontal Wake	Min/Max= −4.887E−02/ 4.353E−02 V/pC ,	Loss Factor= 6.624E−03 V/pC
Vertical Wake	Min/Max= −8.003E−03/ 4.895E−03 V/pC ,	Loss Factor= −4.865E−03 V/pC
Longitudinal Wake	Min/Max= −4.479E−01/ 3.966E−01 V/pC,	Loss Factor= −7.976E−02 V/pC

- Modes can escape to the outside if the chamber sizes on both sides of IP masks are equal.

- Q-value due to the finite conductivity of Be chamber:

$$Q_{loss} \sim 2b/d = 1.4 \times 10^4$$

- If Q-values of escaping modes are much smaller than this, they go away before leaving a significant power in the Be chamber.

- The wake potential for the axis-symmetrical model was computed by ABCI up to 10 meter.
- If modes are trapped, their Q-values are determined by this artificial truncation of the wake potential:

  ~ 250 oscillation $\longrightarrow$ Q ~ 800
- It was found that their actual Q-values are much smaller:

  $Q_{max} \leqq 70 \longrightarrow$ Only 0.5 % of power loss goes to the Be chamber ($P_{loss} \leqq 1.2W$)
- The maximum enhancement factor due to resonance with the bunch spacing:

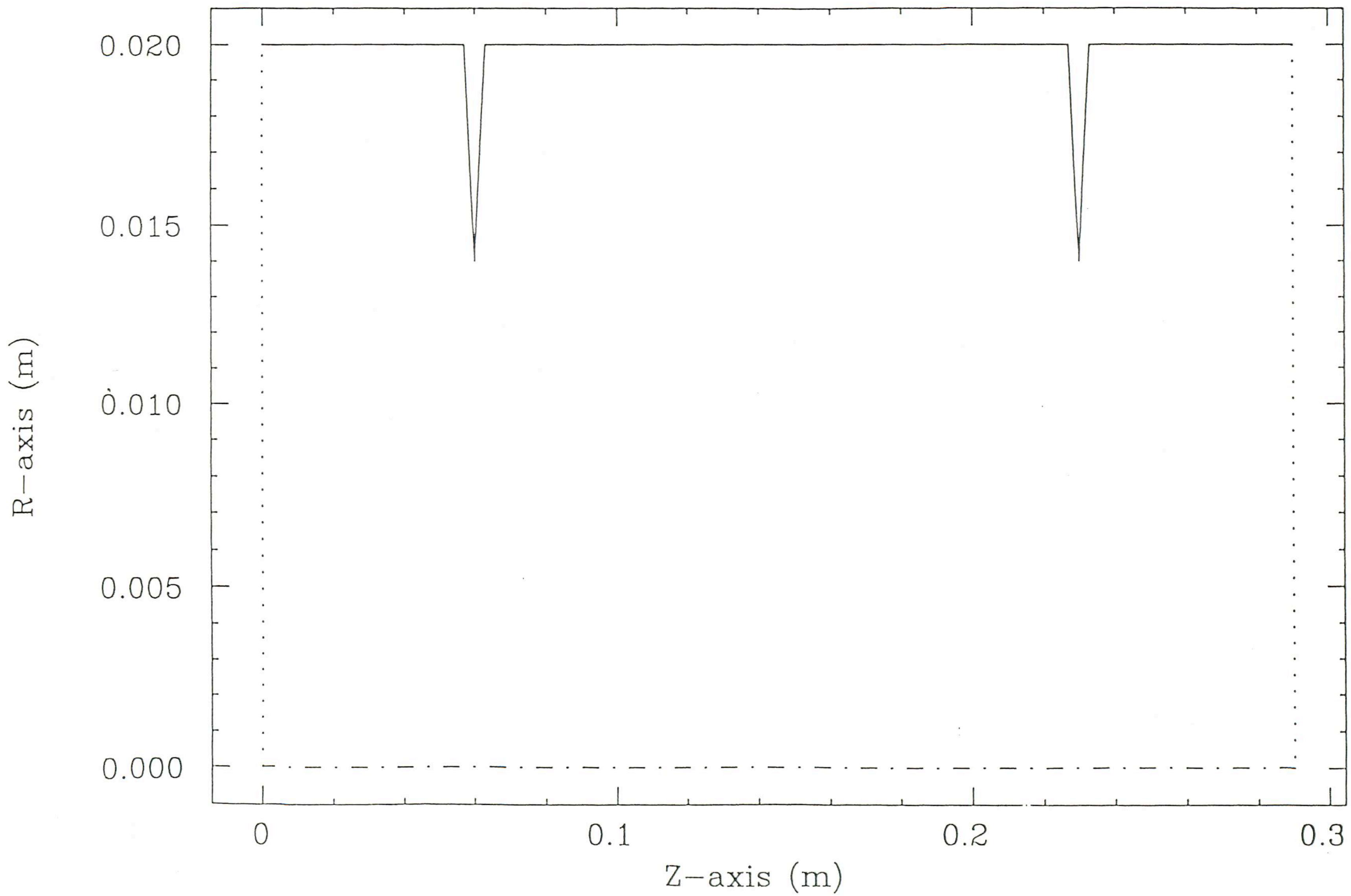
  $D_{max} = 4Q_{max} c/w_m s_b \sim 3.5 \longrightarrow D_{max} P_{loss} \leqq 4.2W$

