Head-tail Instability and Microwave Instability in the KEK-PS

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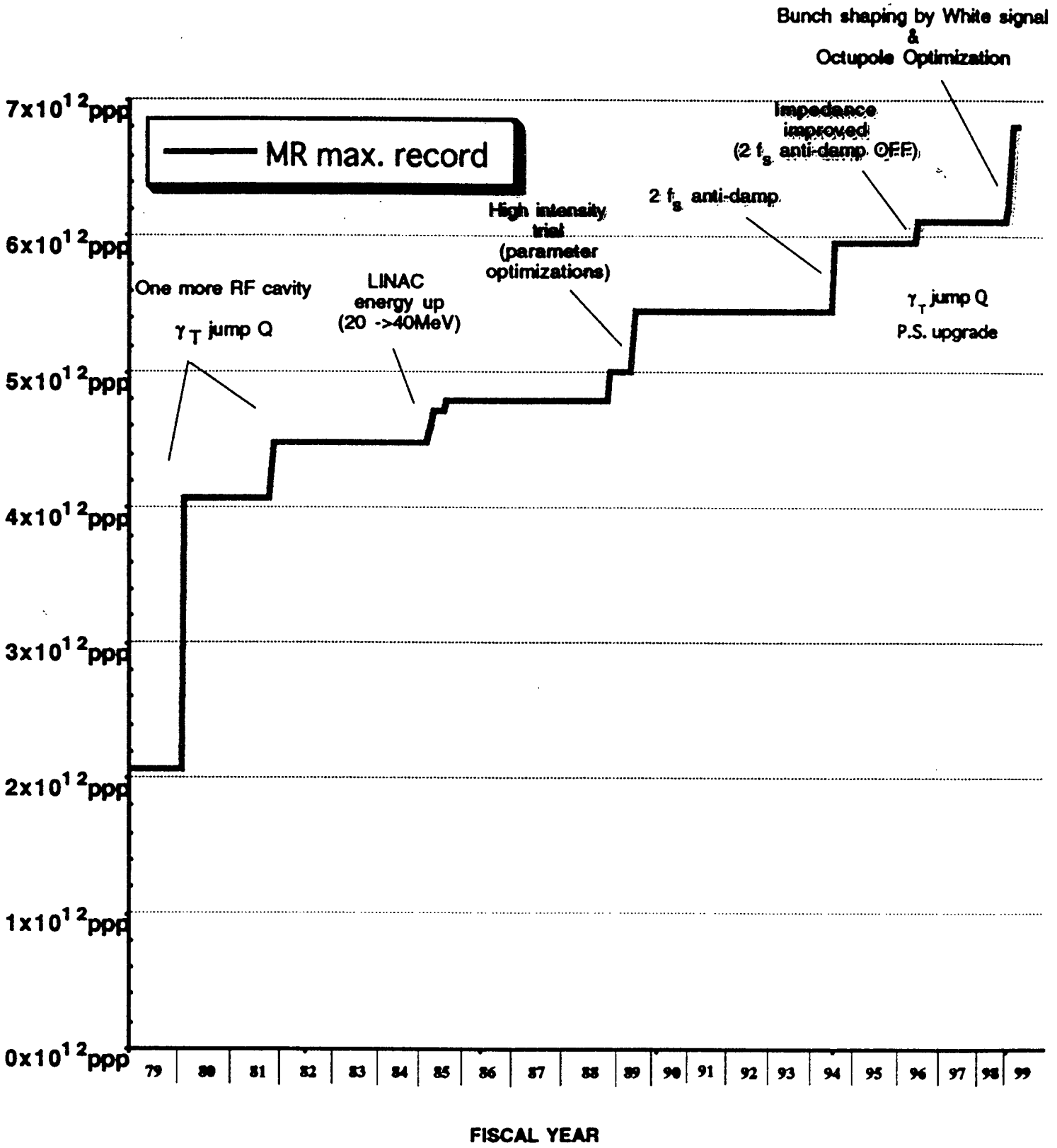
-Commissioning

-Microwave instability at the transition energy

-Head-tail instability

-Bunch shaping


Bunch shaping by White signal
&
Octupole Optimization
7x10^12ppp
MR max. record
Impedance
improved
(2 f_s anti-damp OFF)
2 f_s anti-damp
High intensity
trial
(parameter
optimizations)
6x10^12ppp
One more RF cavity
γ_T jump Q
LINAC
energy up
(20 ->40MeV)
γ_T jump Q
P.S. upgrade
5x10^12ppp
4x10^12ppp
3x10^12ppp
2x10^12ppp
1x10^12ppp
0x10^12ppp
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
FISCAL YEAR

Summary

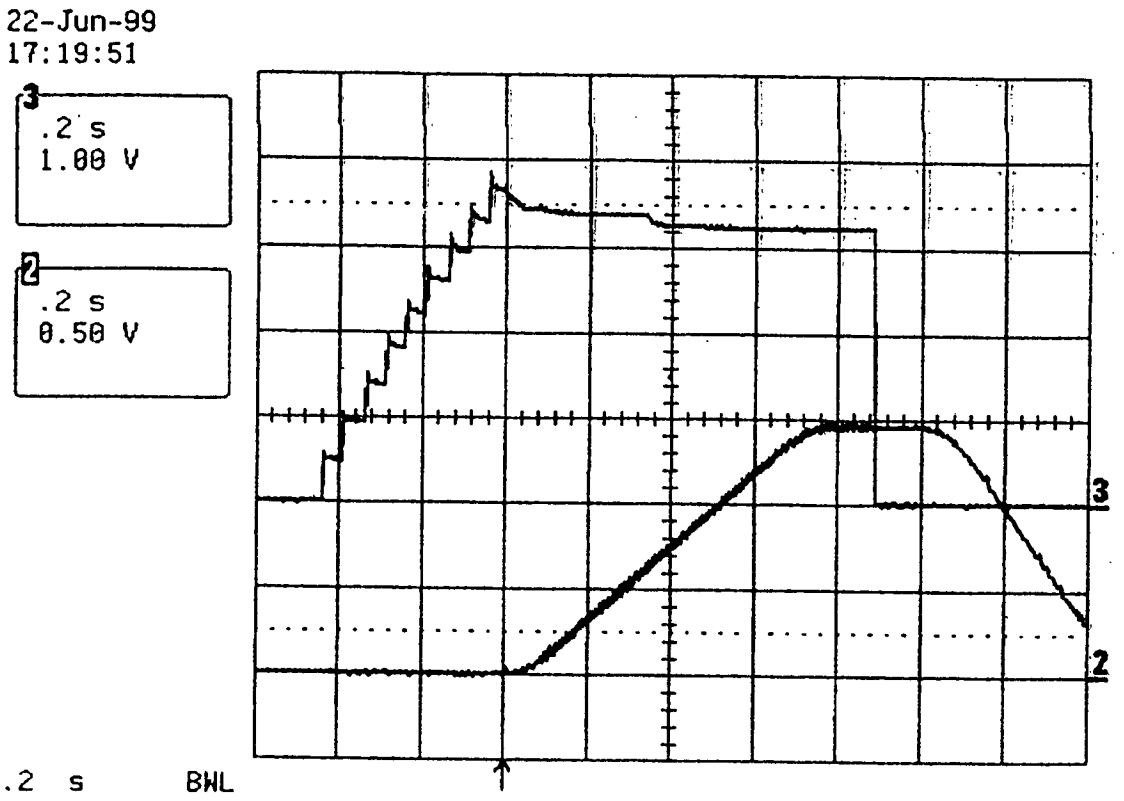
- Microwave instability
  - dominant source: narrow band resonances
  - explained by klystron model
  - vacuum component replaced
  - γ_T jump Q power supply upgraded

- Head-tail instability
  - key: ξ_x --- eddy current induced sextupole
  - kickers, resistive wall & broad band impedances explains the instability
  - measurements:
    - eddy current induced sextupole of the vacuum pipe
    - kicker impedances
  - Landau damping by octupole magnets
  - Cu pipes in the gaps between FX kicker modules

- Bunch shpaing
  - RF voltage modulation by a band-limited white signal successfully implemented

$N_B > 6 \times 10^{12}$ ppp achieved

Typical MR Beam Intensity

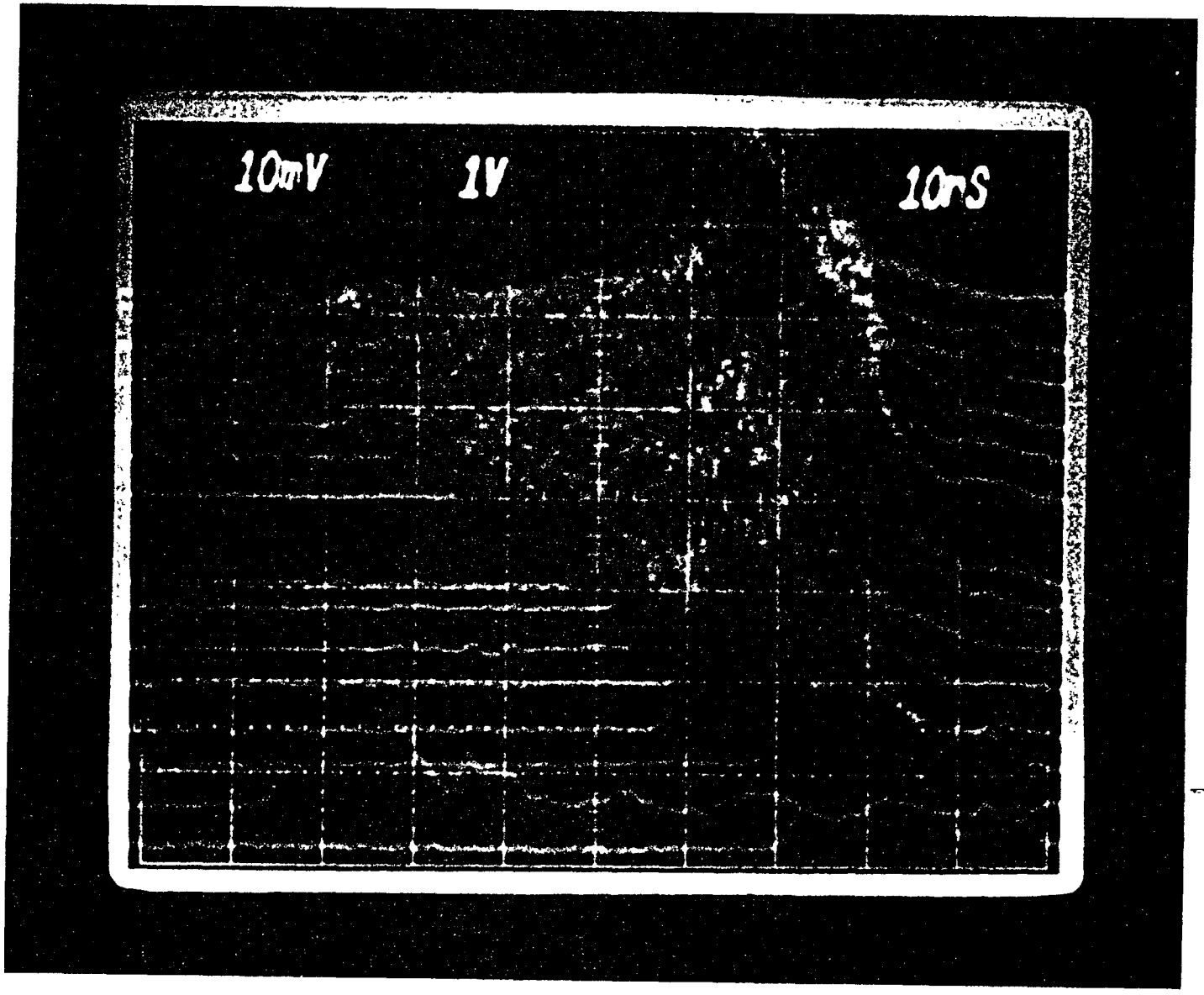


Upper trace: Beam intensity 2×10^{12} ppp/div

Lower trace: Bending Fields

Typical Microwave Instability

N = 6×10"/ bunch



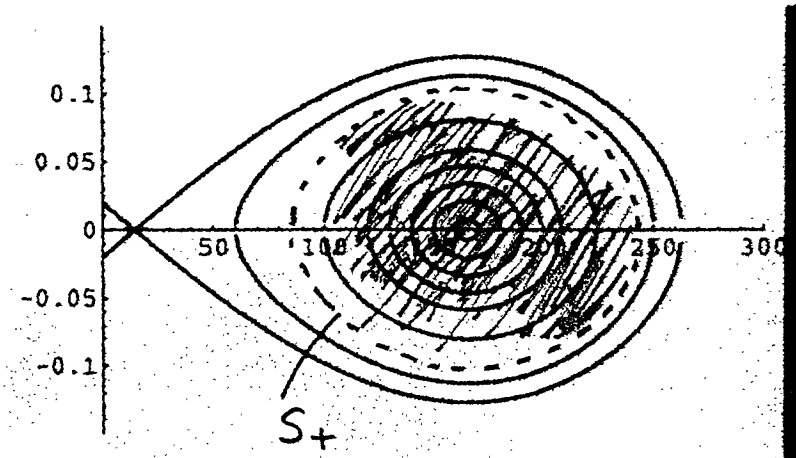
every 3/2 turn
(~800 μs)

