

BEAM INSTRUMENTATIONS OF KEKB

KEKB Beam Monitor Group

S.Hiramatsu

1. Beam Position Monitors (BPMs)
2. Beam Current Monitors (DCCTs)
3. Beam Loss Monitors (Ionization chambers)
4. SR Monitors (SR Image, Streak camera & Interferometers)
5. Others

Bunch current monitors

Tune monitors

Turn-by-turn BPMs

Realtime bunch-length monitors

Fast CTs

* Outline and initial performance of these system were reported at the last committee.

1. Beam Position Monitors

- Electrostatic pickup with 4 buttons (12mm ϕ)
454 BPMs @ LER / 443 BPMs @ HER
- Electronics system is distributed in 20 local control buildings (LC).
- Frontend electronics (special 240 VXI modules)
 - superheterodyne (signal; 1.018GHz, IF; 19kHz)
 - beam signal detection; spectrum analysis by DSP
 - S/N~86 dB ; expected resolution $\sim 1.2 \mu\text{m}$ (rms)
 - (4 average of 2048-point FFT @DSP)
 - one frontend processes 4 BPMs(2 of LER & 2 of HER) .
- Processing time for COD measurement of 2 rings is $\sim 2\text{sec}$.
- Resolution measured by 3-BPM correlation method;
 - average 2-3 μm for $I_b > 10\text{mA}$ (limited by orbit oscillation)
- Orbit oscillation has been observed at 0.47Hz(or 0.25Hz) and 11-13Hz with the resolution of $\sim 1\mu\text{m}$.
- Completed beam based calibration of BPM center offset by Quad/BPM-response method.

Δk_n : change of K-value at Q_n

Δx_k : COD produced by Δk_n at (BPM)_k

X_n : measured beam position at (BPM)_n

ΔX_n : offset of (BPM)_n center against Q_n center

$$\frac{\Delta x_k}{\Delta K_n} = -\frac{\sqrt{\beta_k \beta_n} l_n}{2 \sin \pi v} (X_n + \Delta X_n) \cos(\pi v - |\phi_k - \phi_n|)$$

$$\Delta x_k / \Delta K_n = 0 \Rightarrow \Delta X_n = -X_n$$

COD: 0.6-0.7 mm_{rms} (without offset correction)

\Rightarrow 0.3-0.4 mm_{rms} (with correction)

- Special BPMs at IP
 - * Specially designed 4(3) BPMs were installed in the QCS beam chambers (55mm ϕ inner diameter) for the orbit feedback at IP.
 - * Both of e⁻ and e⁺ pass the BPM signal pickup.
 - * pickup; 8 buttons with 6mm ϕ diameter to separate e⁻ orbit and e⁺ orbit.
 - * 10Hz signal processing is available for the orbit feedback.

2. DCCTs

- Developed KEKB-original DCCTs (parallel feedback circuit).

response;	DC-20kHz
offset drift;	$\sim 4\mu\text{A}/\text{deg}$ [$< 20\mu\text{A}$ (long term)]

3. Beam Loss Monitors

- Beam loss is monitored by free-air ionization chambers.

	Ring	IR	BT line
# of chambers	109 (5m long)	16 (1m long)	23 (8-10m long)

4. Synchrotron Radiation Monitors

- SR extraction & Primary optical beam lines
LER; FUJI(QR4/QR5)-D8 / HER; OHO(QR3/QR4)-D4
 - Surface distortion of the extraction mirror is monitored by Shack-Hartmann sensors.
 - Primary SR beam from the weak bend extracted by a Be mirror is divided into 3 lines.
 - (a) Beam image - focused onto CCD camera
Diffraction spreading of 30-40 μm will be corrected;
- on going program
 - (b) Streak camera - measurement of bunch length and structure
 - (c) Double-slit interferometer - automatic beam size measurement
- usefull for collision tuning
- High speed gated CCD camera - bunch profile observation
Extension of beam line for the gated camera for LER will be completed in February.

5.Others

5-1 Bunch Current Monitors

- Bunch current is detected by the frontend similar to that of the bunch-feedback system using $4f_{rf}$ reference.
- Available for 50Hz data-processing of 5120 bunches.
- Beam injection is controlled by bunch-current monitors.

5-2 Tune Measurement

- Transverse tunes are measured by spectrum analyzers using feedback kickers to excite beam oscillations.

5-3 Turn-by-turn BPMs

- 4 BPMs in LER and 4 BPMs in HER can be switched to wideband signal processors with $\sim 20\text{MHz}$. bandwidth.
- Used for injection tuning.