Cavity Shape Input

05/06/95 03.34.33

A B C I 9.2 : AN AXIS-SYMMETRICAL MODEL FOR KEKB MASK AT IP

DDZ= 0.500 mm, DDR= 0.500 mm

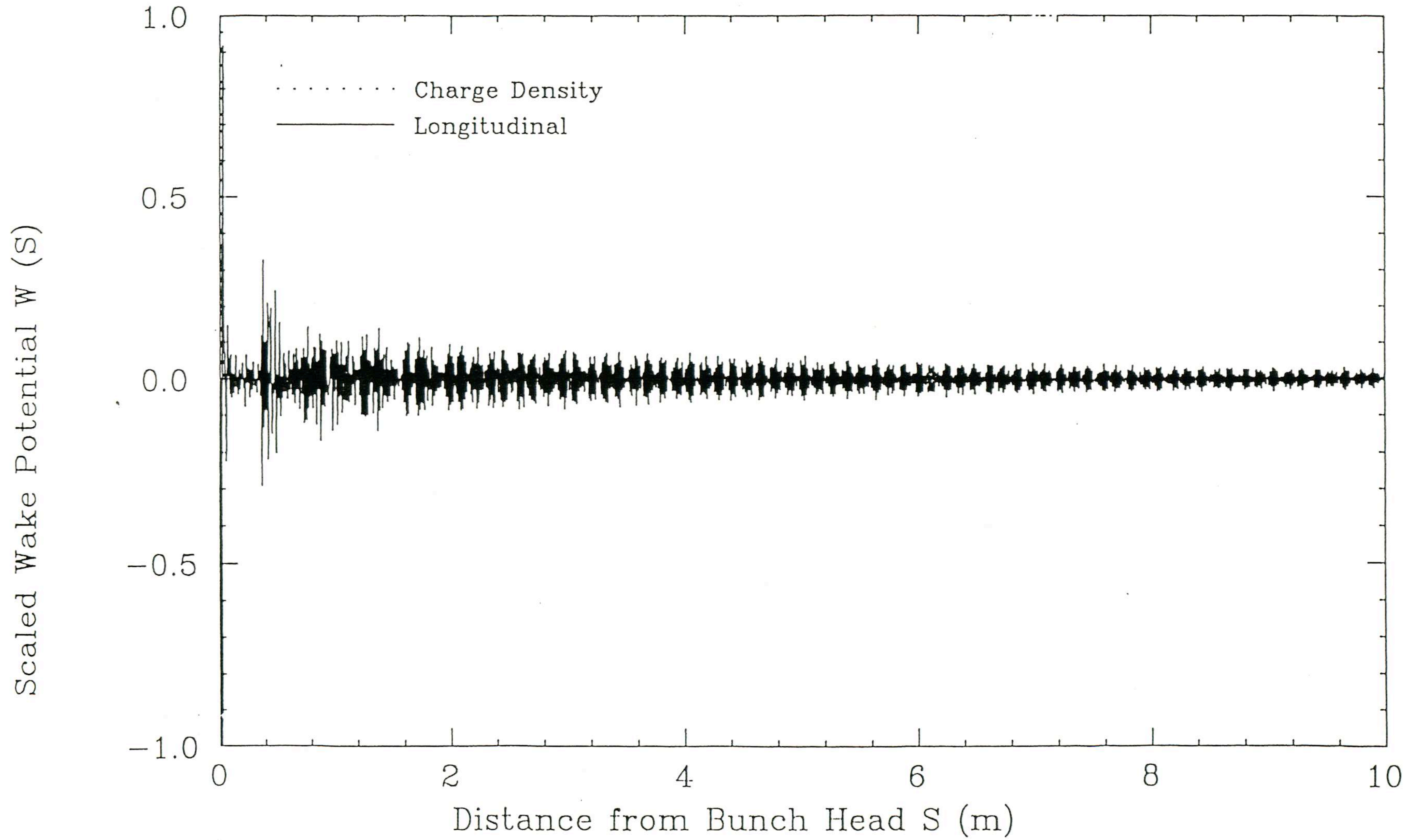


Cpu Time Used: 3.060E+03(s)
05/06/95 18.43.13

Wake Potentials

A B C I 9.2 : AN AXIS-SYMMETRICAL MODEL FOR KEKB MASK AT IP

MROT= 0, SIG= 0.400 cm, DDZ= 0.500 mm, DDR= 0.500 mm



Longitudinal Wake Min/Max= −1.309E+00/ 1.201E+00 V/pC, Loss Factor= −4.680E−01 V/pC