$\gamma_s > \gamma_T$

→ Phase jump

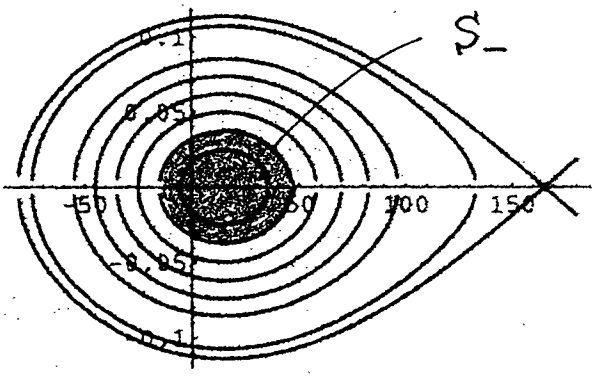
$\gamma_s < \gamma_T$

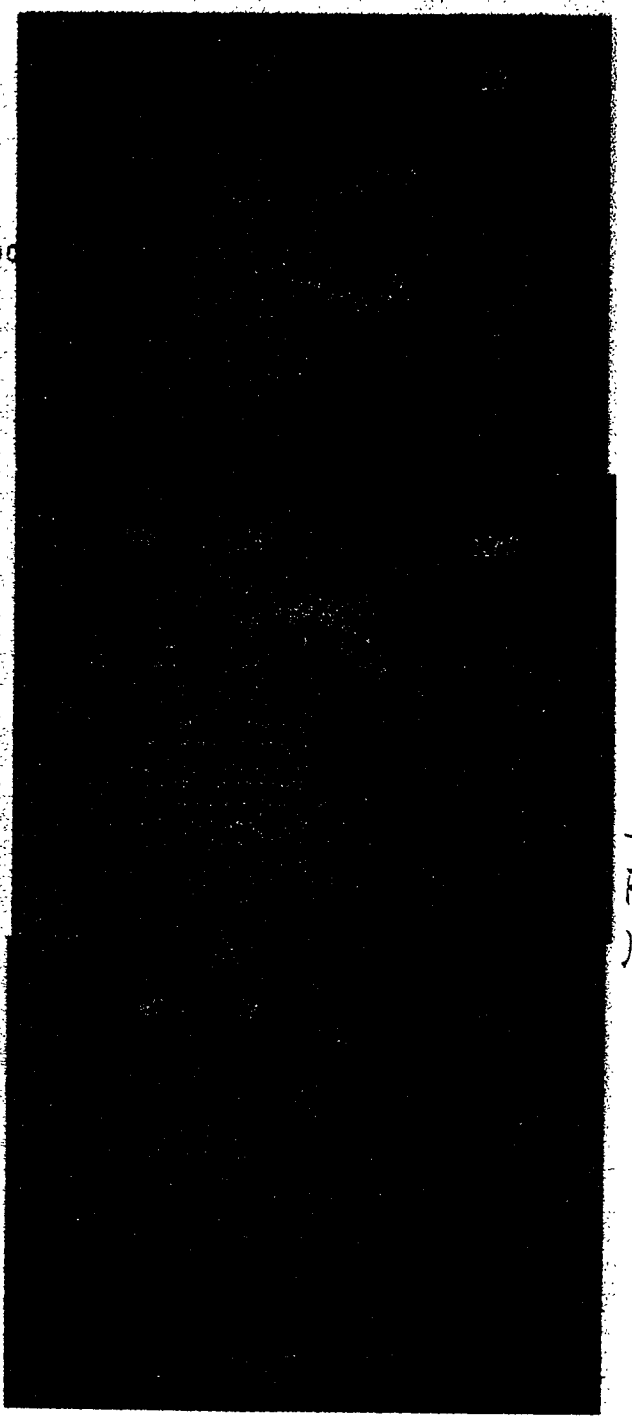
t=+10msec



Emittance Blow-up Ratio = $\frac{S_+}{S_-}$

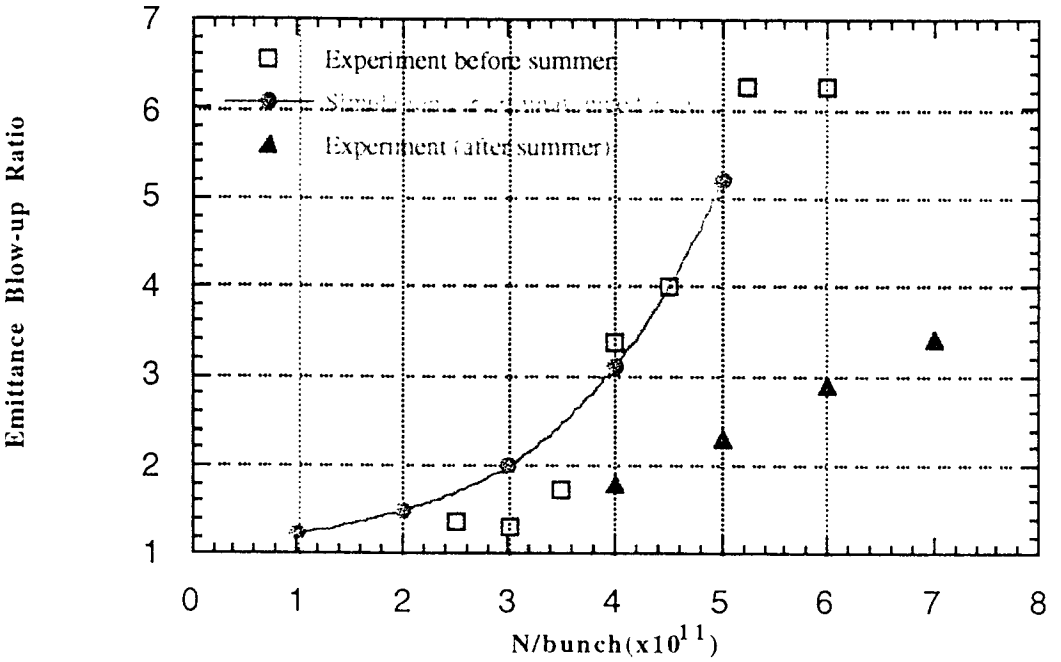
t=-10msec

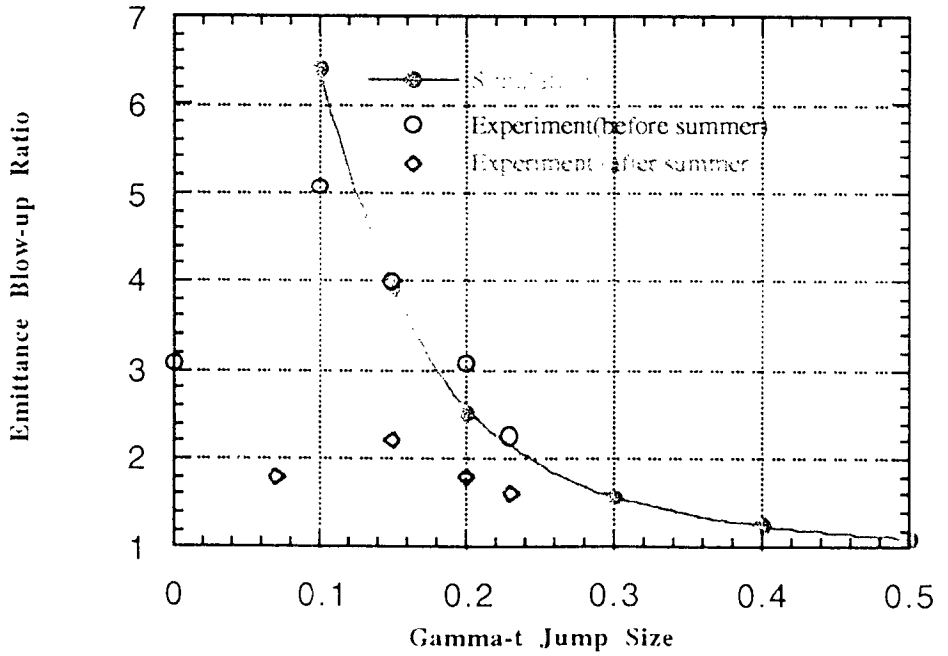




→ Phase jump

Experiments and Simulation





Emittance Blow-Up's Mechanism at Transition

Emittance Blow-Up

Mismatching at Transition----------> Filamentation

- Nonlinear Chromatic Mismatching(Inherent)
- Space-Charge Mismatching(Inherent)
- Phase-jump mistiming(operational)

Evolution of Microwave Instability(inherent) ----------> Rapid blow-up
Negative Mass Instr.

Succeeding Beam-Loss

- Leak from RF Buckets(longitudinal)

- Exceeding momentum aperture($x_{eq}=\eta(s)\frac{\Delta p}{p}$)(transverse)

Minimization of Blow-Up(at present)

- γ_T-jump (remarks on side effects: transient COD)

- ΔR feed-back

B

SX

Steering

BPM

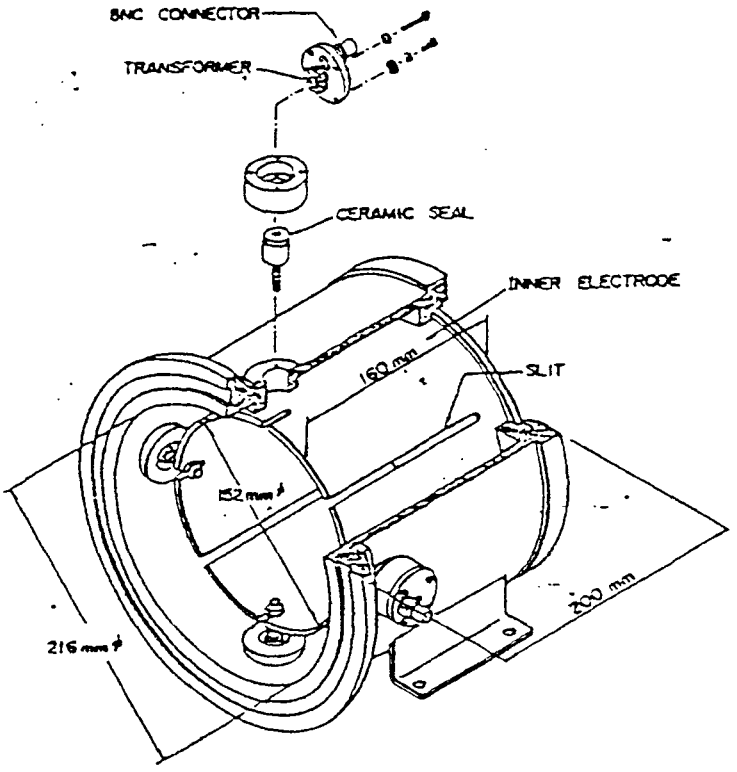
Q

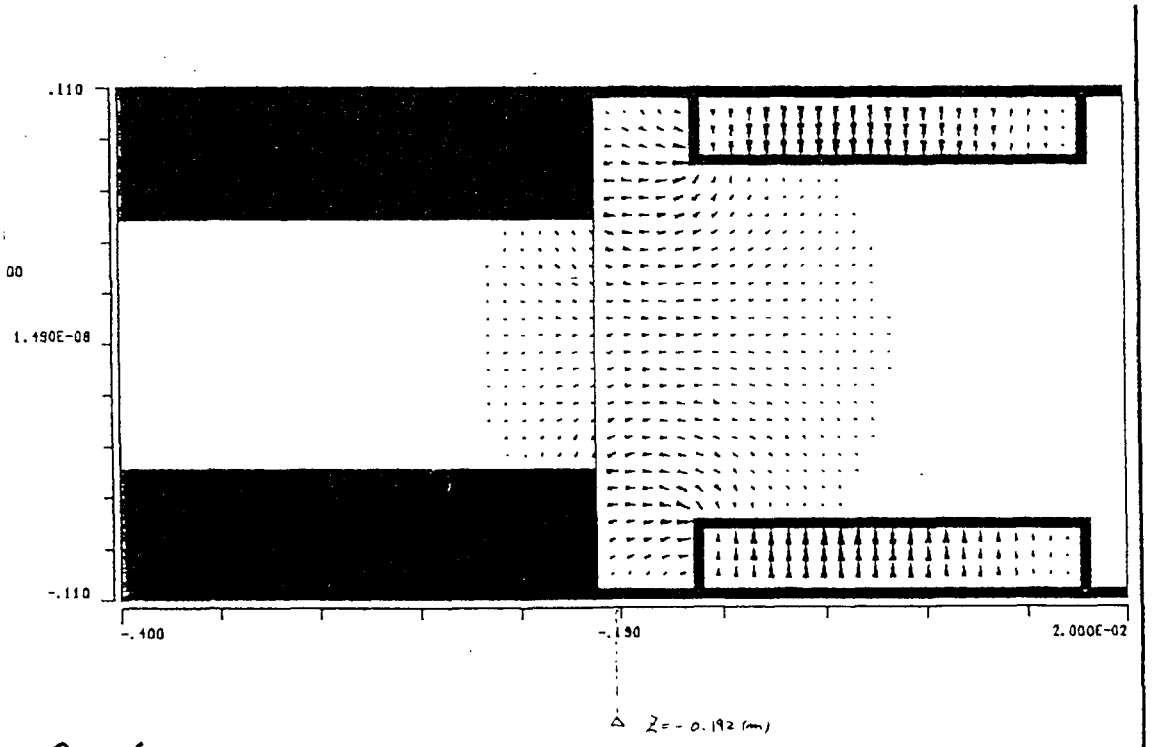
Cavity-like Vacuum Chamber

(CVC)

B

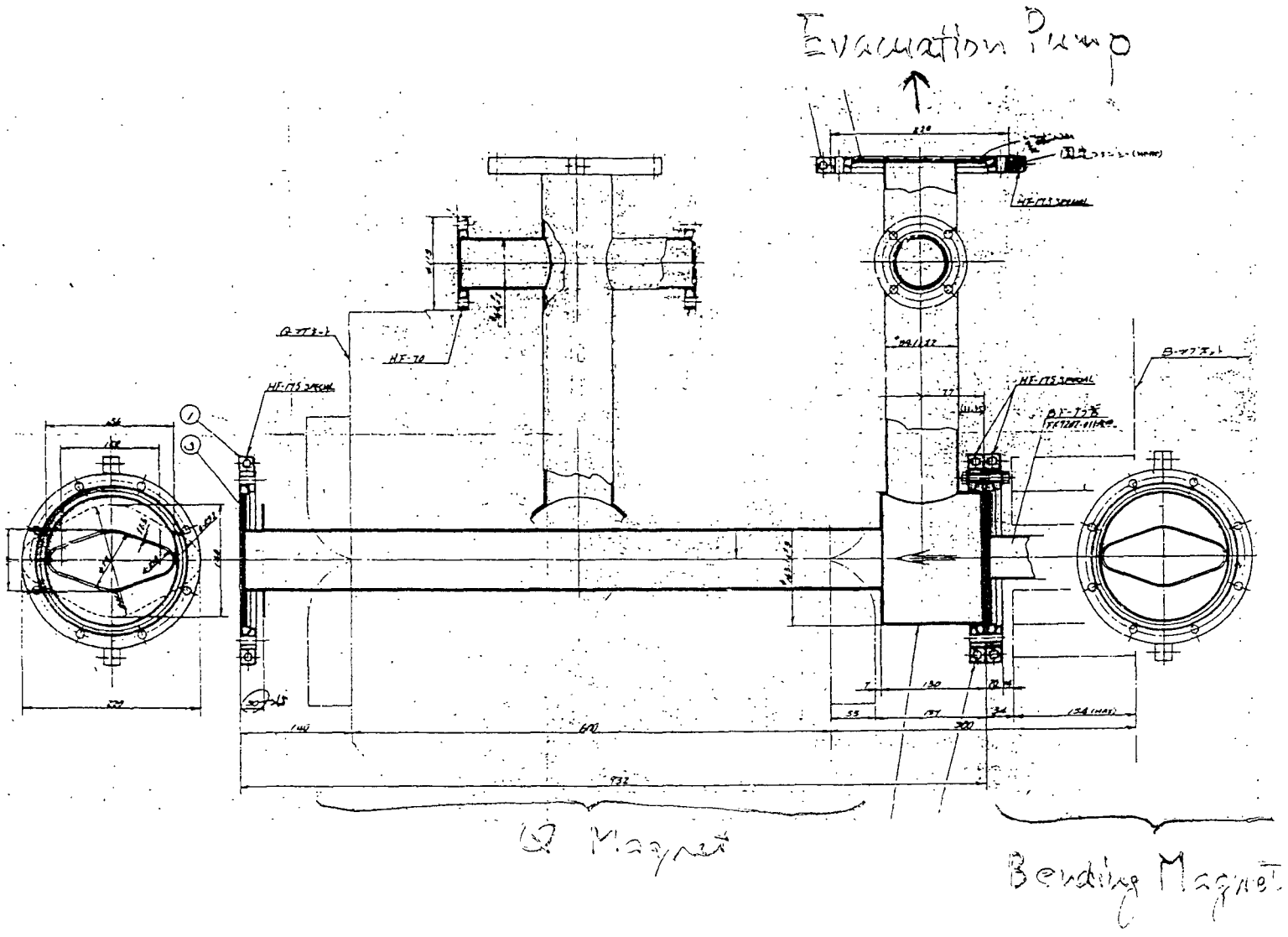
Wall-Current Type Position Monitor





$\lambda/4$ semi coaxial-cavity

Cavity-like Vacuum Chamber (CVC)



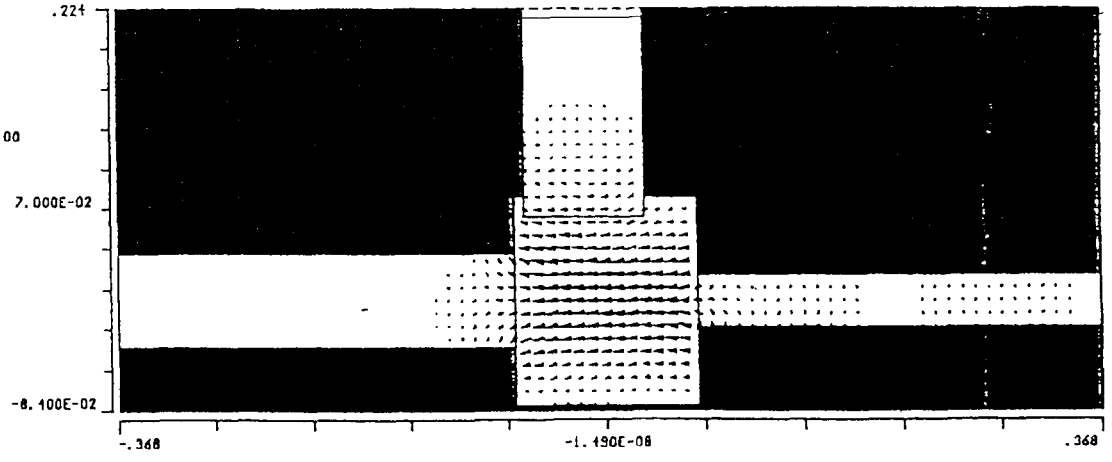


Table 1 List of the machine and beam parameters near transition.