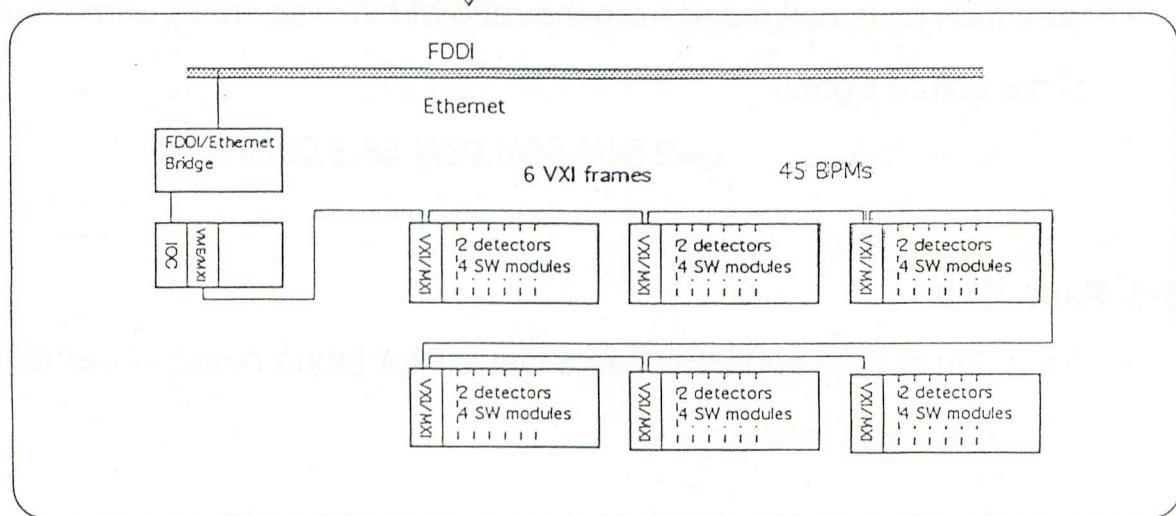
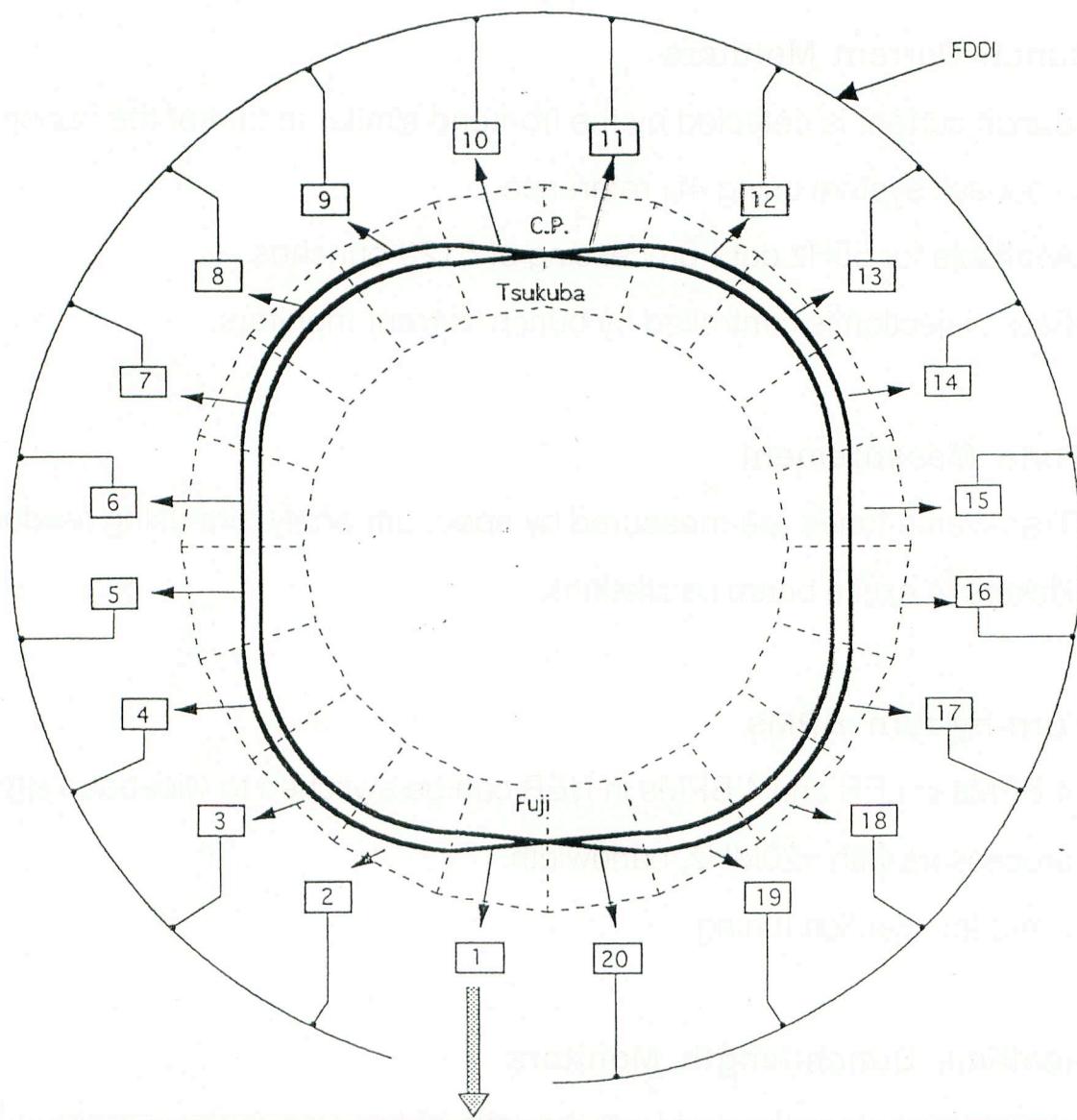
5-4 Realtime Bunch-length Monitors