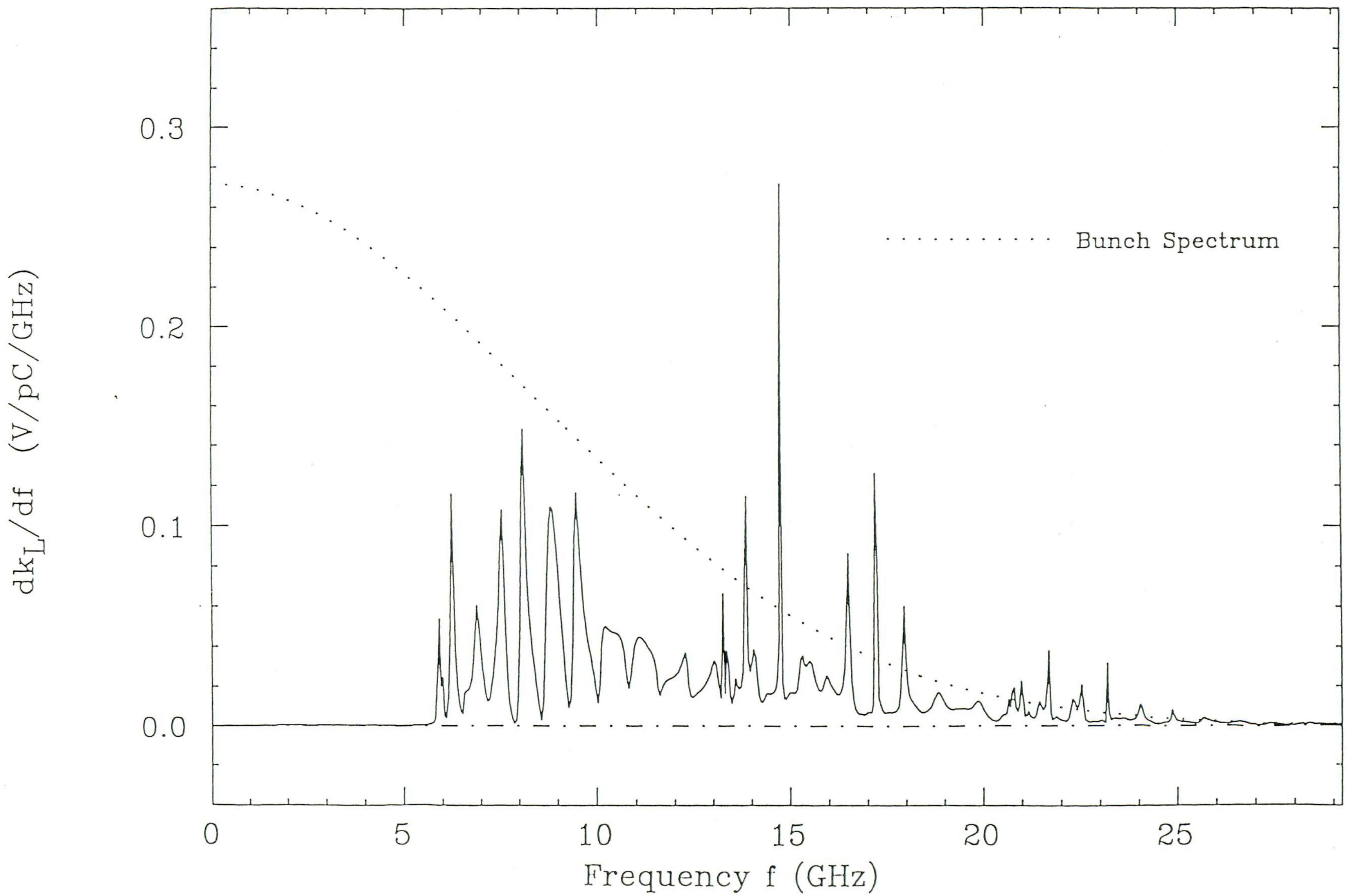
$Z_{max} = 10m$

Frequency Spectrum of Loss Factor

05/06/95 03.34.33

A B C I 9.2 : AN AXIS-SYMMETRICAL MODEL FOR KEKB MASK AT IP

MROT= 0, SIG= 0.400 cm, DDZ= 0.500 mm, DDR= 0.500 mm



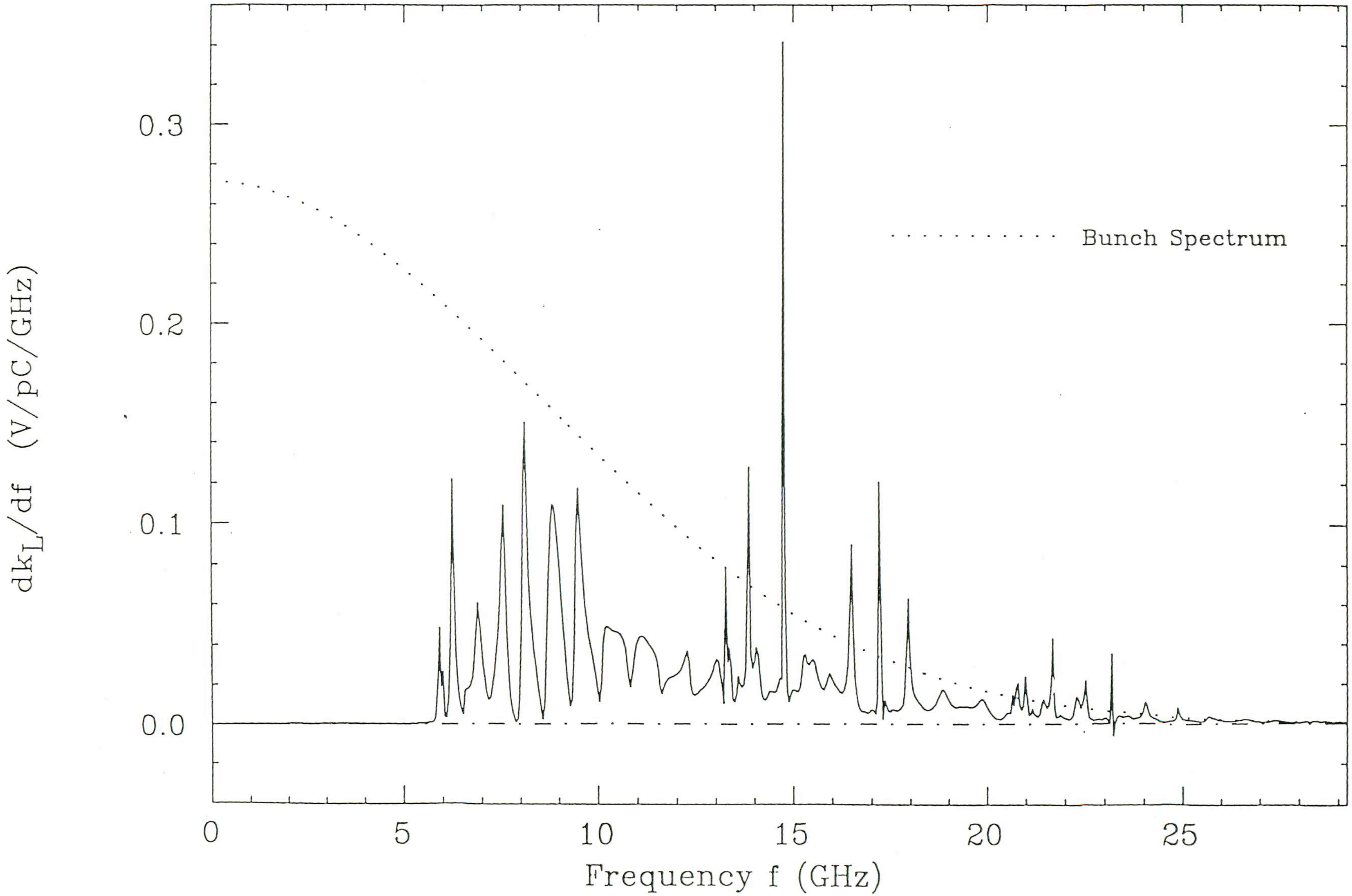
$Z_{max} = 20m$

Frequency Spectrum of Loss Factor

05/06/95 03.34.33

A B C I 9.2 : AN AXIS-SYMMETRICAL MODEL FOR KEKB MASK AT IP

MROT= 0, SIG= 0.400 cm, DDZ= 0.500 mm, DDR= 0.500 mm



3-7. IR Chamber + Recombination Chambers

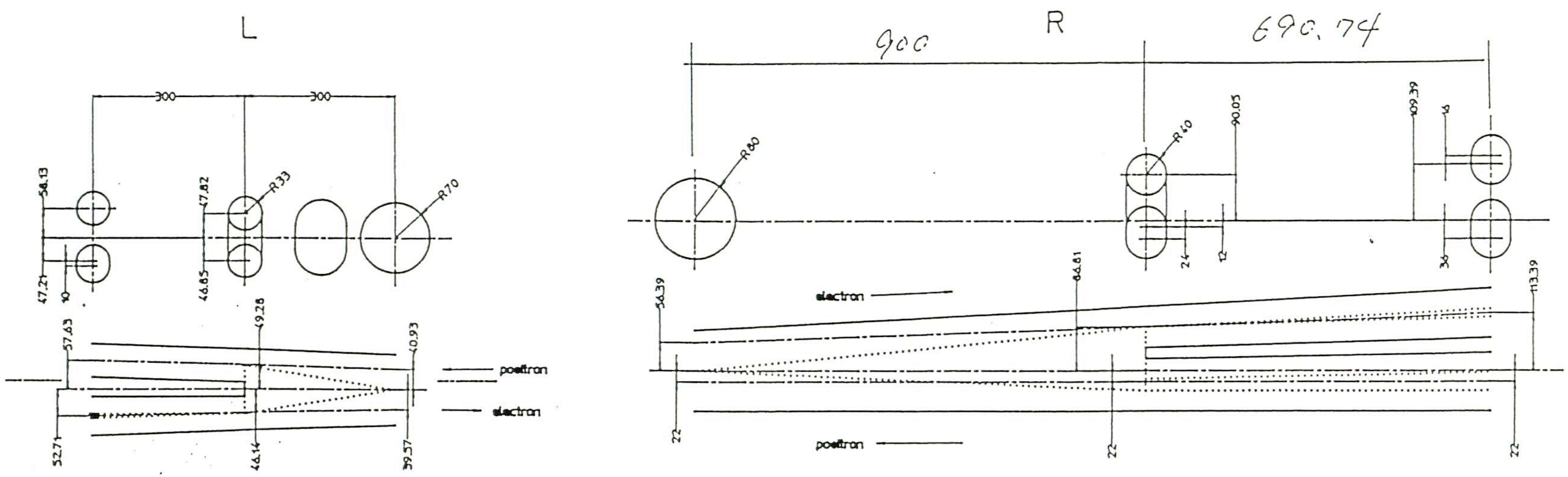
- IR chamber produces (ABCI)

  HOM power loss ~ 3 kW

- Two y-shaped recombination chambers on both sides of IP (3 m away) produce (ABCI)