Transition gamma	γ_0	6.63
Circumference	C_0	340 m
Accelerating voltage	V	92 kV
Accelerating frequency	$\omega_{rf}/2\pi$	~7MHz
Hamonic number	h	9
Synchronouse phase (before/after TC)	ϕ_s	15/165 degrees
Speed of γ_t-jump (fixed time-period)	$d\gamma_t/dt(\Delta t)$	$0\text{-}5\times10^2$/sec(1msec)
Particle numbers per bunch	N_0	$1\text{-}5\times10^{11}$
Averaged beam/chamber radius	a/b	1.5/5.5 cm
Number of resonant structures	M	56

Table 2 Resonant impedances (measurement/calculation)

	$\omega_\lambda/2\pi$(GHz)	Q	$R_{shunt}(\Omega)$	R/Q (Ω)
Beam position monitor	0.636/0.667	77/2650	$1.5\times10^3/2.6\times10^4$	14.5/9.8
	/ 1.13	/3769	$/6.2\times10^4$	/16.3
	1.498/1.377	230/8222	$5.3\times10^3/3.3\times10^5$	17.4/40
Cavity-like vacuum	/1.44	/4846	$/1.39\times10^5$	/28.8
chamber junction	/1.84	/4078	$/1.94\times10^5$	/46.6

Proton-Klystron Model

Cumulative Power Growth in Highly Resonant Impedances

$$V_{int}(\phi) = M\frac{2e\omega_{rf}}{TTF}\left(\frac{R_{shunt}}{Q}\right)\int_{\phi_{Head}}^{\phi}\exp\left(-\frac{\omega_\lambda(\phi-\phi')}{2Q\omega_{rf}}\right)\sin\left[\frac{\omega'_\lambda}{\omega_{rf}}(\phi'-\phi)\right]\frac{\partial\lambda(\phi')}{\partial\phi'}d\phi' \propto \int_{\phi_{Head}}^{\phi}W'(\phi-\phi')I_0(\phi')d\phi'$$

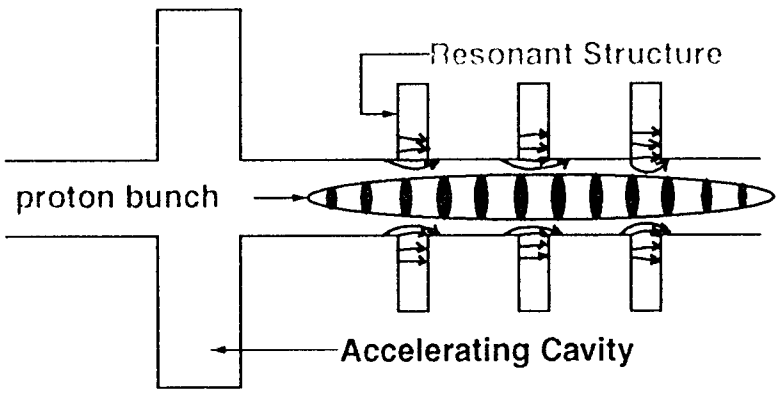
(the impedance is fully resistive.)

$\lambda(\phi)$: beam line-density,

TTF : the transit-time factor of the RS,

R_{shunt}, Q, ω_λ, and $\omega'_\lambda(=\omega_\lambda\sqrt{1-(1/2Q^2)} \approx \omega_\lambda)$: shunt impedance, quality factor, and angular frequency of the RS

M: the number of the RS, 56.



In detail, K.Takayama, D.Arakawa, J.Kishiro, K.Koba, and M.Yoshii, *Phys. Rev. Lett.* **58**, 871 (1997)

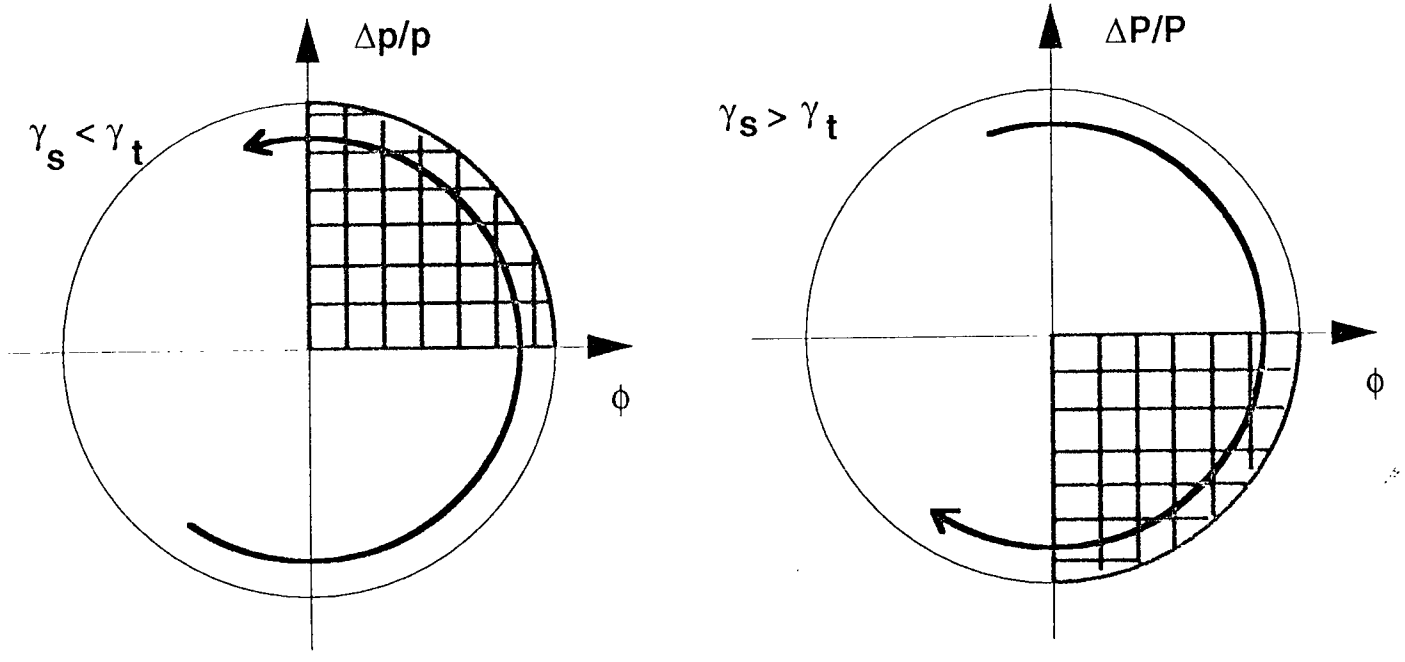
Microstructure Formation

- Essential Feature of Beam-Wake Interaction

  Under nearly frozen global phase motion

  - Wake's amplification <-------> Beam Deceleration
  - Wake's phase follows the motion of decelerating core.
  - Convective due to a finite Q-value: head -------> tail

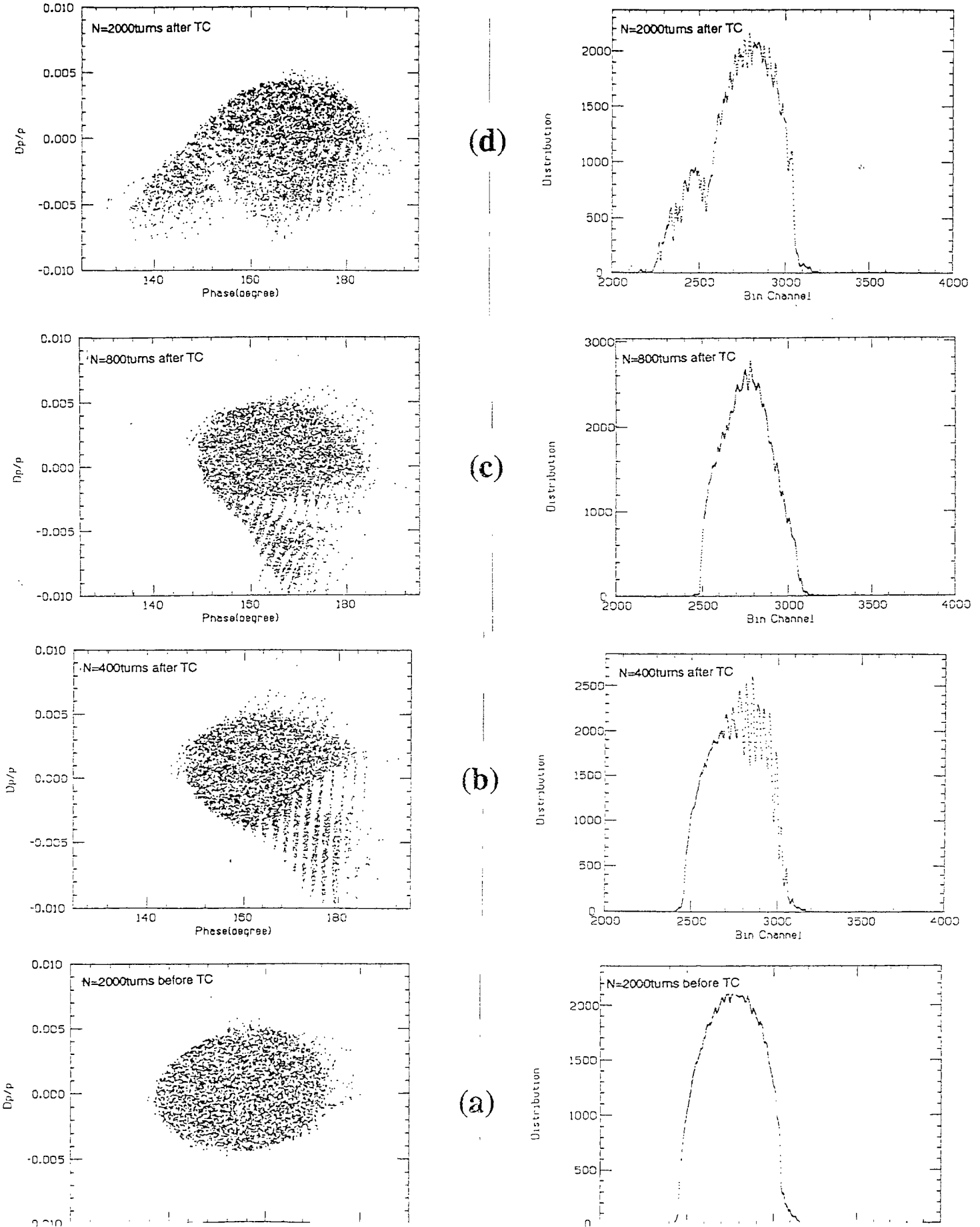
- Its Schematic View on Phase-Space



$R_s/Q = 10\,\Omega$

$Q \sim 10^2$

Fig. 5



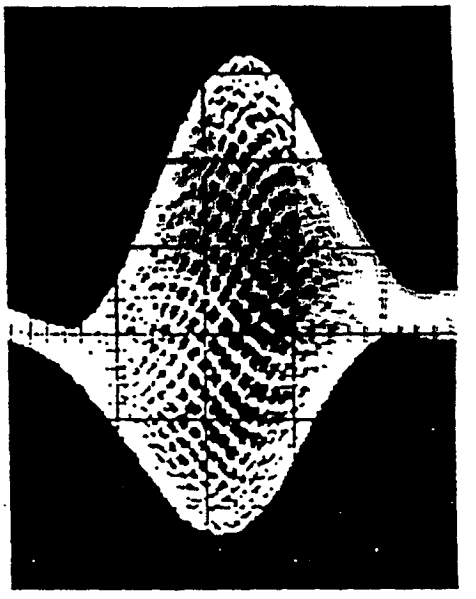


Figure 1: Horizontal coherent oscillaltion.

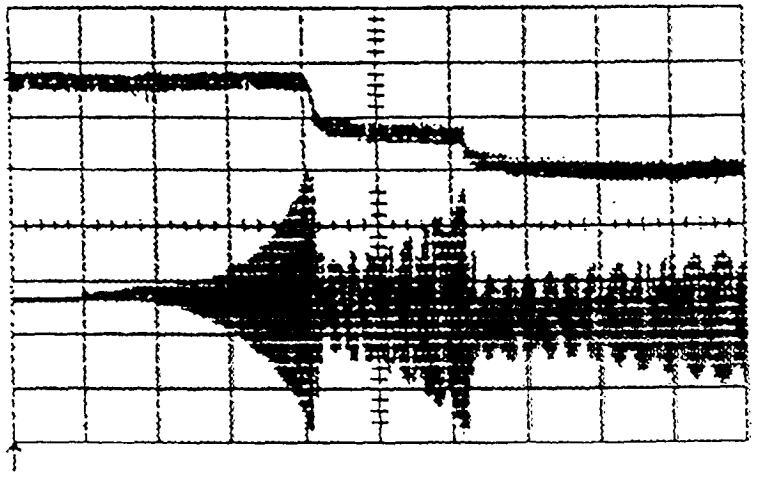


Figure 2: Growth of the coherent oscillation. Upper trace: beam intensity ($10^{11} protons/div$), lower trace: coherent oscillation, abscissa: 5 k samples/div.