- Bunchlength is estimated from the ratio of two frequency components of the button signal.

$$f_1=509\text{MHz}, \quad f_2=2.54/3.56/4.07/4.58/5.09\text{GHz}$$

5-5 Fast CTs

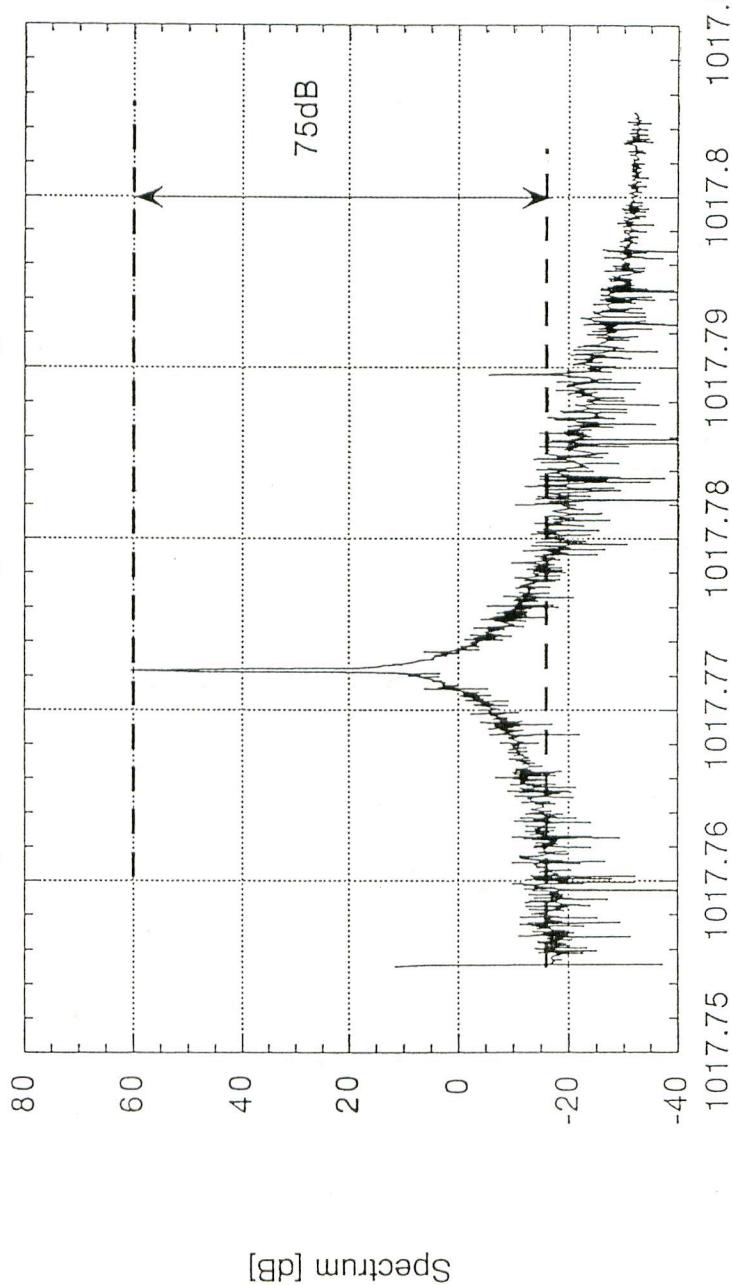
- Each ring of LER and HER has a fast CT for beam bunch observation.
response; $\sim \text{nsec}$