  HOM power loss ~ 16 kW

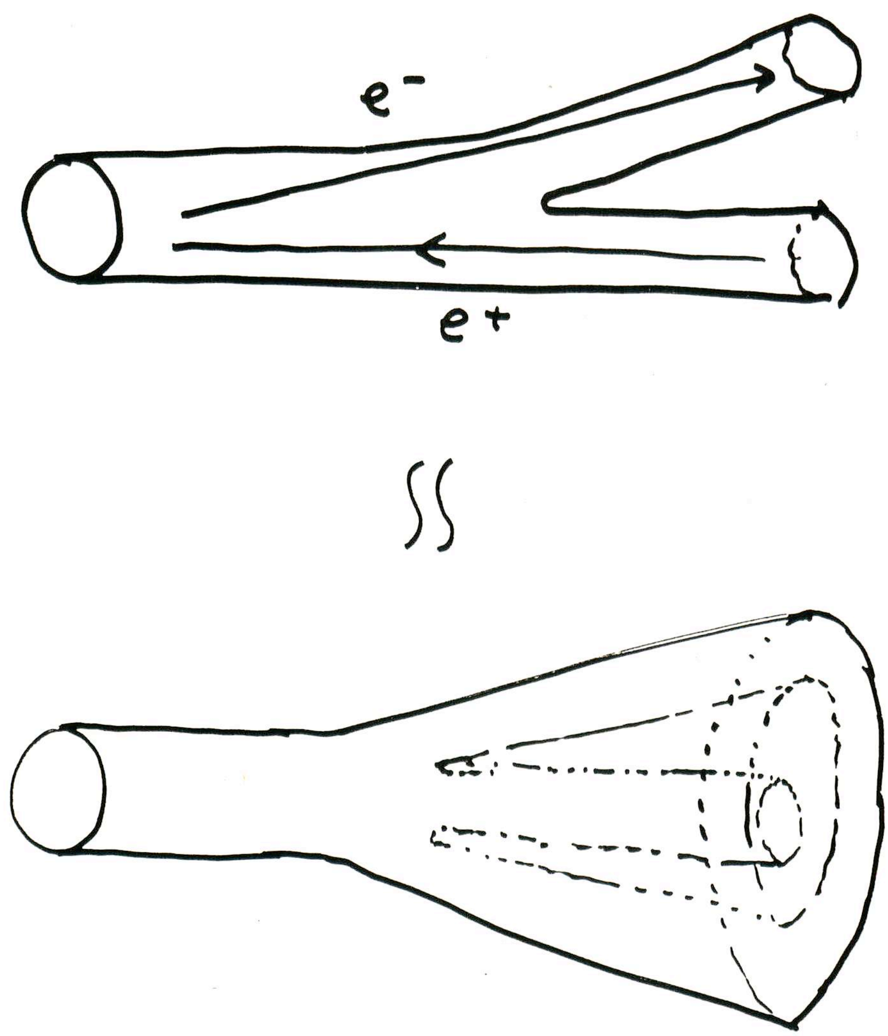
- These power must be taken care, e.g., by putting an absorber in the chamber.



L
300
300
58.13
47.21
10
47.82
46.85
R33
R70
57.63
52.71
49.28
46.14
40.93
39.57
positron
electron
R
900
690.74
R80
R40
90.05
109.39
16
24
12
36
56.39
86.81
113.39
22
22
22

金澤
1/26/95

Y-shaped junction at IR :



$\times \frac{1}{4} \sim \frac{1}{2}$

↑

最悪の
caseとして
この比を使う

$K_L = -\ 1.6\ V/pC \quad \times \frac{1}{2} \quad \times 2$

(見込み角) (左右)

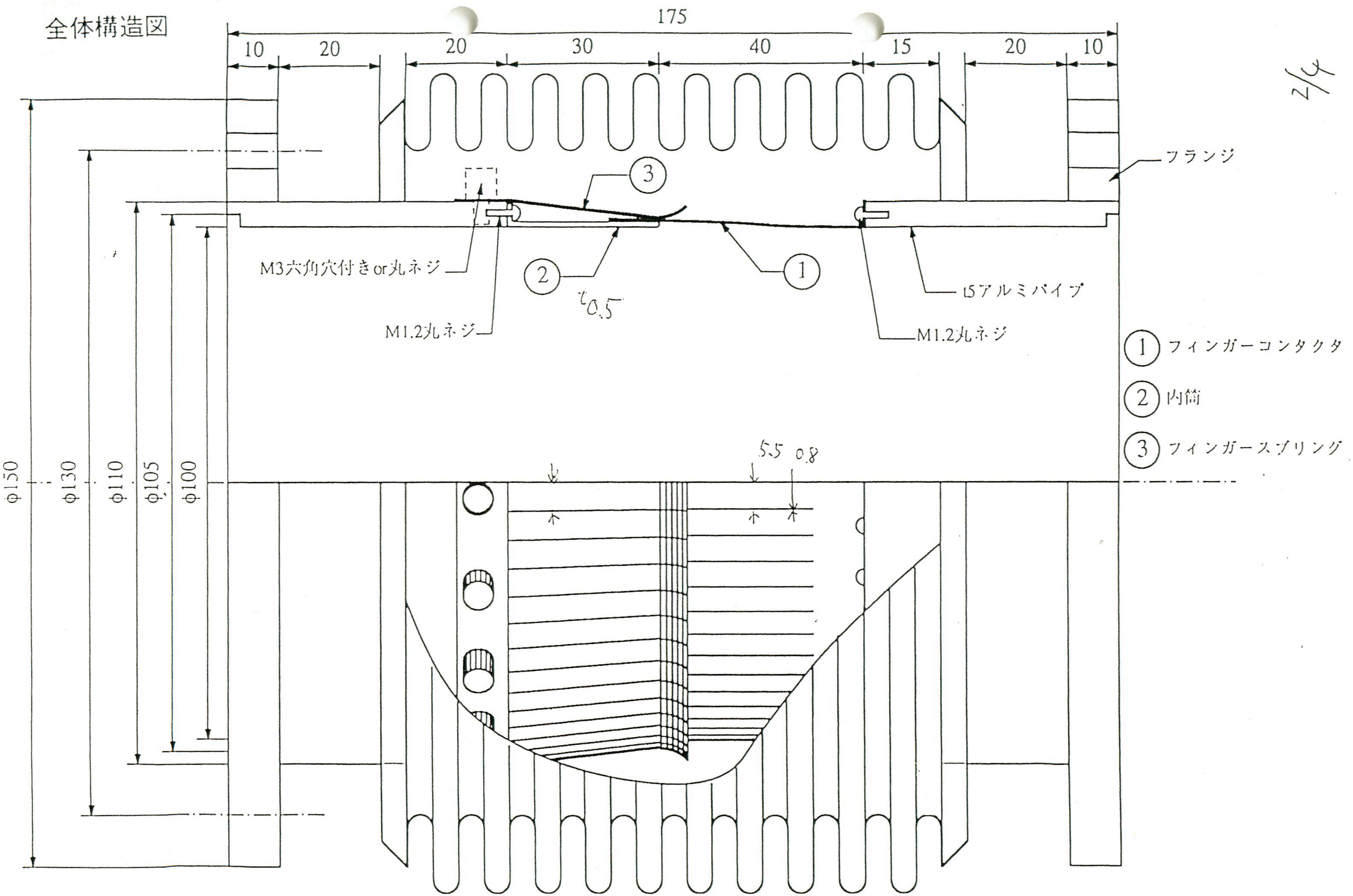
(ARES 2個分ぐらいの発熱)

3-8. Bellows

- Sliding finger structure type employed.