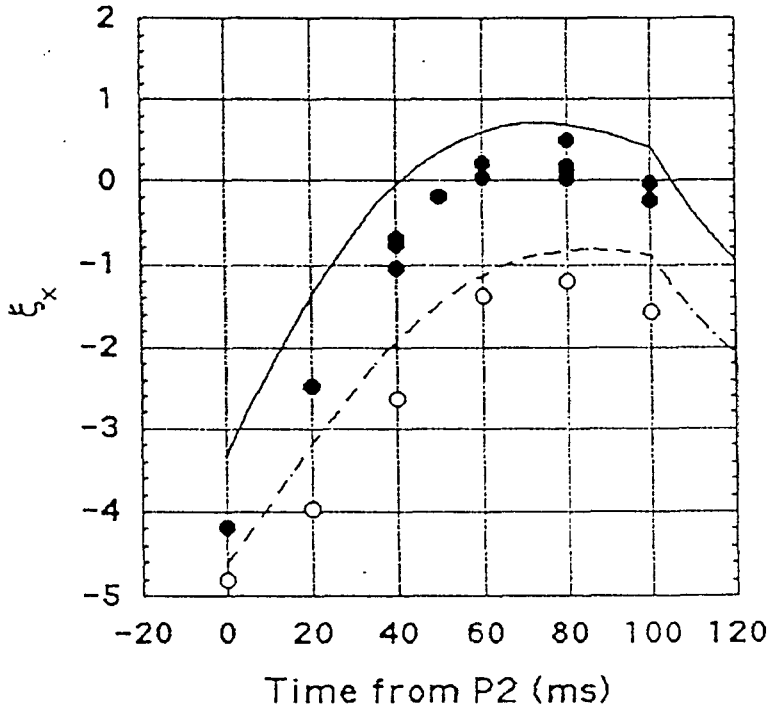


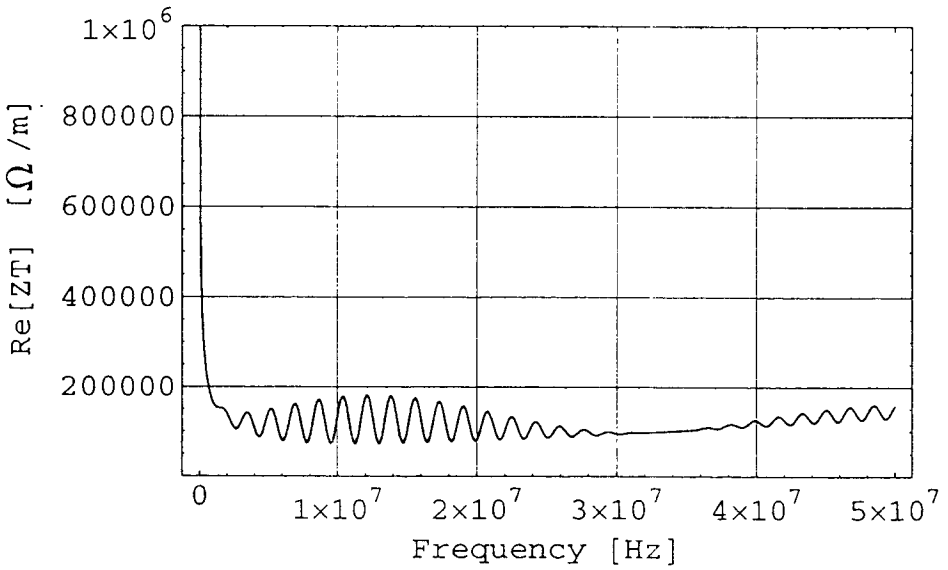
Figure 3: Horizontal chromaticity after the acceleration start.

Head Tail Instability

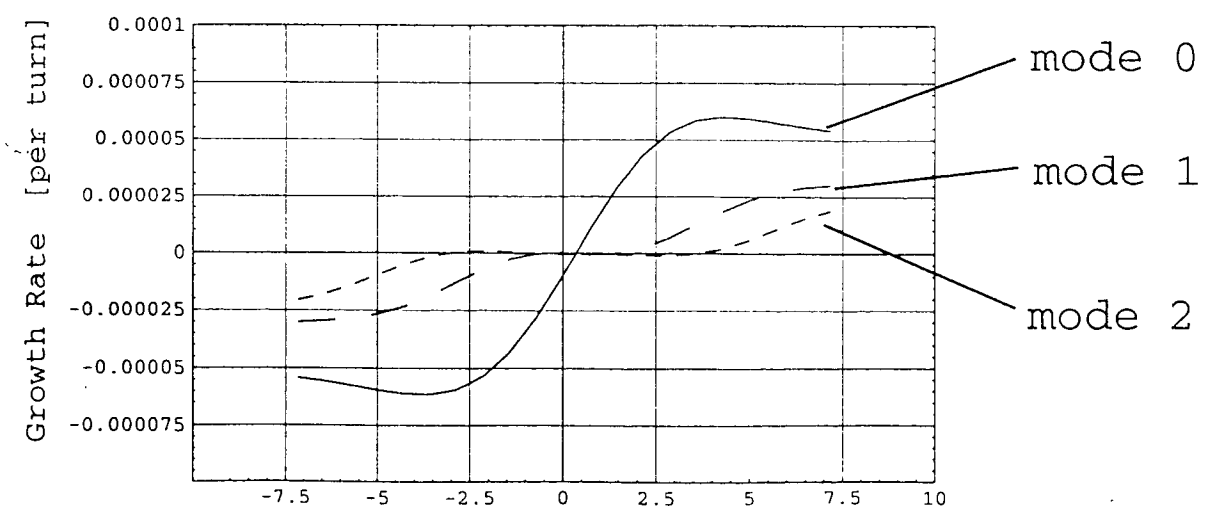
before installing FX kickers

inj. kickers + resistive wall + broad band

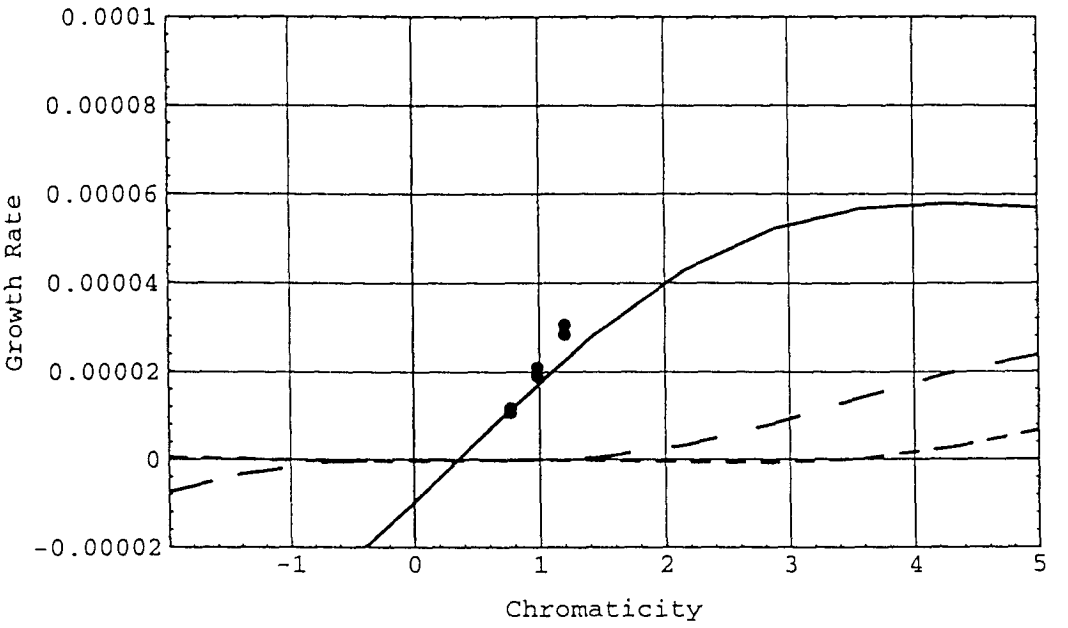
Transverse Impedance



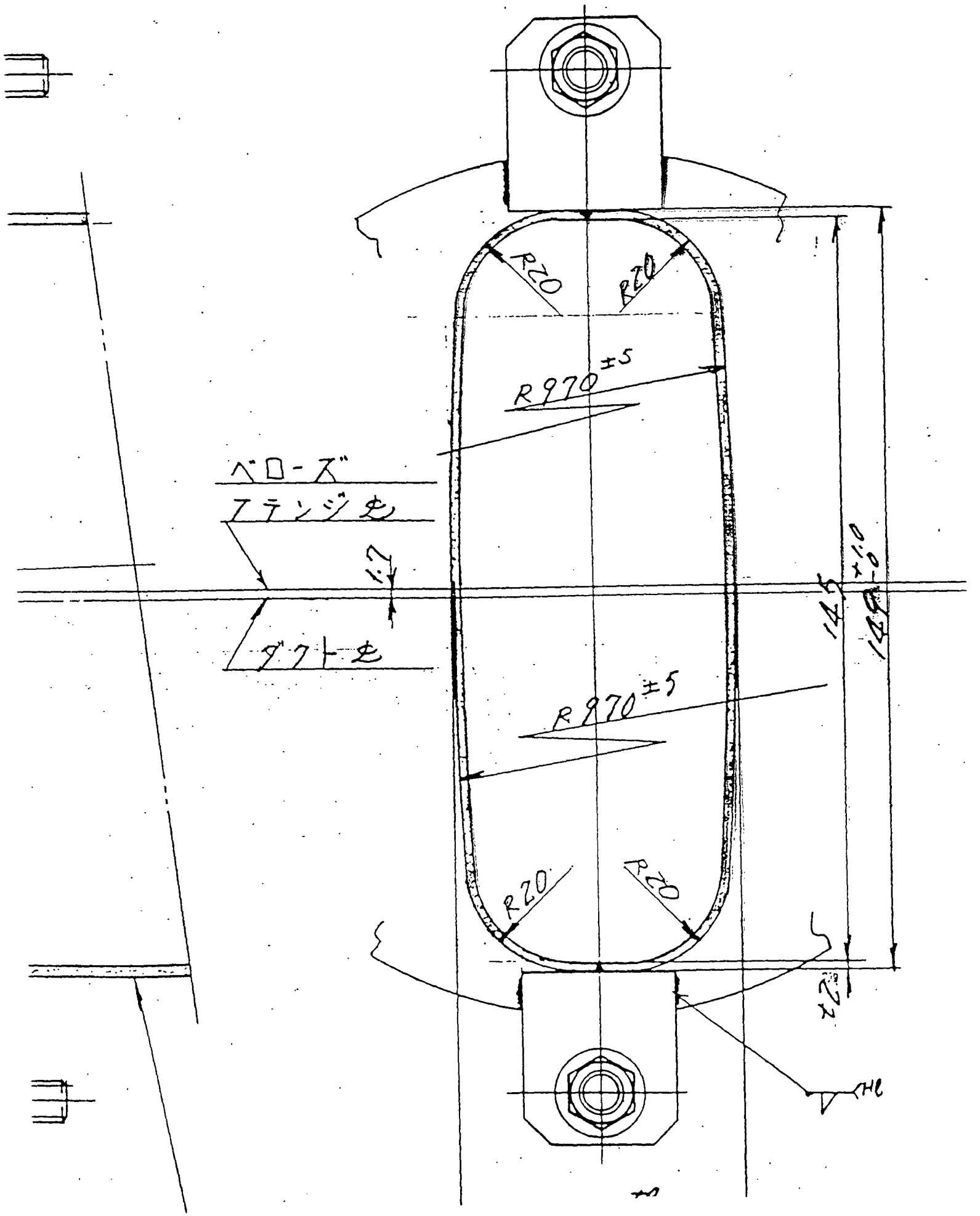
Growth Rate



Contribution of
the resistive wall, kickers and broad band impedance



Filled circles ..... measured
Solid line ..... mode=0
Broken line ..... mode=1
Dotted line ..... mode=2