Beam Position Monitor System for B-Factory
240 Detector circuits

— Spectrum_A

Spectrum data by calculating of DSP

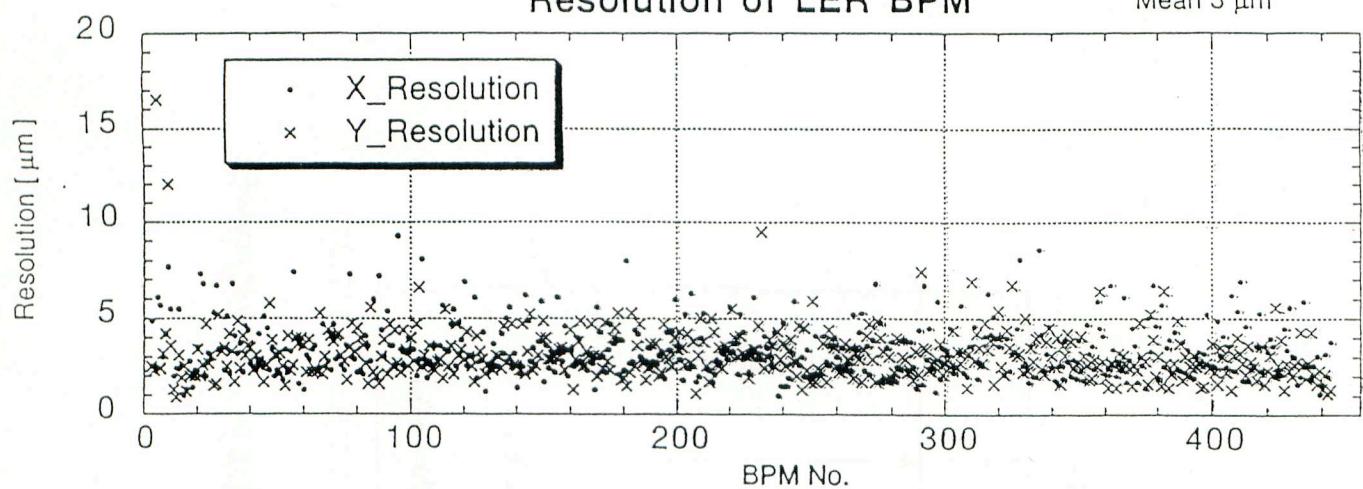


FFT/DSP : 2048 points

Figure 5

Resolution of LER BPM

Mean 3 μm



Resolution of HER BPM

Mean 3 μm

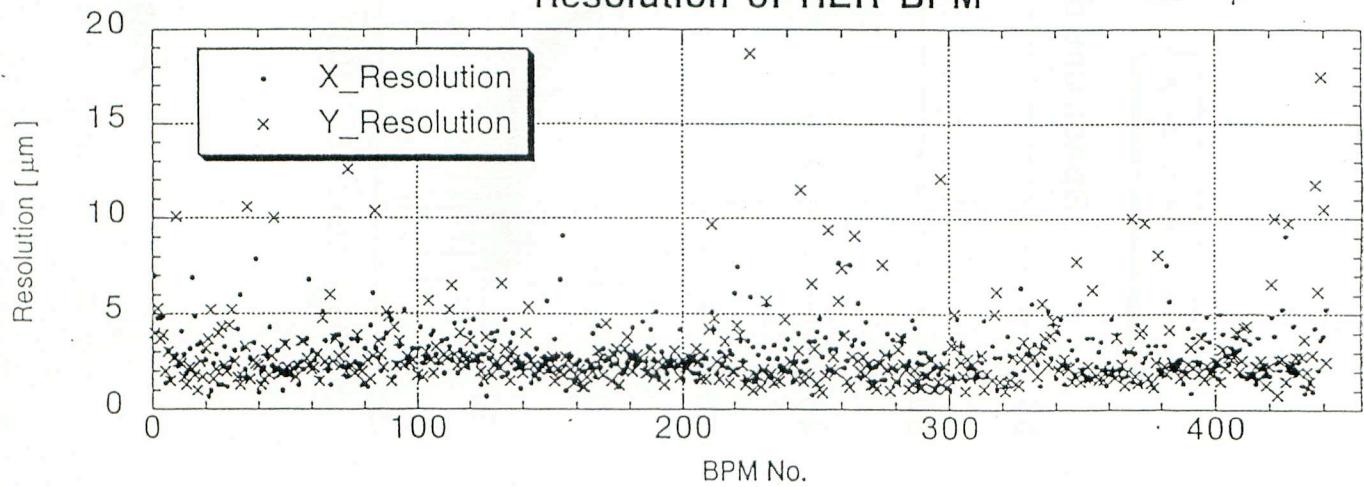
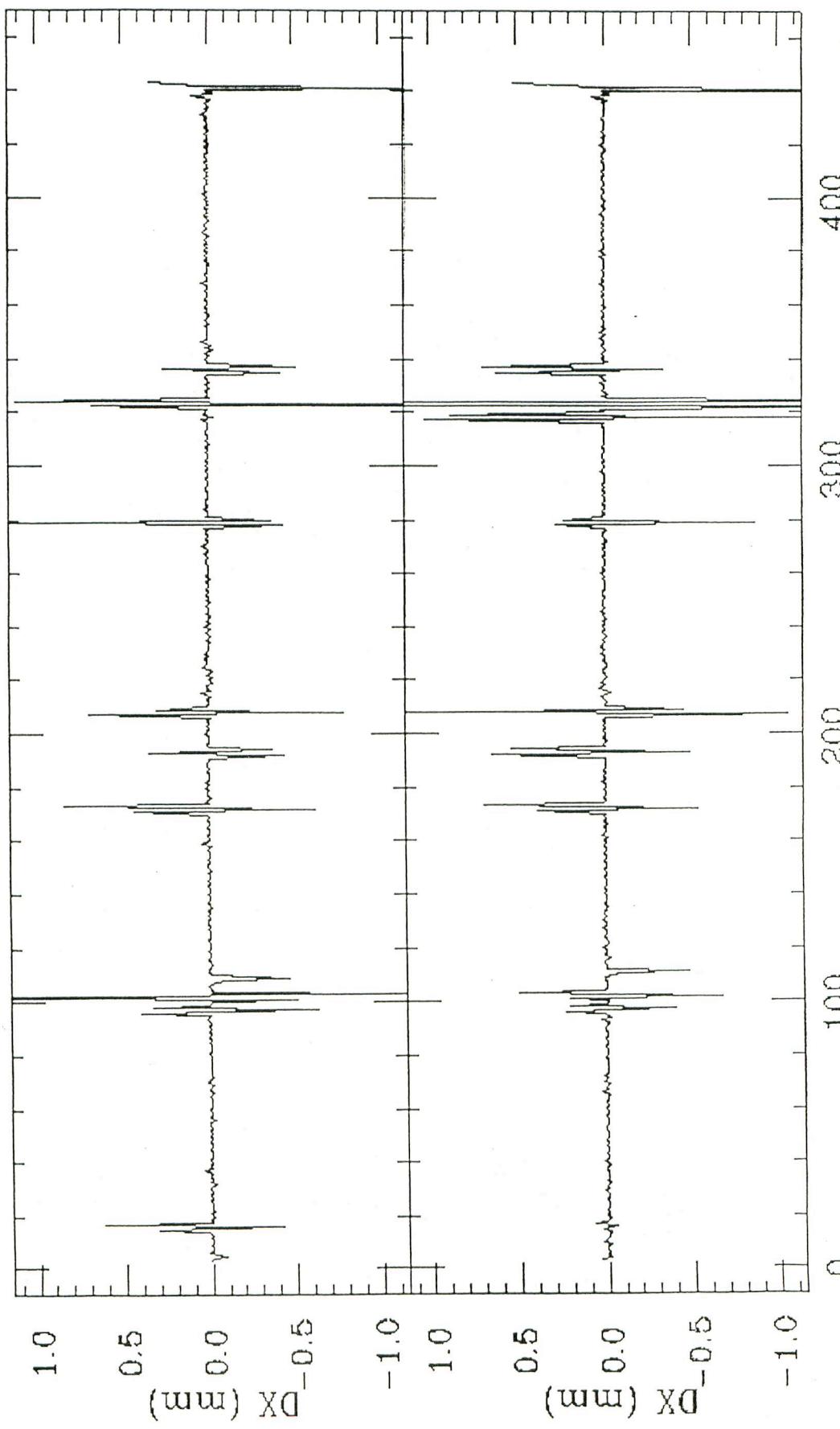