  - k_L = 2.5 V/pC for 1000 bellows in LER
  - k_L = 5.0 V/pC for 1000 bellows in HER

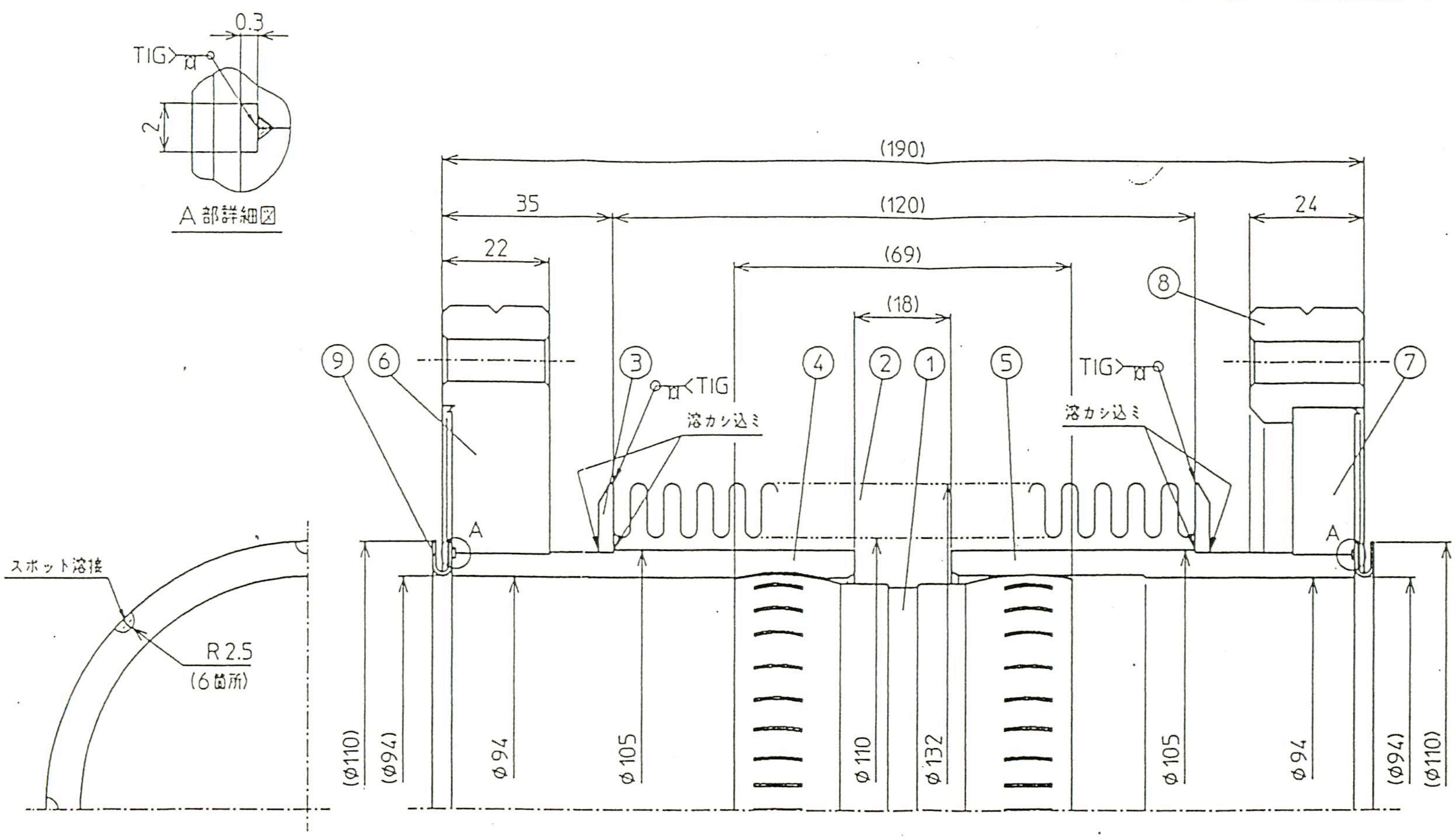
全体構造図



175
10
20
20
30
40
15
20
10
フランジ
t5アルミパイプ
M1.2丸ネジ
M3六角穴付きor丸ネジ
M1.2丸ネジ
t0.5
5.5
0.8
φ150
φ130
φ110
φ105
φ100
① フィンガーコンタクタ
② 内筒
③ フィンガースプリング

CODE(DRAWING)NO. WD-0016805|00001

試作検討用図



NO.	PART NAME		QTY
9	RING		2
SUS316L			
8	RECEIVE FLANGE		1
SUS316L		ICF 954-5140	
7	INSERT FLANGE		1
SUS316L		ICF 954-7064	
6	FLANGE		1
SUS316L		ICF 954-7054	
5	PIPE		1
SUS316L			
4	PIPE		1
SUS316L			
3	END FITTING		2
SUS316L			
2	BELLOWS CRE		1
SUS316L			
1	TUBE SEAL		1
INC 718			
MATERIAL		CODE	

SCALE	DRAWN	APP.
NONE	Y. Iguso	Sakamoto
DATE. 94.7.18		CH'KD H. Suzuki

OPTIONAL CODE

OPERATING CONDITIONS

FLUID (流体)	INSIDE (内側)	—	OUTSIDE (外側)	—	
PRESS. (圧力)	INSIDE (内側)	—	OUTSIDE (外側)	—	
TEMP. (温度)	— °C	SPRING RATE (バネ定数)	AXIAL (軸方向)	(—)	N/mm kg/mm
LIFE (寿命)	1X10^5 cycles		RADIAL (軸直角方向)	(—)	N/mm kg/mm
OFFSET (変位量)	AXIAL (軸方向) ±10 mm		ANGULER (曲げ)	(—)	N/rad kg/deg
	RADIAL (軸直角方向) 2 mm	MAX.LEAK RATE (許容リーク量)		(—)	Pa·m³/s atm·cc/sec
	ANGULER (曲げ) 0 deg				

BELLOWS CORE	
INDIA.	φ 110 mm
OUTDIA.	φ 132 mm
THICKNESS	0.3 mm
CONVOLUTION	17 山

KEY.	DATE (CHANGE NO.)	BY	APP.

REVISIONS

NOTE

DRAWING INTERPRETATIONS PER JIS B 0001. THIRD ANGLE PROJECTION

EQUIPMENT

ORIGINAL PRODUCT CODE

CUSTOMER 高エネルギー物理学研究所殿

CUSTOMER CODE

USER CODE

CUSTOMER DWG.No.

ITEM	TYPE	SIZE	MAT.CODE
WF	01212	110132	F4

NAME: FORMED BELLOWS

CODE(DRAWING)NO.: WD-0016805|00001 REV.