R20
R20
R970±5
ベローズ
フランジ芯
1.7
ダクト芯
R970±5
R20
R20
145
149 +1.0 -0
27
Hl

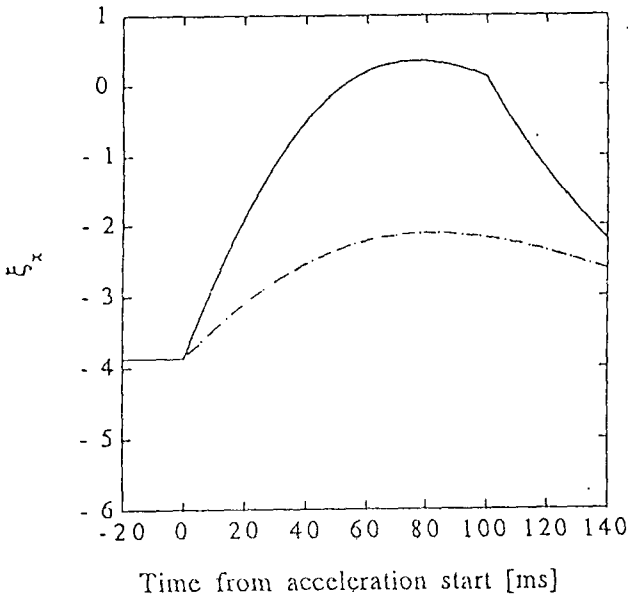


FIGURE 7. Calculated horizontal chromaticity

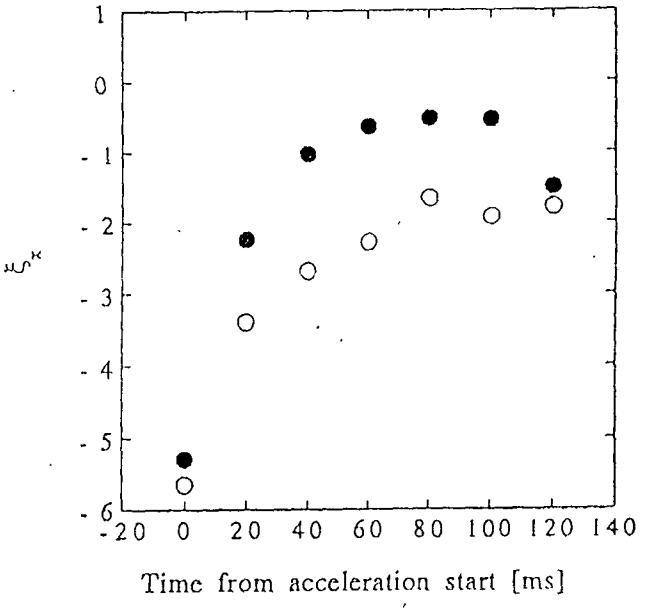


FIGURE 8. Measured horizontal chromaticity

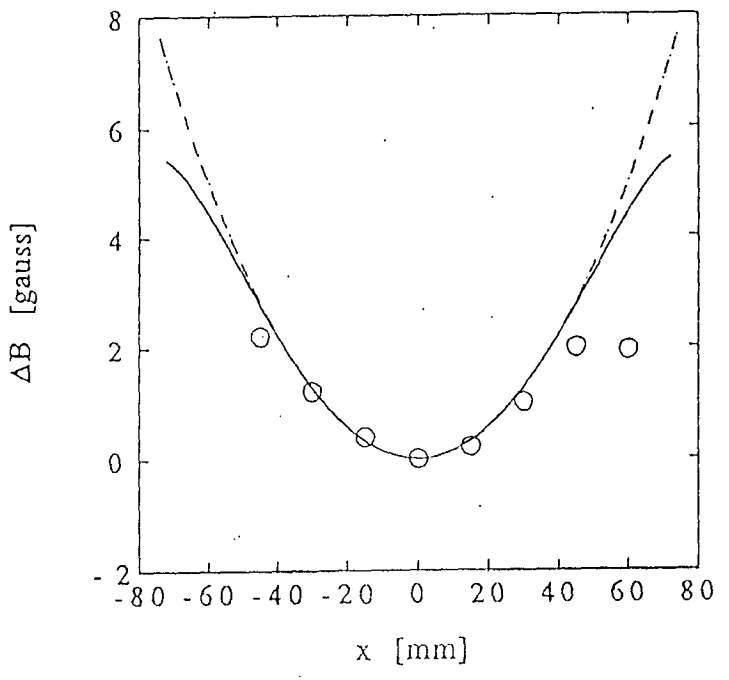
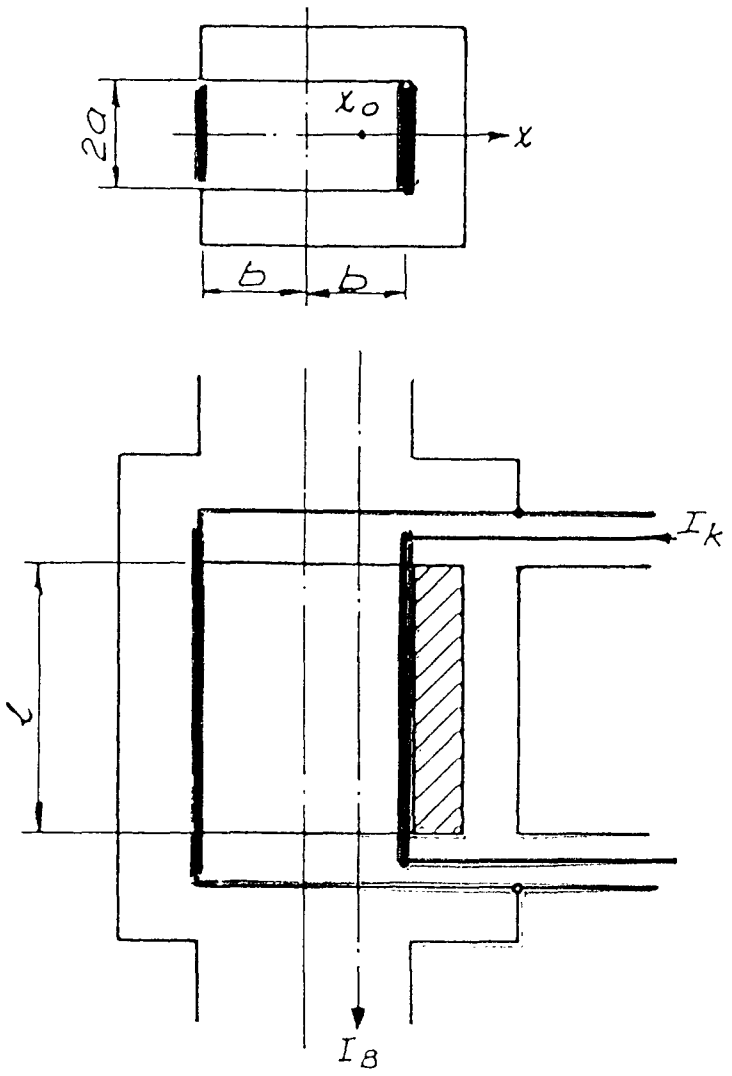
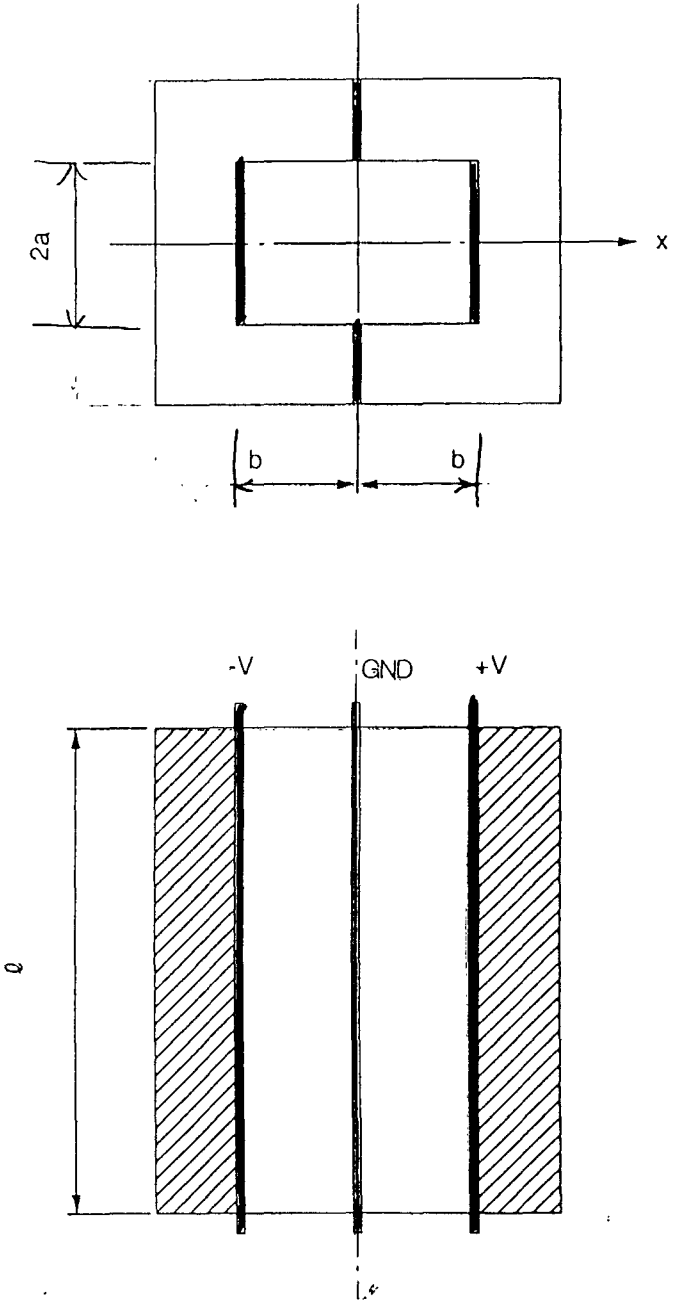


FIGURE 9. Field variation due to eddy current in the vacuum pipe



C-type kicker
viewed from front and top



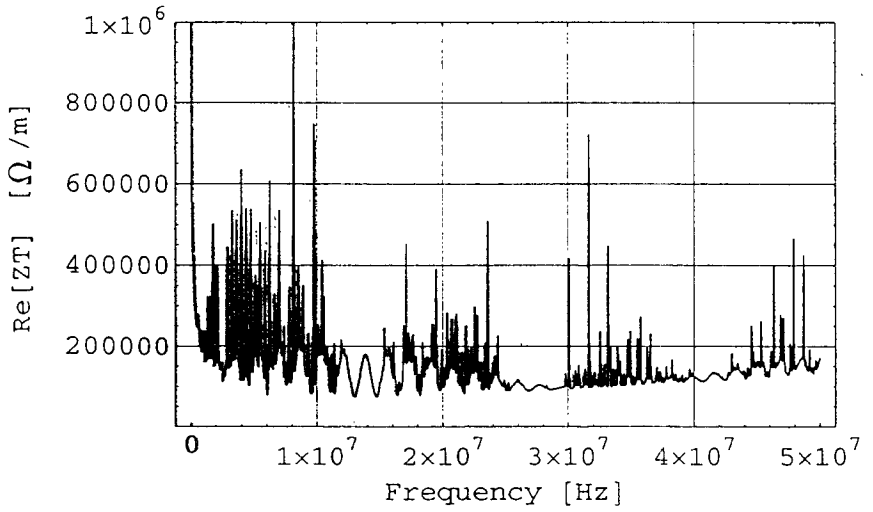
Twin C-type kciker
viewed from front and top