Figure 11

10_16_1999_07:54:35

a) ZHQFRNE1, b) ZHQFRNE2



Lattice model dependent
3-BPM correlation method

3BPM

$M = m_m$

$\lambda = 3 \quad 2 \quad 1$

BPM No.

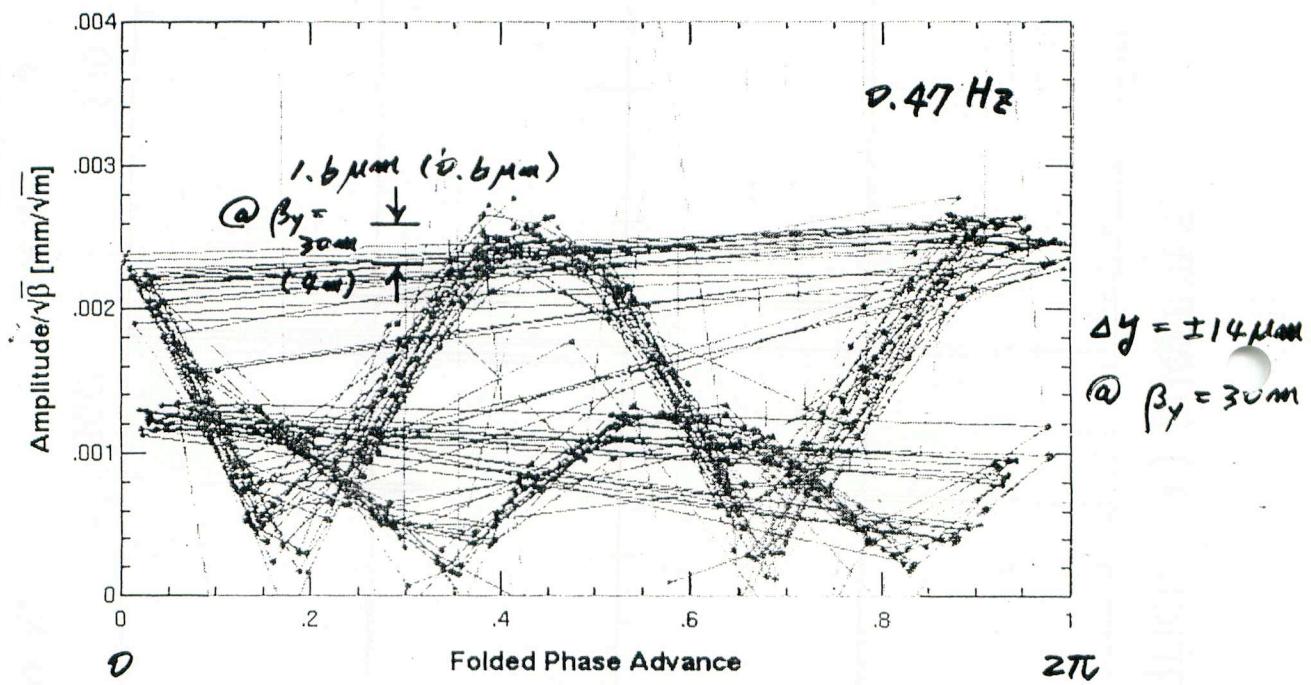
400
300
200
100
0

$$x_{ij}^{cal} = \frac{m_{12}}{m_{12} + m_{23}} x_{i1} - \frac{m_{12}}{m_{12} + m_{23}} x_{i2}$$