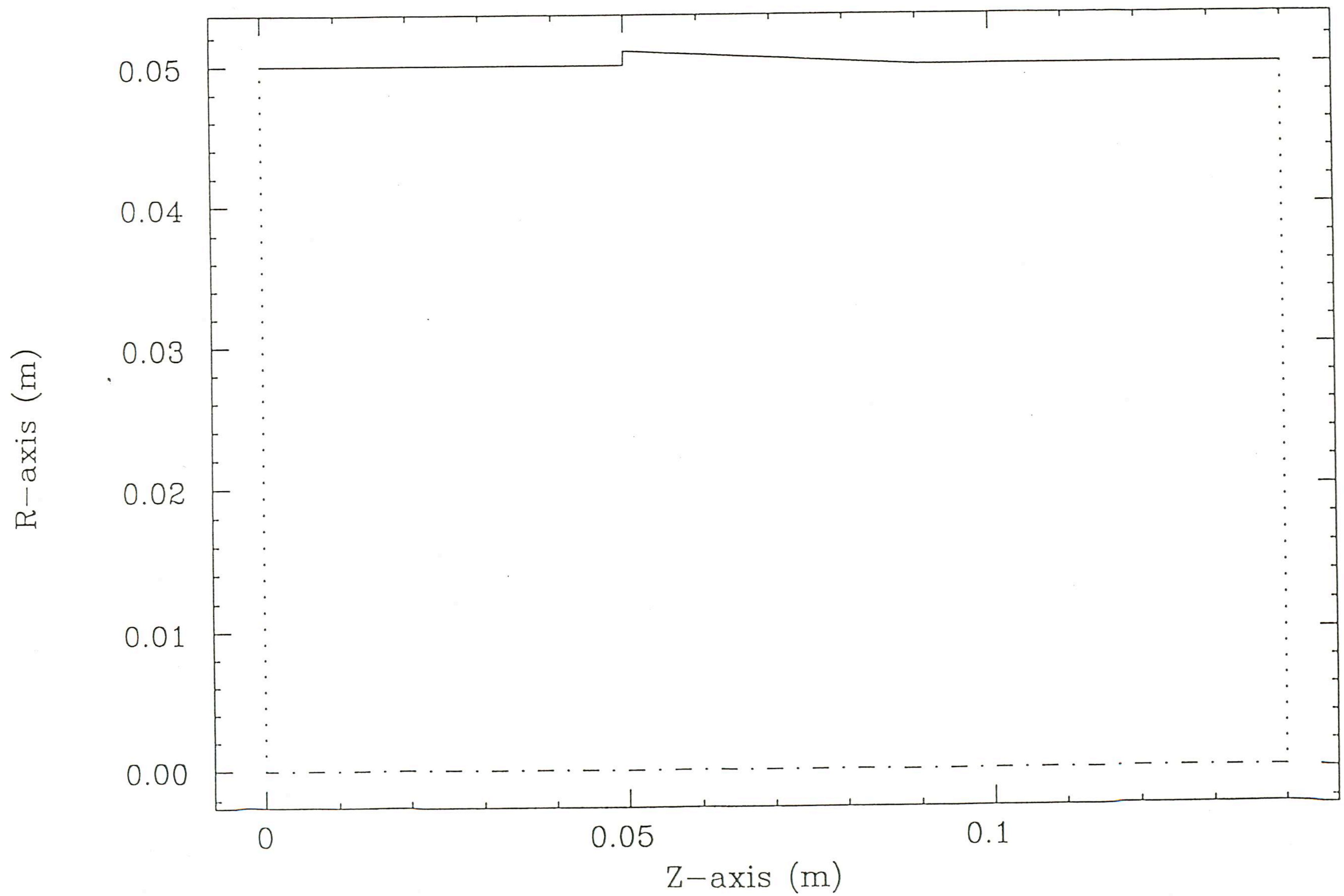
EAGLE INDUSTRY CO.,LTD.

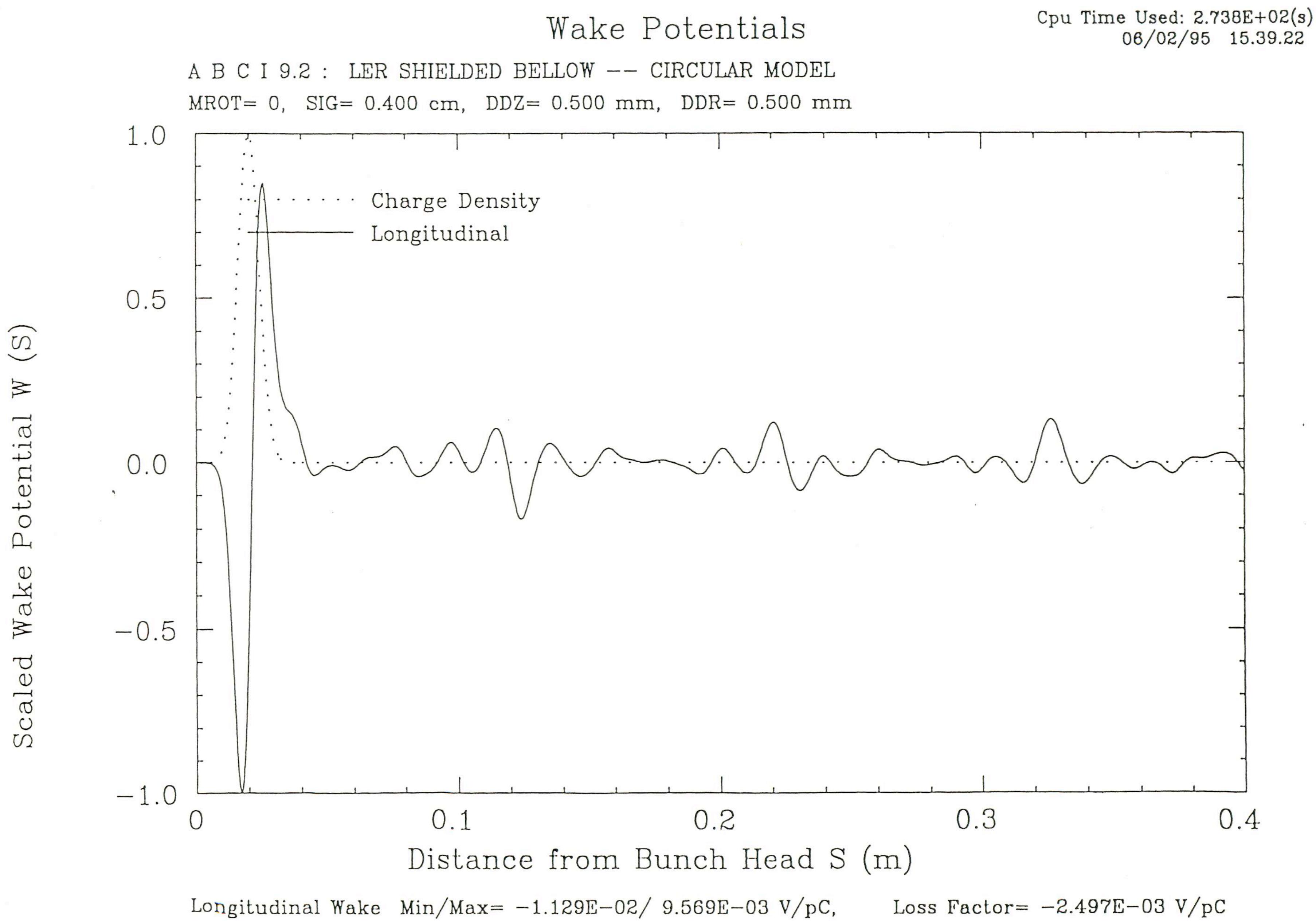
Cavity Shape Input

06/02/95 15.39.22

A B C I 9.2 : LER SHIELDED BELLOW -- CIRCULAR MODEL

DDZ= 0.500 mm, DDR= 0.500 mm





Wake Potentials
Cpu Time Used: 2.738E+02(s)
06/02/95 15.39.22
A B C I 9.2 : LER SHIELDED BELLOW -- CIRCULAR MODEL
MROT= 0, SIG= 0.400 cm, DDZ= 0.500 mm, DDR= 0.500 mm
Charge Density
Longitudinal
1.0
0.5
0.0
−0.5
−1.0
0
0.1
0.2
0.3
0.4
Scaled Wake Potential W (S)
Distance from Bunch Head S (m)
Longitudinal Wake Min/Max= −1.129E−02/ 9.569E−03 V/pC, Loss Factor= −2.497E−03 V/pC