Head Tail Instability

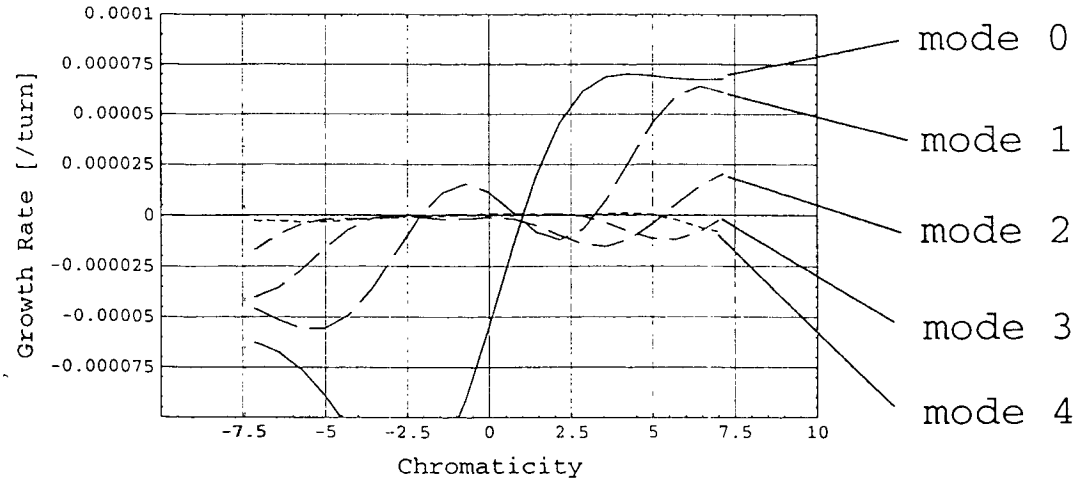
after installing FX kickers

inj. kickers + FX kickers
+ resistive wall + broad band

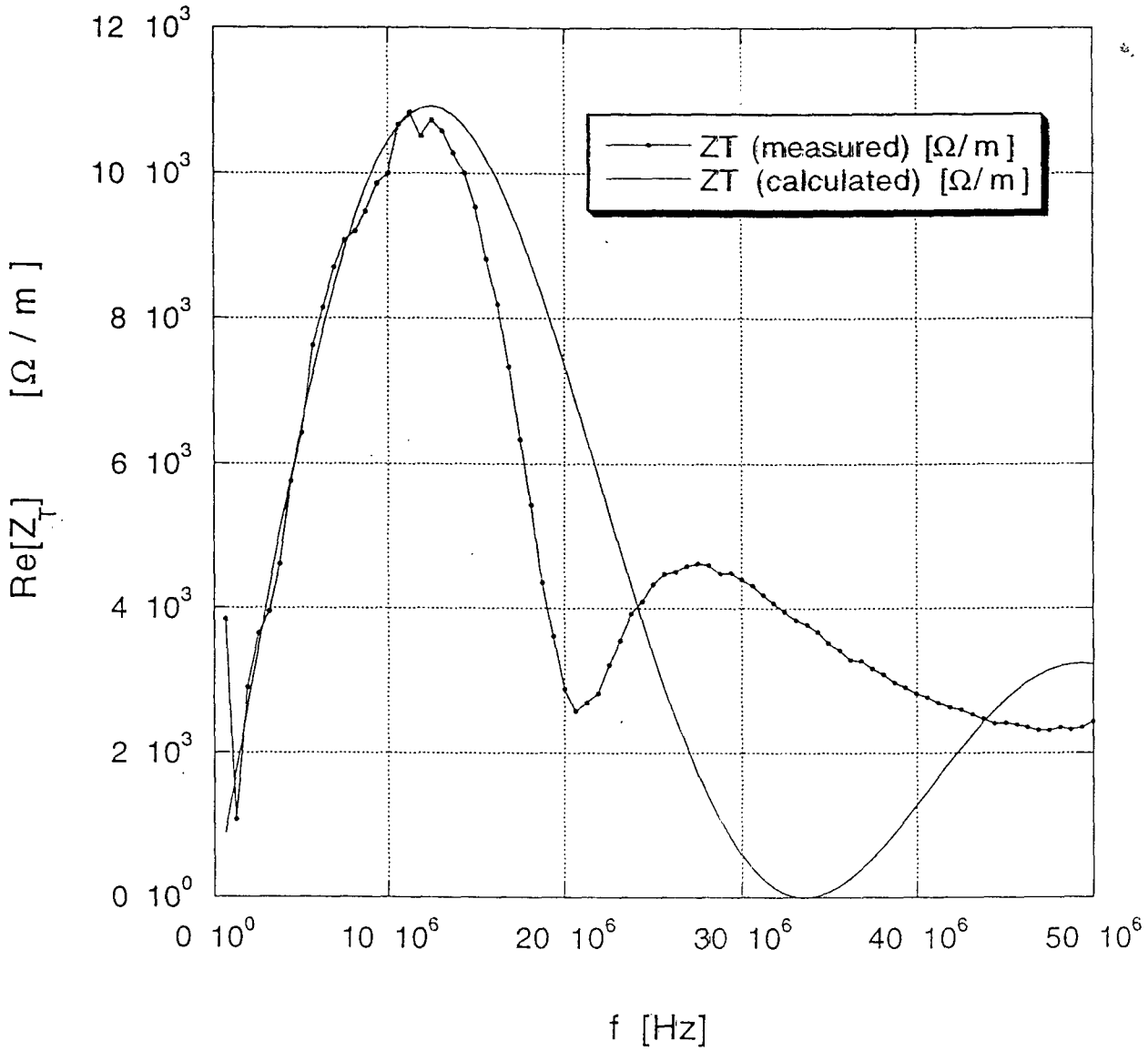
Transverse Impedance



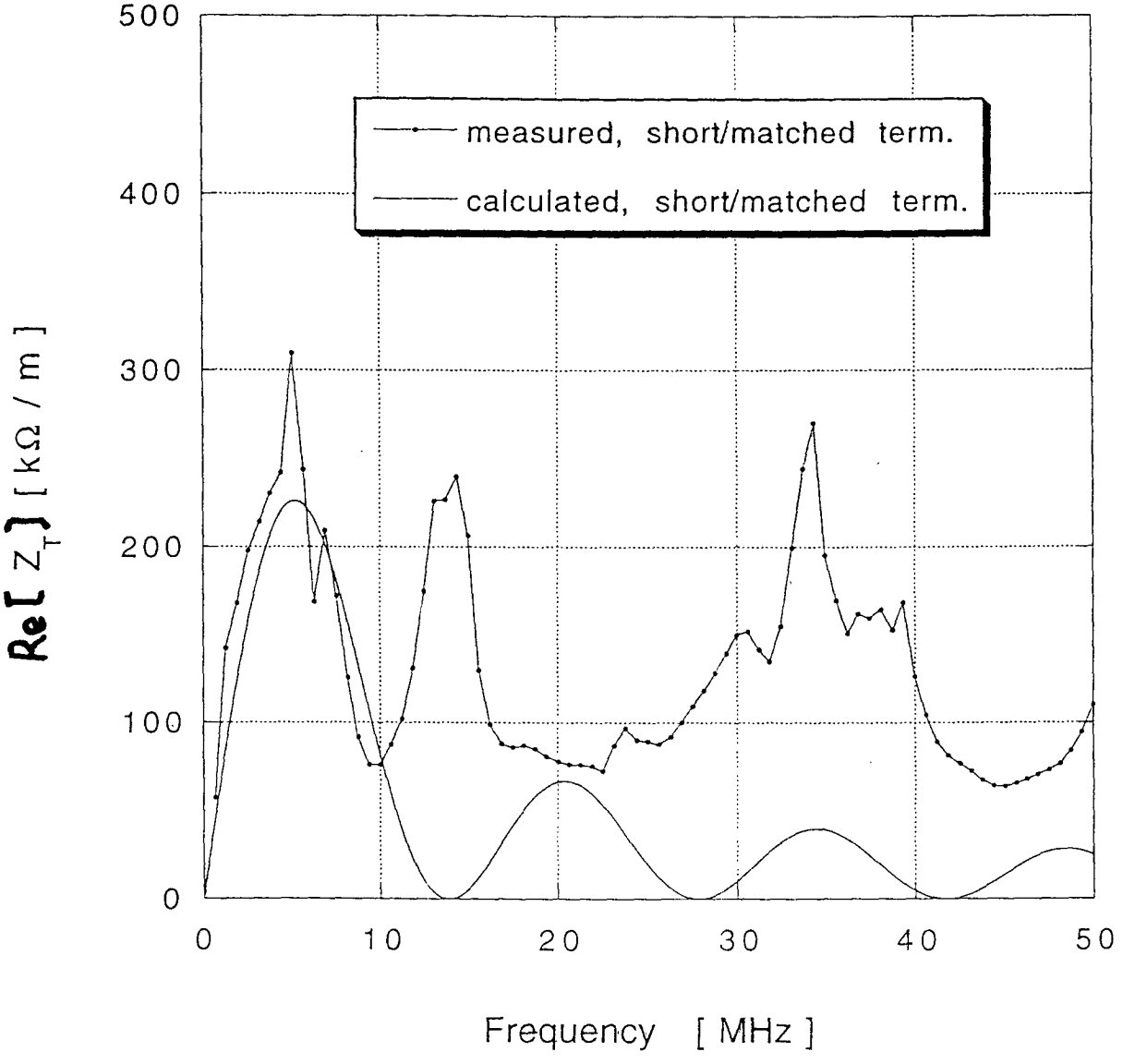
Growth Rate



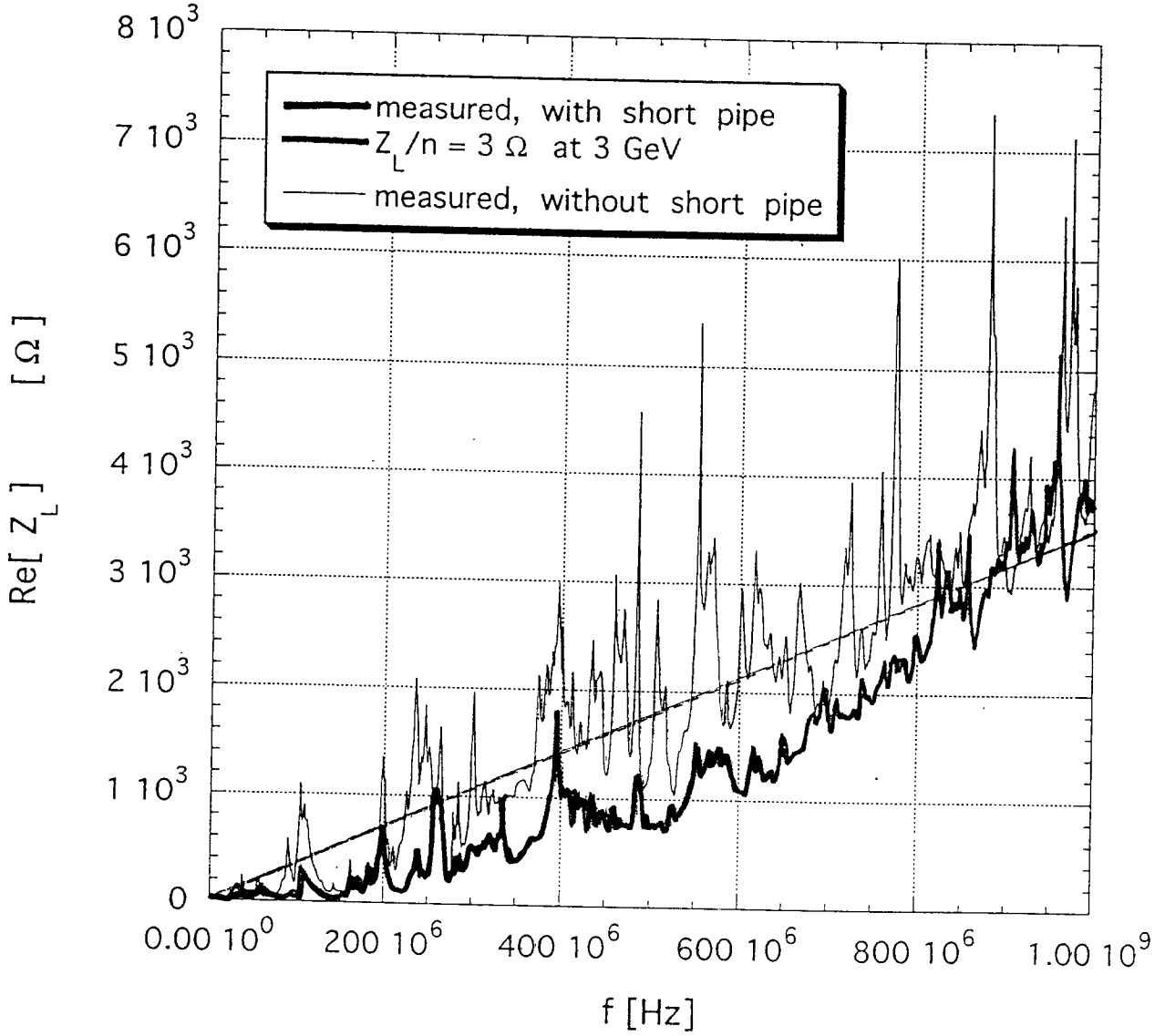
TRANSVERSE IMPEDANCE of
the 12 GeV-PS <u>INJECTION</u> KICKER
(kicker load = 25 Ω / 25 Ω)

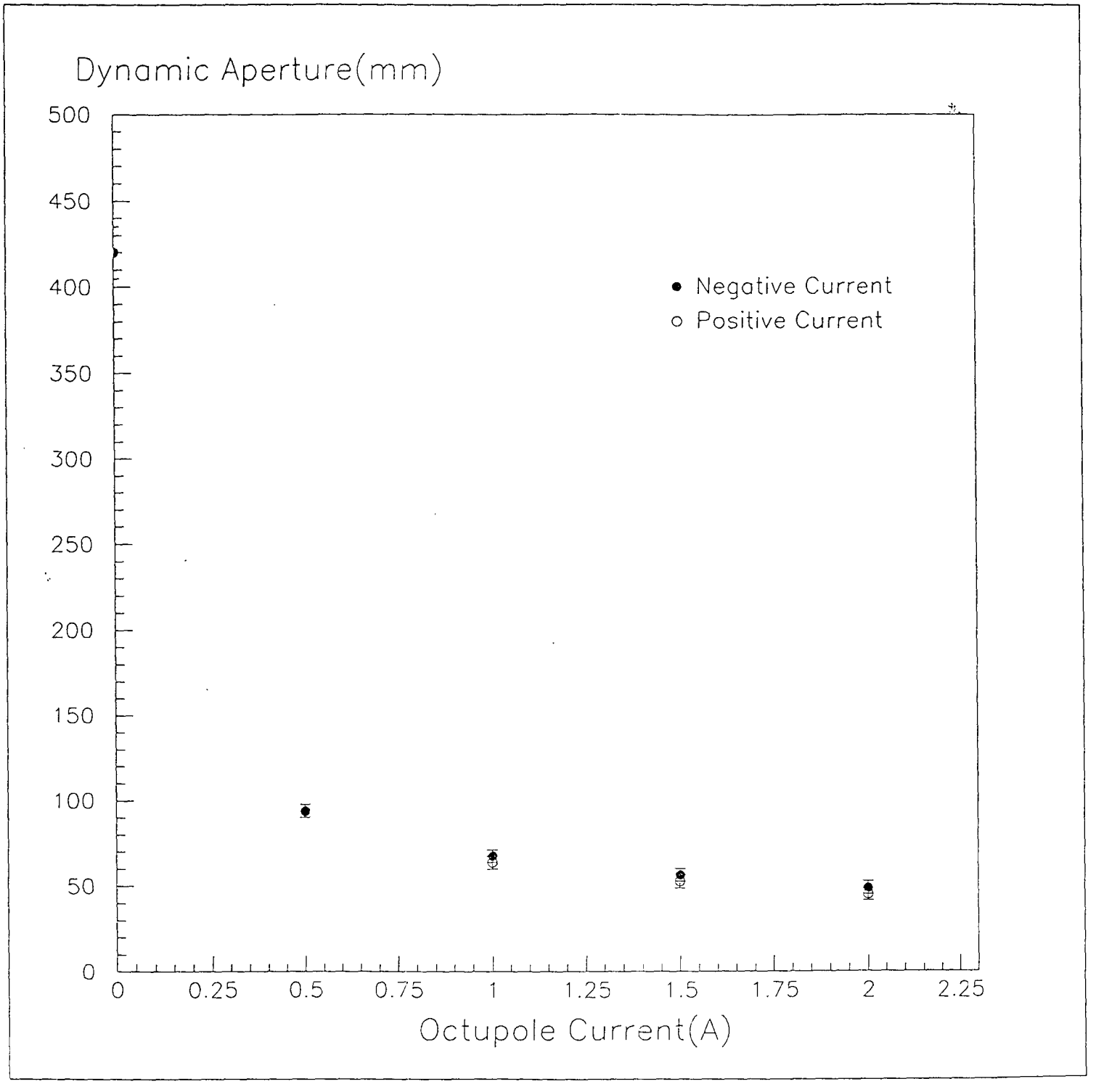


TRANSVERSE IMPEDANCE of the 12 GeV-PS FAST EXTRACTION KICKERS (seven kickers)



LONGITUDINAL IMPEDANCE of
the 12 GeV-PS FAST EXTRACTION KICKERS
(seven kickers)




Dynamic Aperture(mm)
500
450
400
350
300
250
200
150
100
50
0
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
2.25
Octupole Current(A)
Negative Current
Positive Current

Bunch Shaping

- Relax the space charge effects

- Limitation: acceptance inj. & ext. kickers rise time
  FX septum

- RF voltage modulation by a band-limited white signal

  ○ increase bunching-factor
  without emittance blow-up (in principle)
  ○ easy & cost saving
  △ effect is moderate:
  final distrubution: uniform in phase space
  time constant: not small

- Successfully applied to the BR & MR
  (during acceleration)

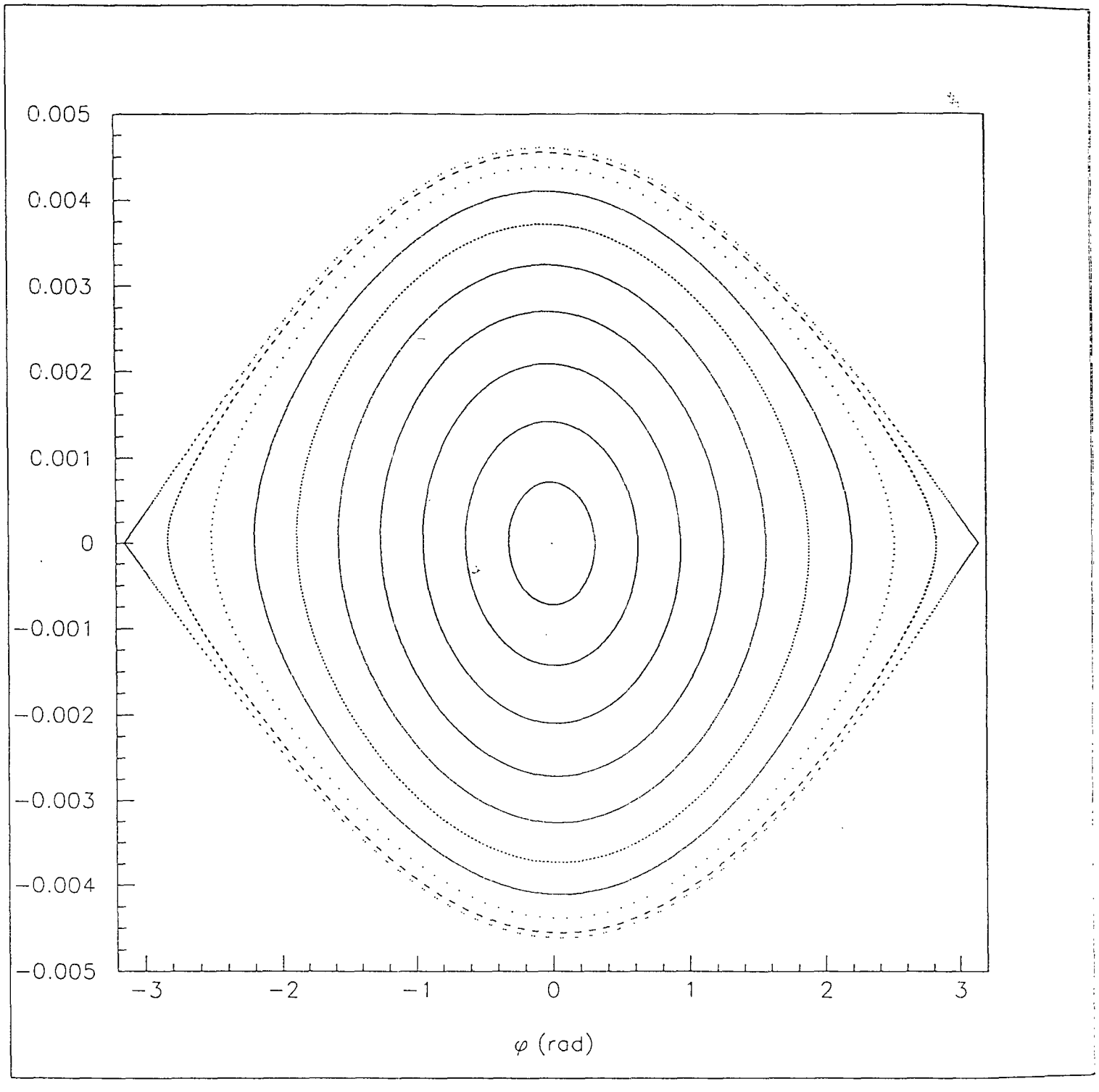
  ○ ~24% intensity gain
  ○ $N_B > 6 \times 10^{12}$ ppp achieved
  ○ stable operation

'98. 7. 7

$\xi_{rms} = 0.$

$V_{rf} = 100$ kV

$p = 1.090$ GeV/c



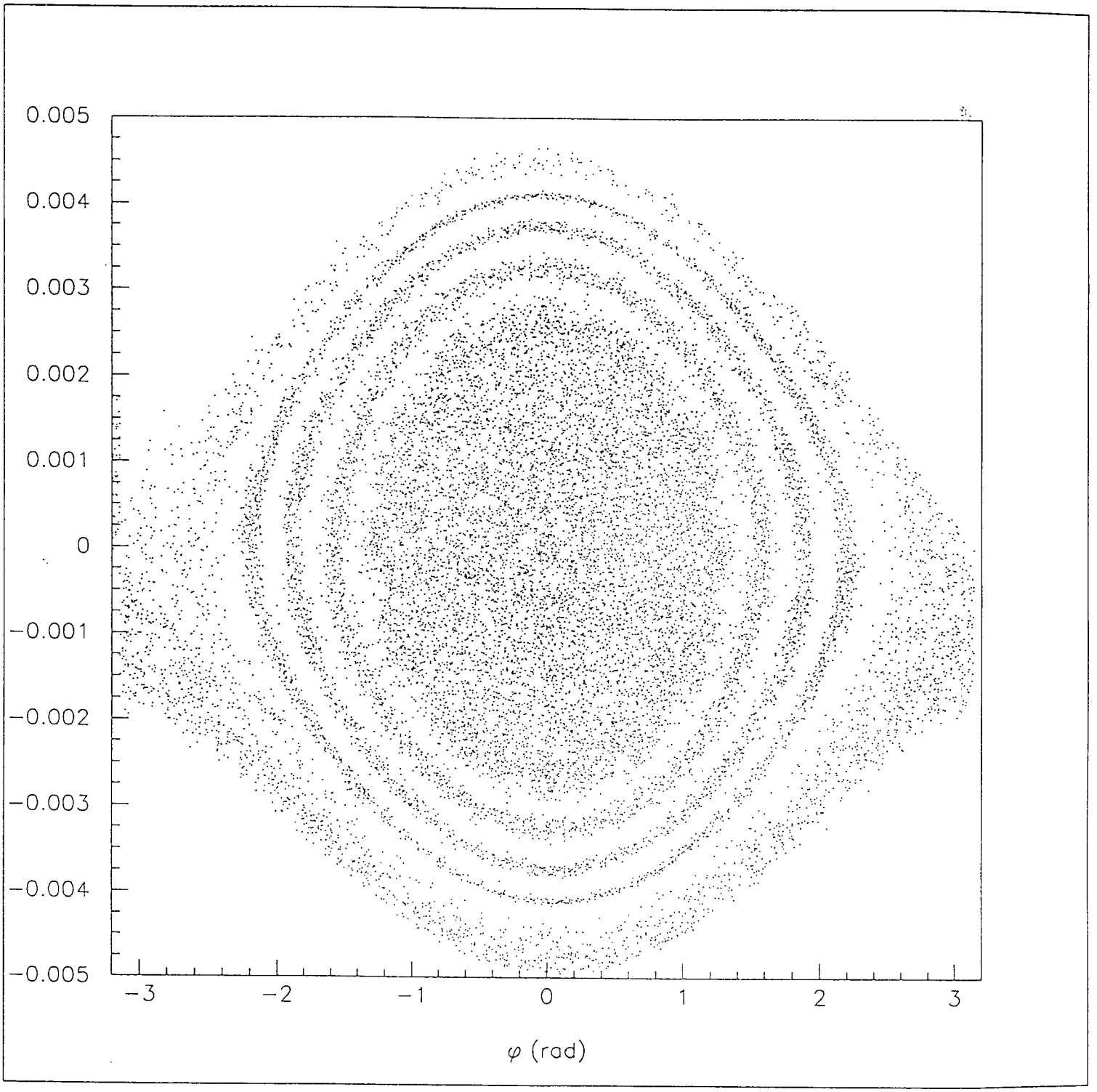
RF Voltage Modulation by Band-limited White Signal