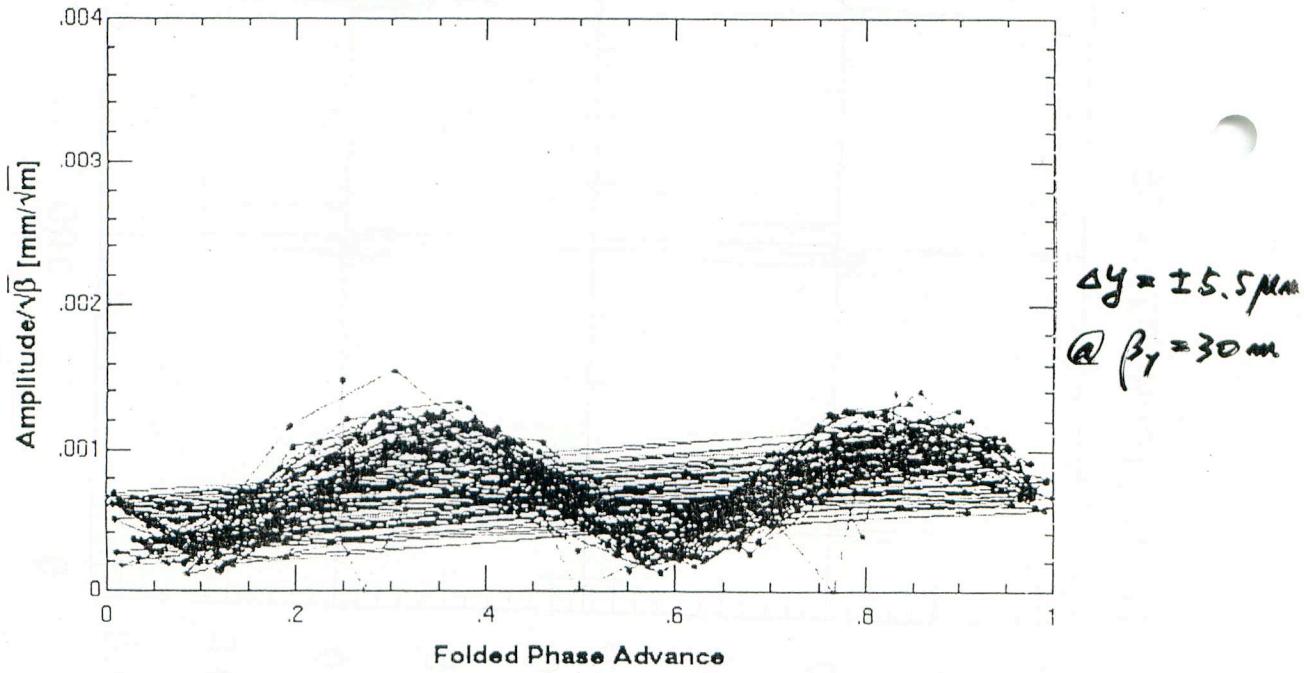
LER vertical orbit oscillation due to PS

FFT/DSP : 2048 point
512 data

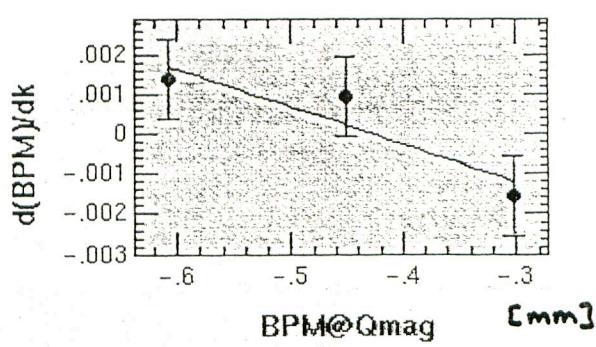
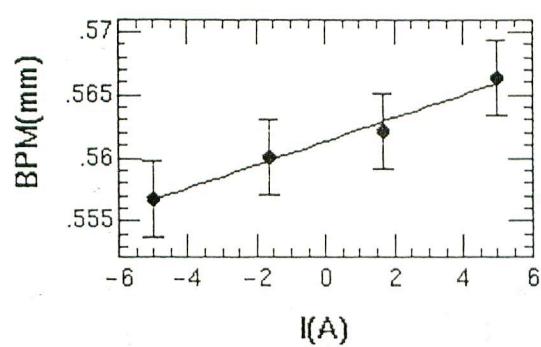
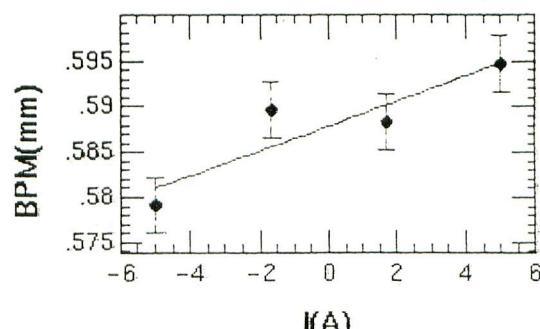
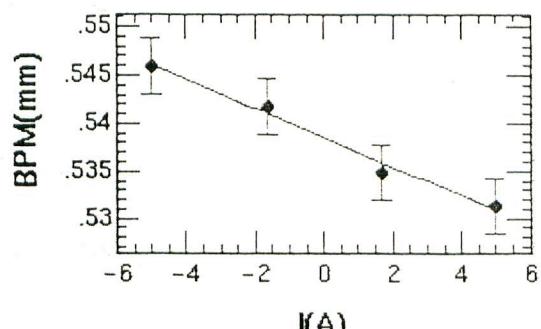
Before compensation (Jun. 1999)