4. Summary

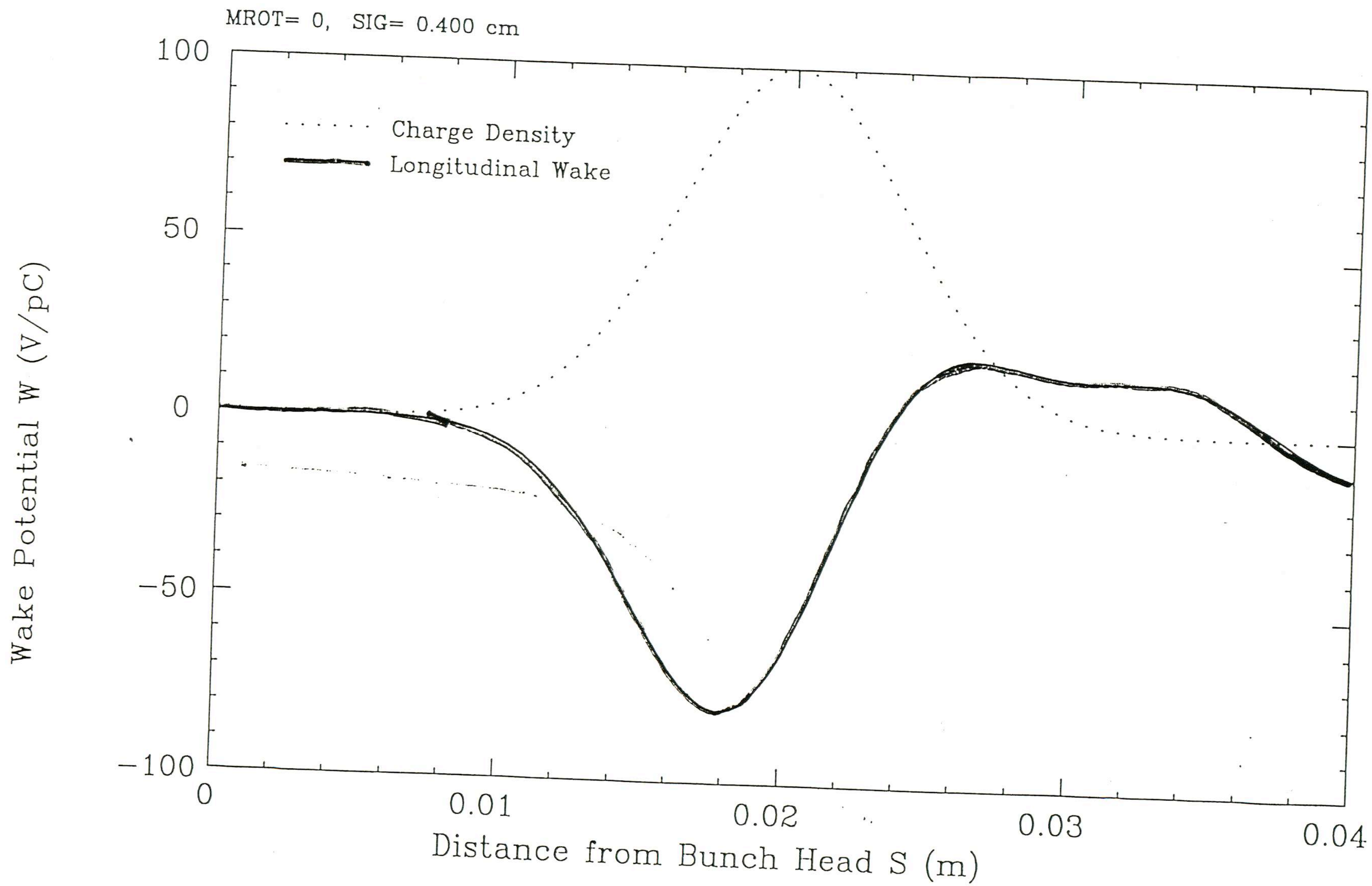
- The total inductive impedance in LER, Im(Z/n) = 0.015
- The total HOM power deposition in LER = 440 kW (300kW without tapers for ARES)
- The total HOM power deposition in HER = 120 kW (90kW without tapers for ARES)

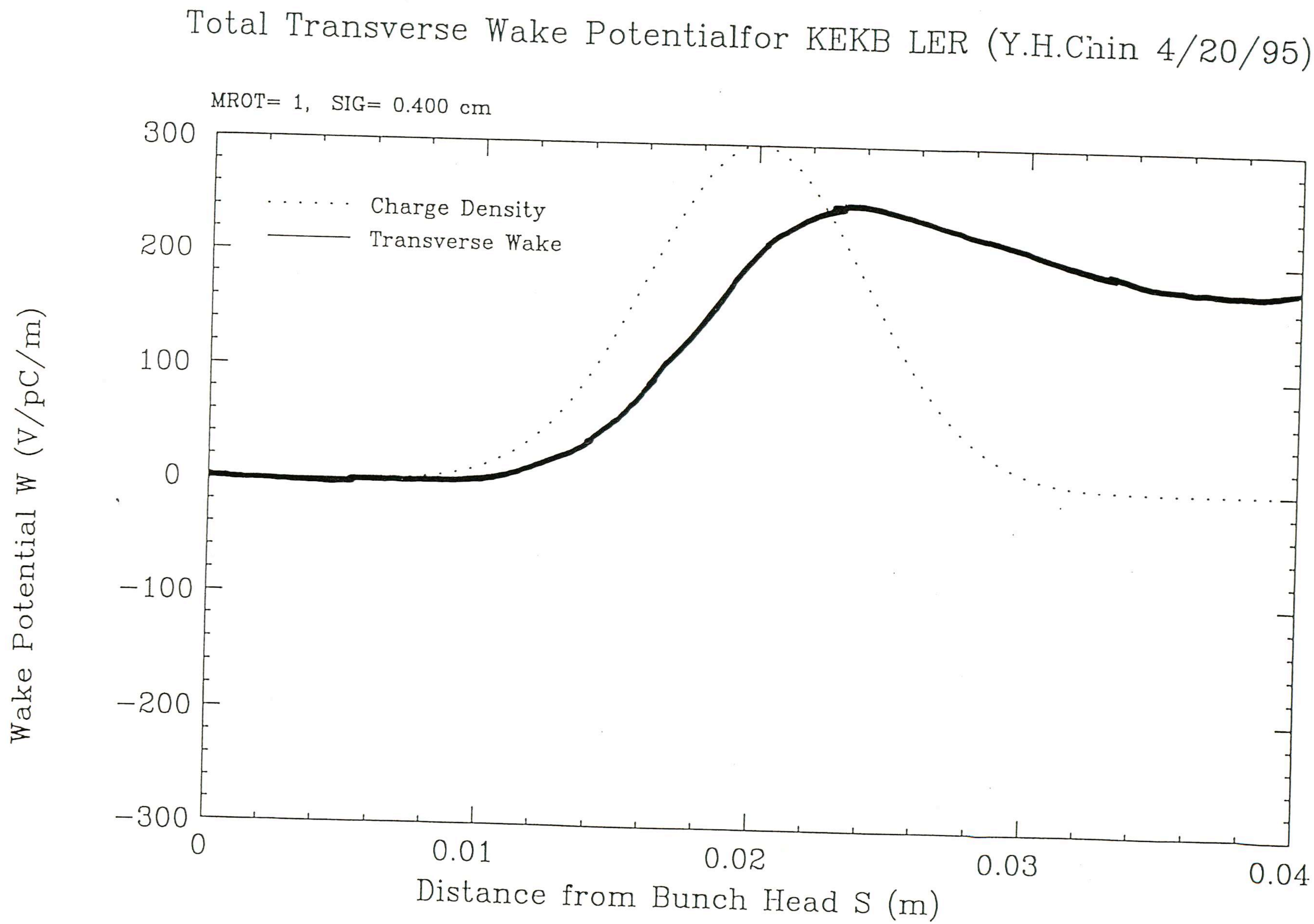
The these numbers are now used for designing RF parameters.