'98, 7. 7

run 20

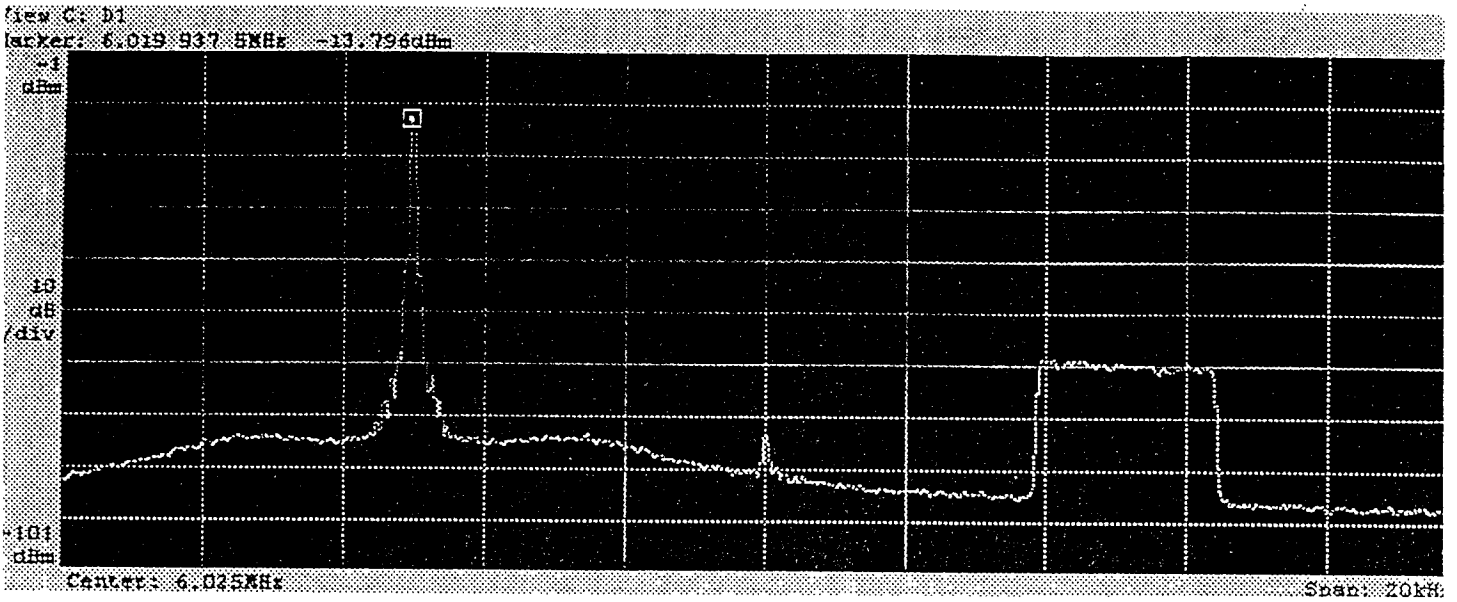
$\xi_{rms} = 0.03$

2×10^5 turns



Frequency Spectrum of V_{RF}

during MR injection flat bottom



$f_{RF} = 9 x f_{rev} = 6.0199$ MHz

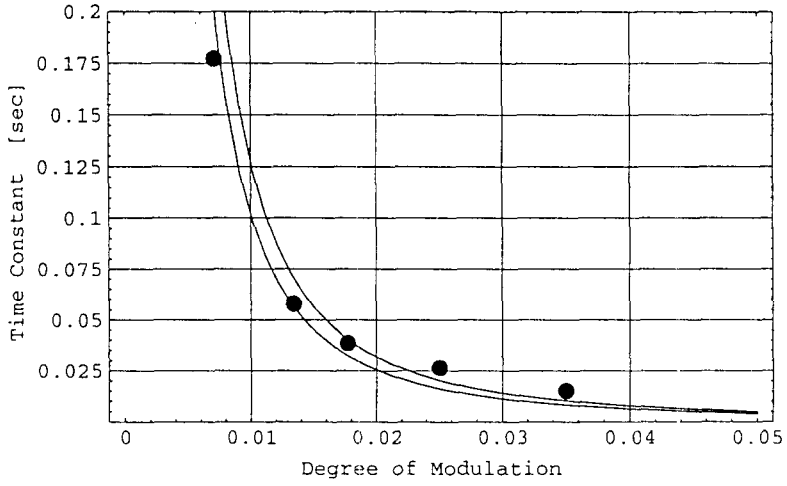
band-limited white signal

6.02883 - 6.03148 MHz

rms degree of modulation

~3.6%

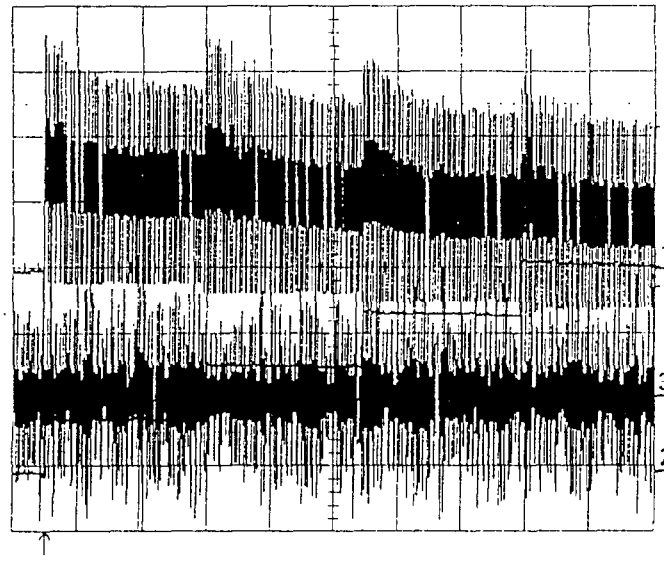
Time constant



analytic

simulation

rms degree of modulation~3%



bunch signal

beam intensity

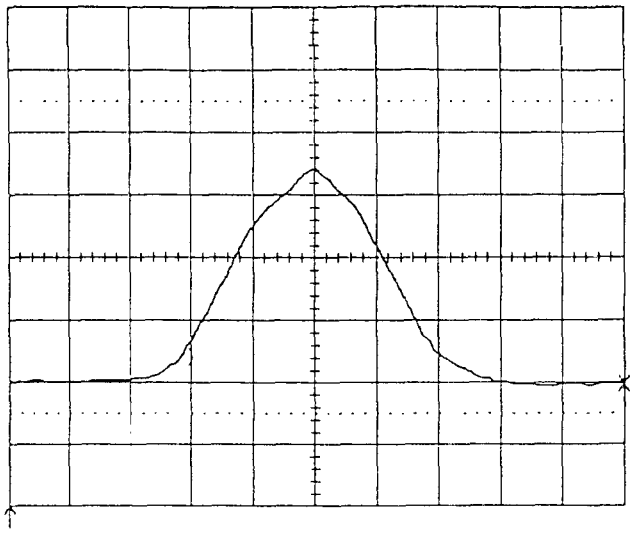
modulation signal

20 ms / div

Fundamental RF Voltage Modulation by Band-Limited White Signal

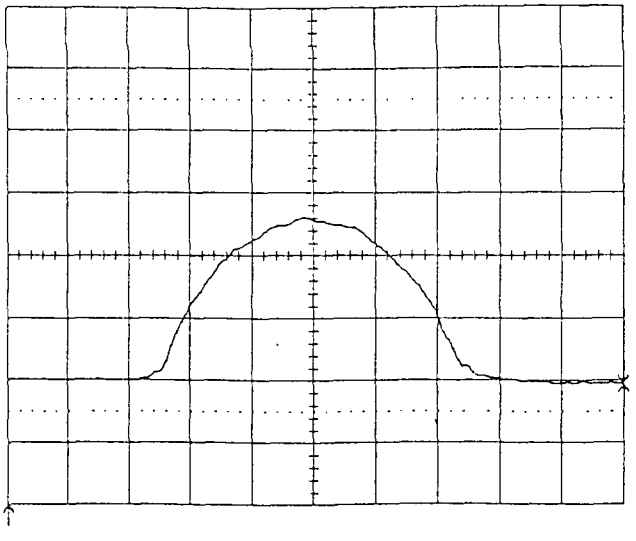
during MR injection flat bottom (500 MeV)