After compensation (Jan. 2000)



/lidata1/KEKB/QuadBPM/QA3LEy.dat



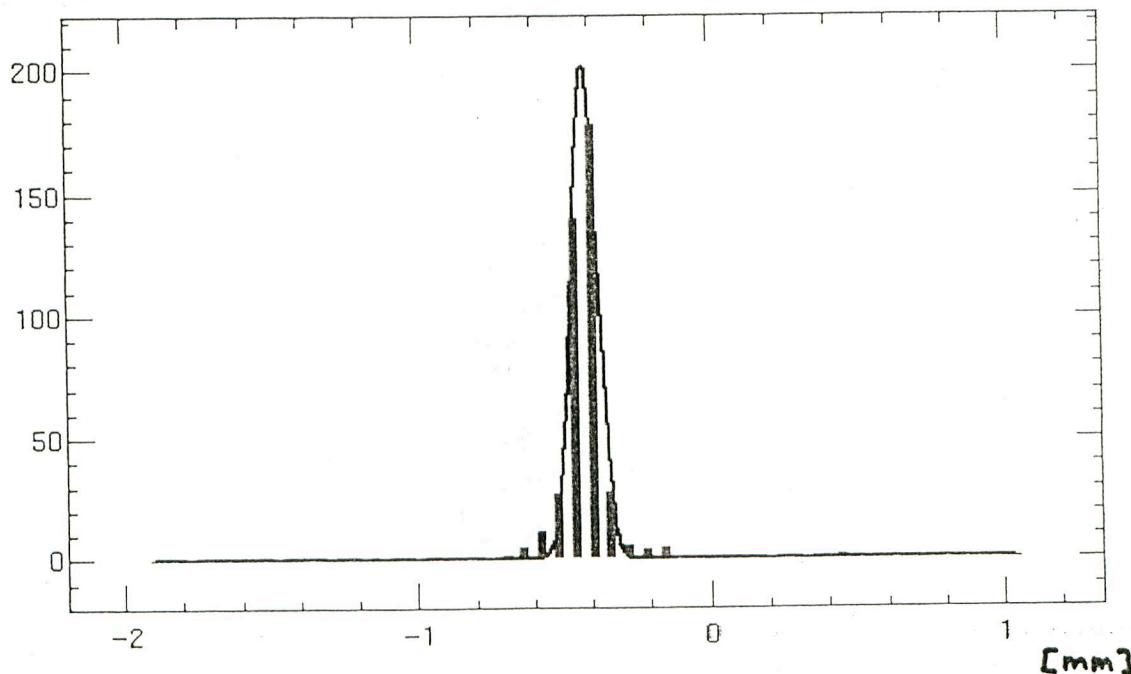
/lidata1/KEKB/QuadBPM/QA3LEy.dat

ChiSquare = 367.311 Goodness = .47256