Impedance and HOM power loss budgets at LER (6/7/95)

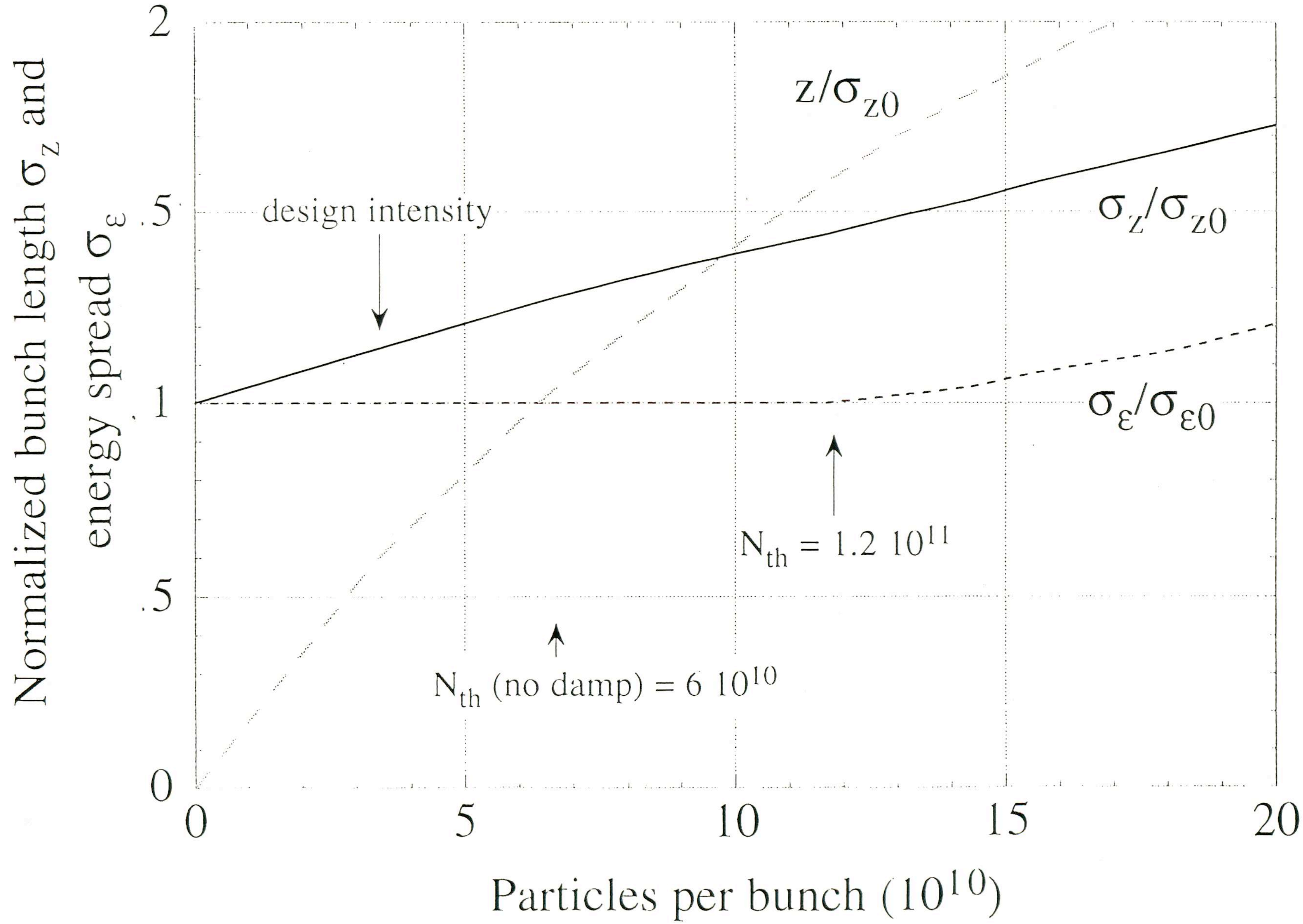
Components	Number	Inductive impedance Z/n (Ω)	Loss factor (V/pC)	HOM power (kW)
Cavities	20	--------	17.8 (10.6)	243(144)
Resistive-wall	3016m	5.2×10^{-3} at 2.3GHz	4.0	54
Masks at arc	1000(5mm)	2.8×10^{-3}	4.6	62
Pumping slots	10 x 1800	1.1×10^{-4}	0.37	5.5
BPMs	4 x 400	1.3×10^{-4}	0.79	10.7
Mask at IP	1	--------	0.08	1.1
IR chamber	1	1.0×10^{-3}	0.29	4
Y-shaped junctions	2	-8.0×10^{-4}	1.6	22
Bellows (1mm)	1000	4.23×10^{-3}	2.5	34
Total		0.015	32.1 (25.7)	440 (330)

Total Longitudinal Wake Potentialfor KEKB LER (Y.H.Chin 4/20/95)





Total Transverse Wake Potentialfor KEKB LER (Y.H.Chin 4/20/95)
MROT= 1, SIG= 0.400 cm
Charge Density
Transverse Wake
300
200
100
0
−100
−200
−300
0
0.01
0.02
0.03
0.04
Distance from Bunch Head S (m)
Wake Potential W (V/pC/m)



Normalized bunch length σz and energy spread σε
2
.5
1
.5
0
0
5
10
15
20
Particles per bunch (10^10)
z/σz0
σz/σz0
σε/σε0
design intensity
Nth = 1.2 10^11
Nth (no damp) = 6 10^10