Without modulation



Wall current monitor signal 20 ns/div

With modulation



Parameters of modulation

$2f_0$=11.6 kHz

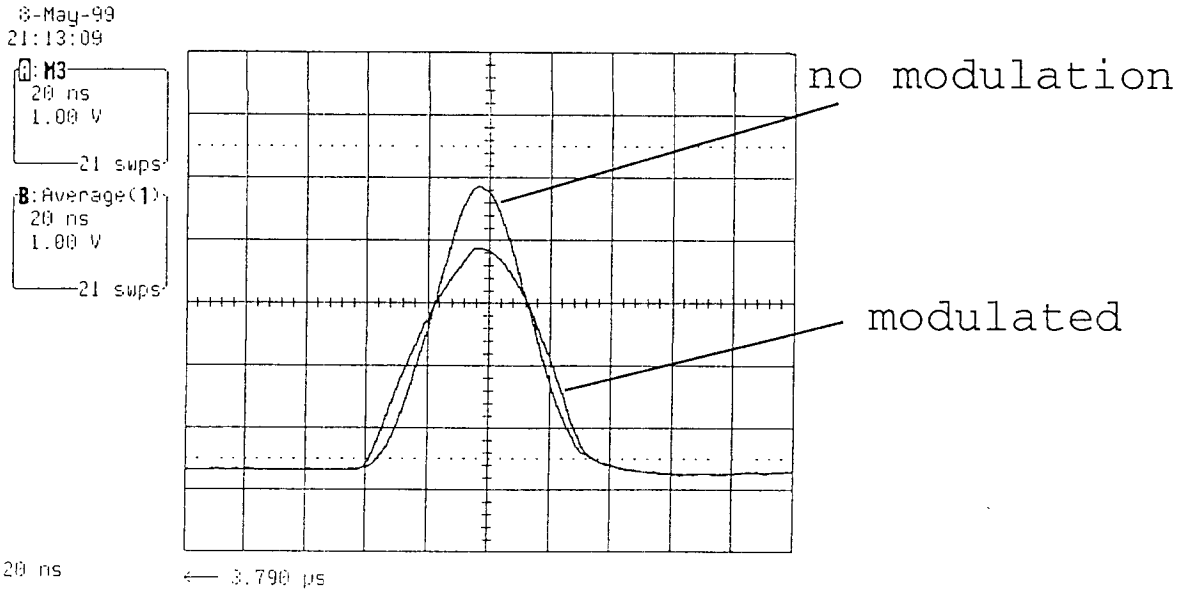
Δf=2.65 kHz

# of spectrum lines~130

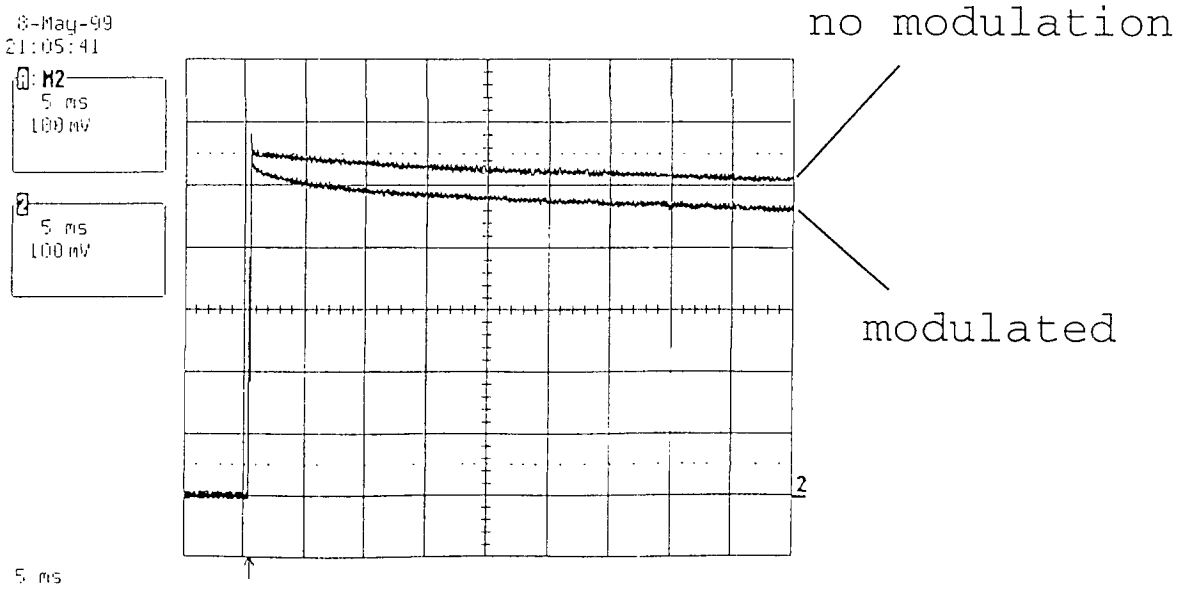
RF Voltage modulation in the BR

~10% gain in intensity

Extracted bunch



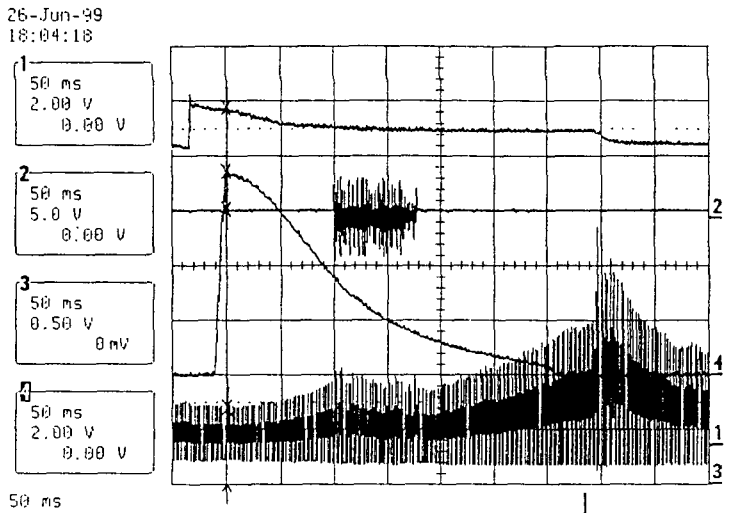
Beam intensity at MR injection



RF Voltage Modulation in th MR

improved γ_T crossing

~14% gain in intensity



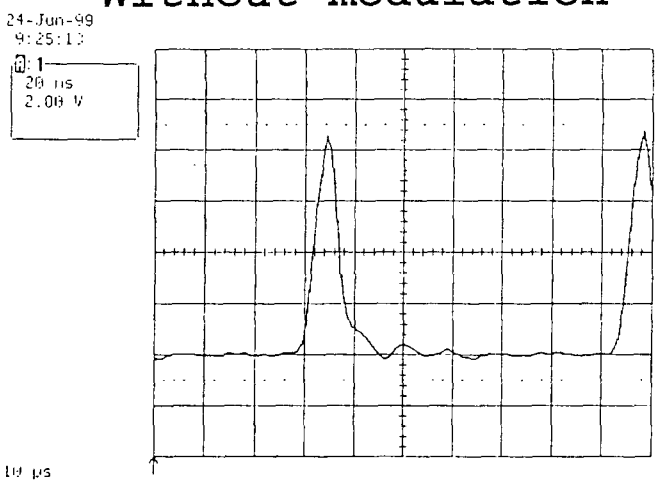
Beam intensity

Modulation signal

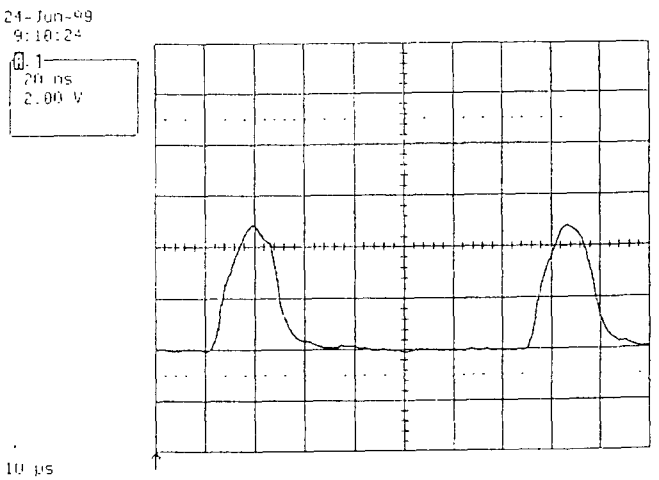
Voltage proportional to f_s

Bunch signal

Without modulation



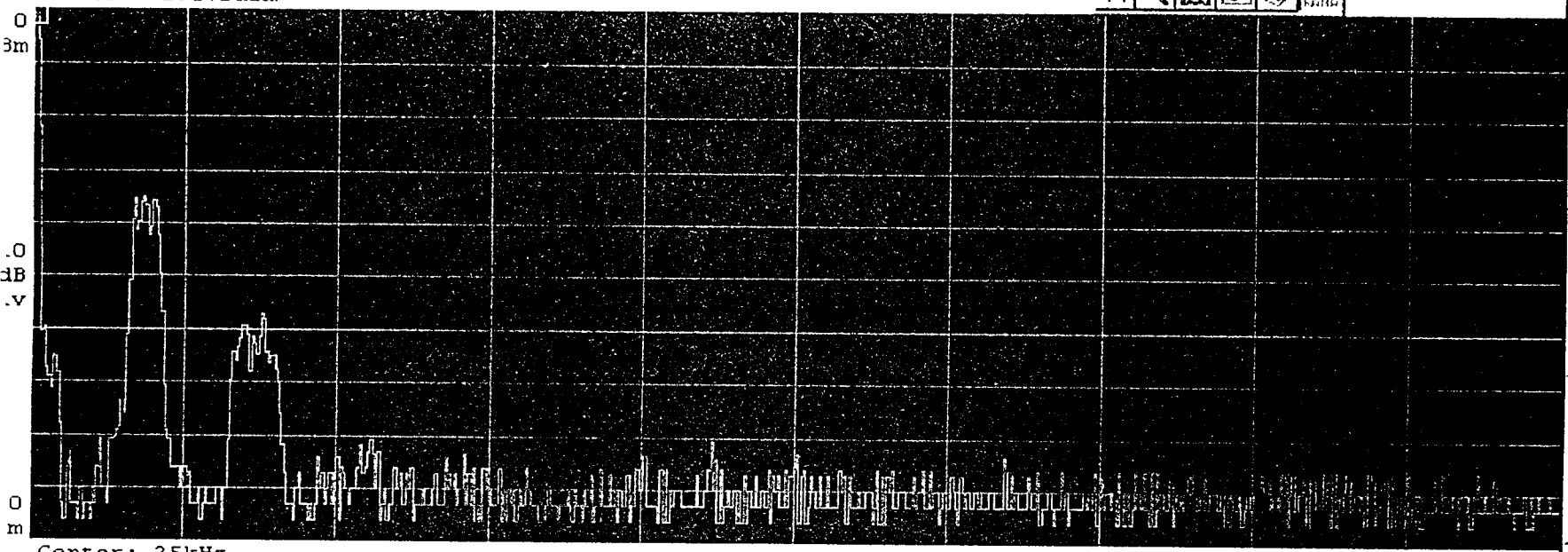
With modulation



RMS degree of modulation ~ 4%

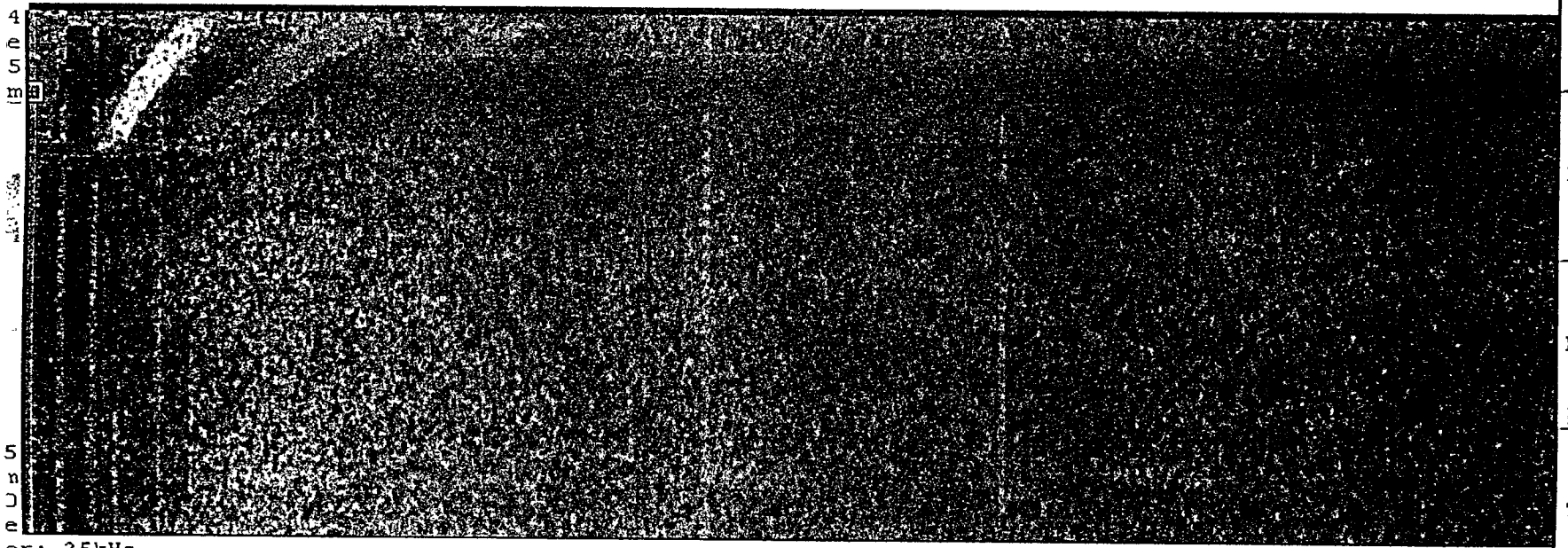
UNCAL OVERLOAD TRIGGERED PAUSE

A: Active, FreqAmpl; 99/05/19 5:26:39
er: 0Hz -1.172dBm



Center: 25kHz Span: 50kHz

B: Active, FreqAmpl; 99/05/19 5:26:39
er: 0Hz -1.172dBm 253frame -253ms



er: 25kHz Span: 50kHz

6MHz Span 2MHz Ref 0dBm VECTOR REALTIME
req AC Blackman 1024 80u(320u) 300 Normal On 1 Time Ext Rise 0%

[Setup]
Standard

Input Mode
RF

Memory Mode
Frequency

Input, FFT...

Freq, Span, Ref...

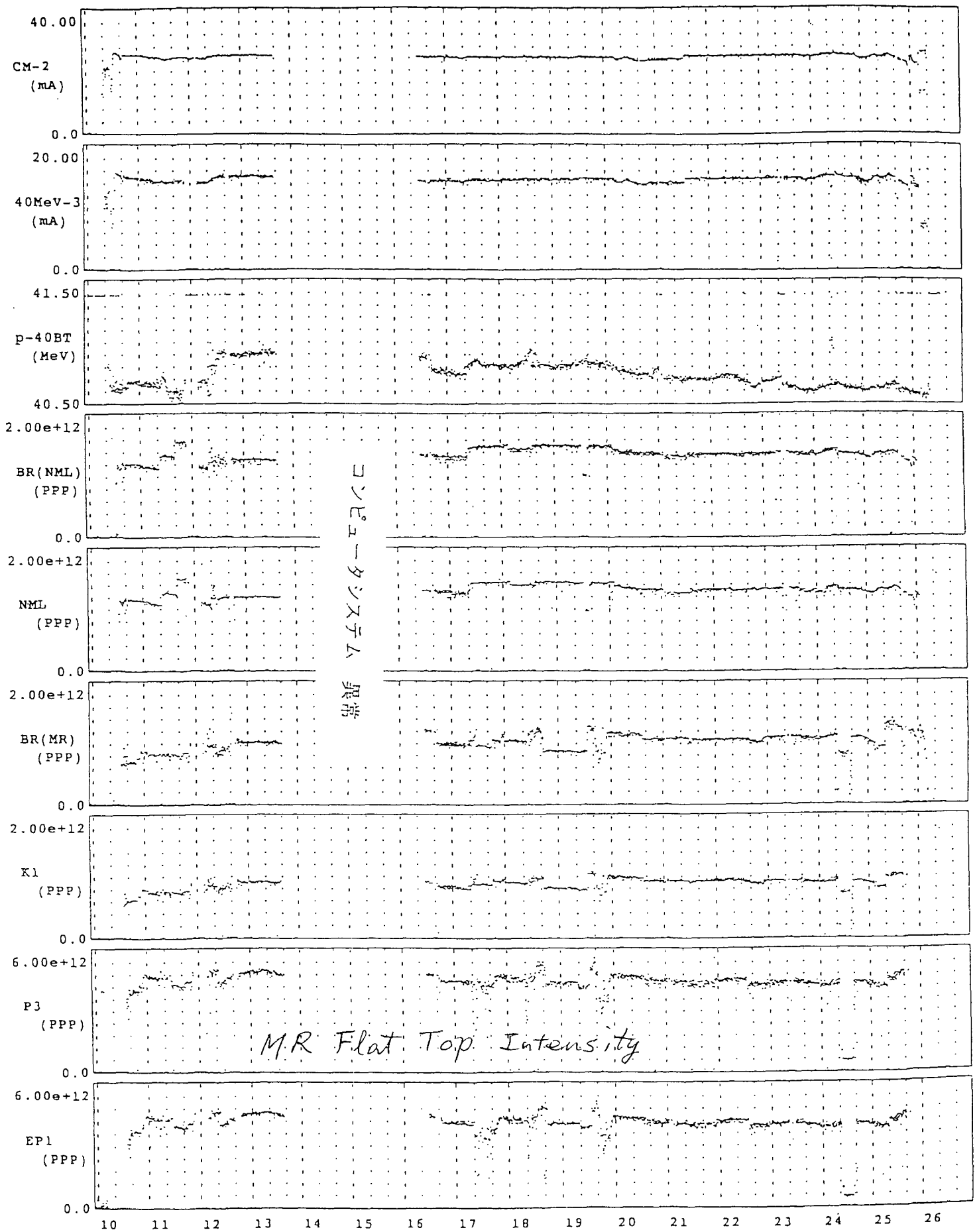
Frame Period [s]
1m

Block Size [frame]
300

Trigger...

PS Op. Record

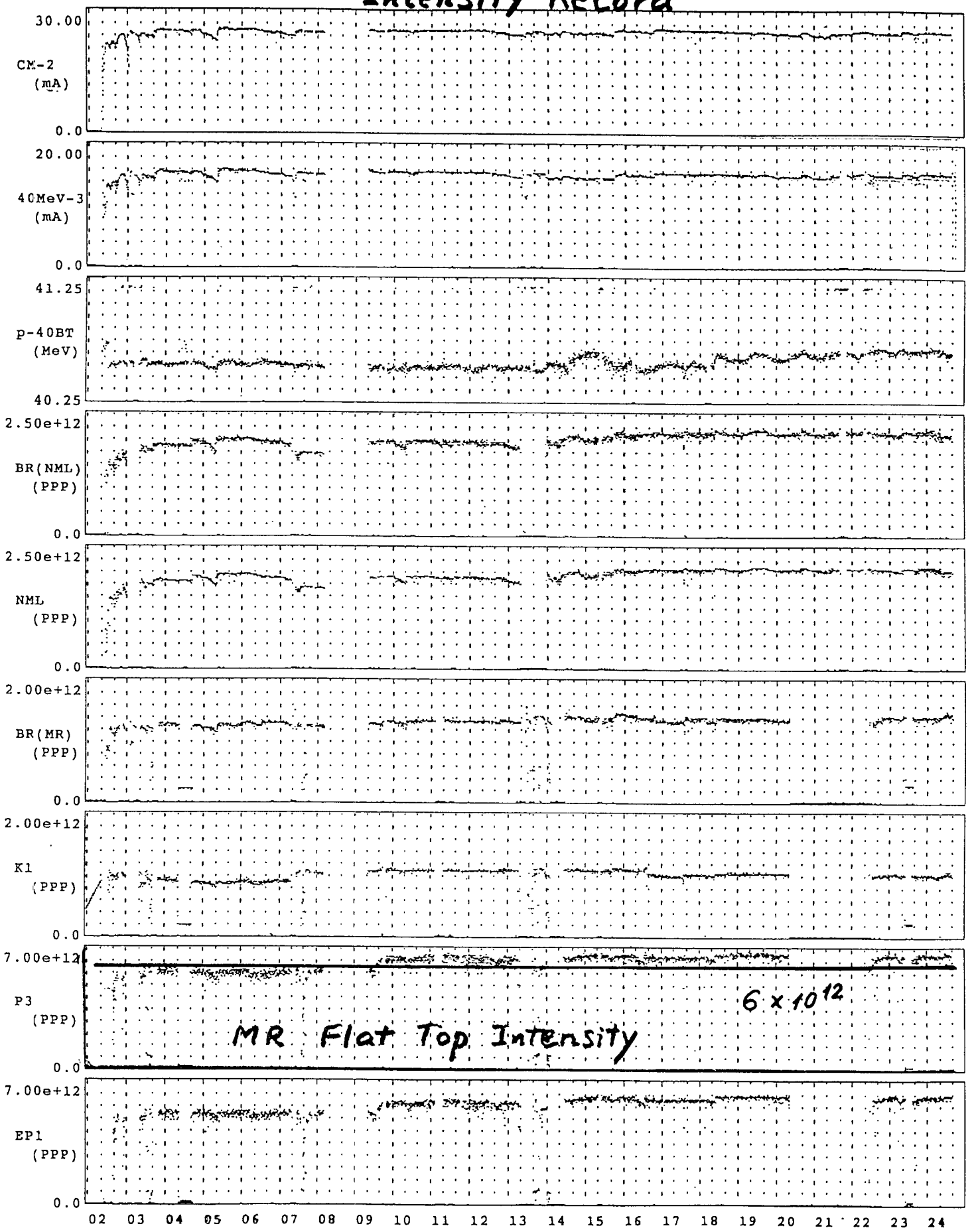
PRINT
03/26/99
14:05:53



PRINT
06/24/99
16:36:59

PS Op. Record

Intensity Record



- Octupole magnets:

  DC power supply ---> AC power supply

- Transverse aperture servey

  & optimization of Octupole

- Further study beam loss mechanism at γ_T

- Reduce the beam loss at extraction (~ 5-10% ?)