a = 201.868 +/- 3.32167

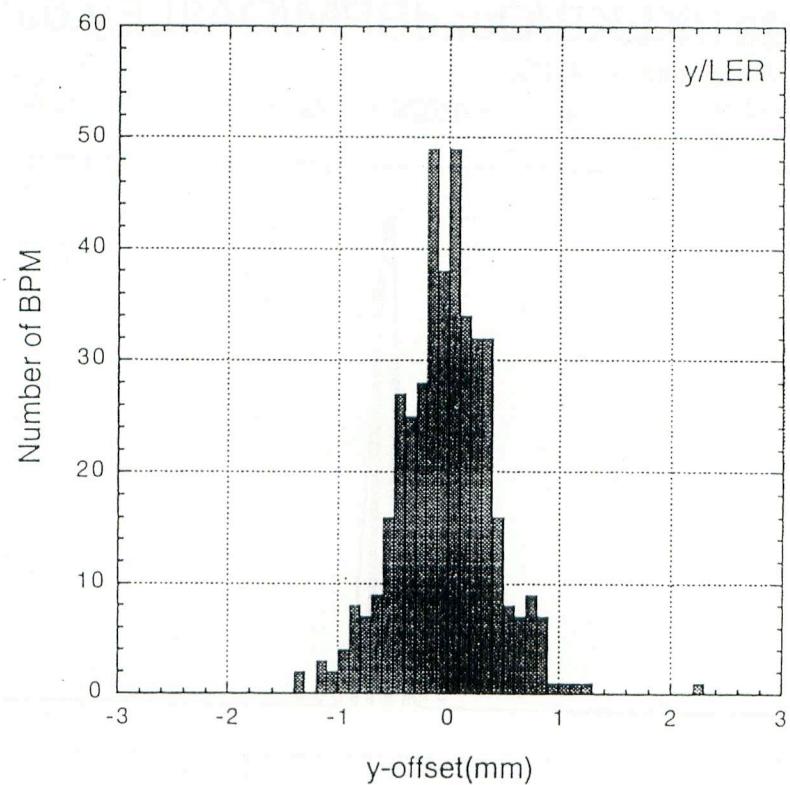
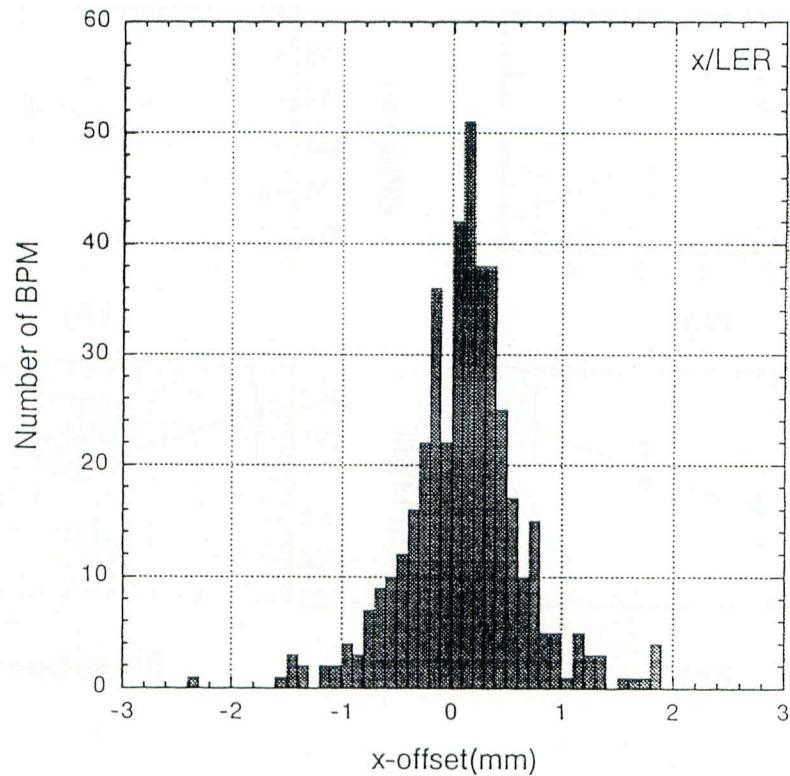
c = -.42076 +/- 7.38E-4

sigma = .04410 +/- 9.00E-

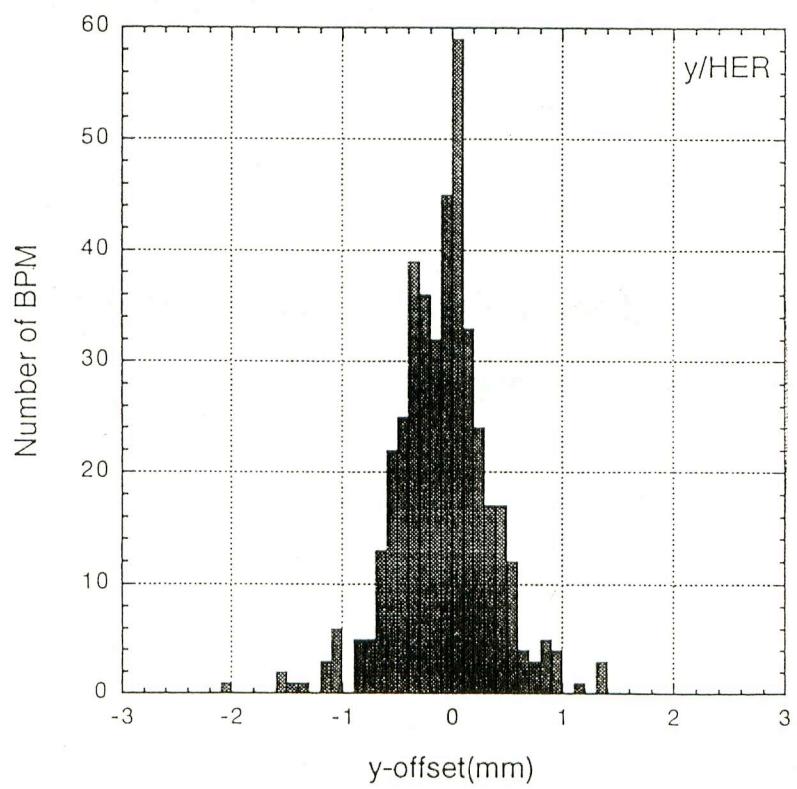
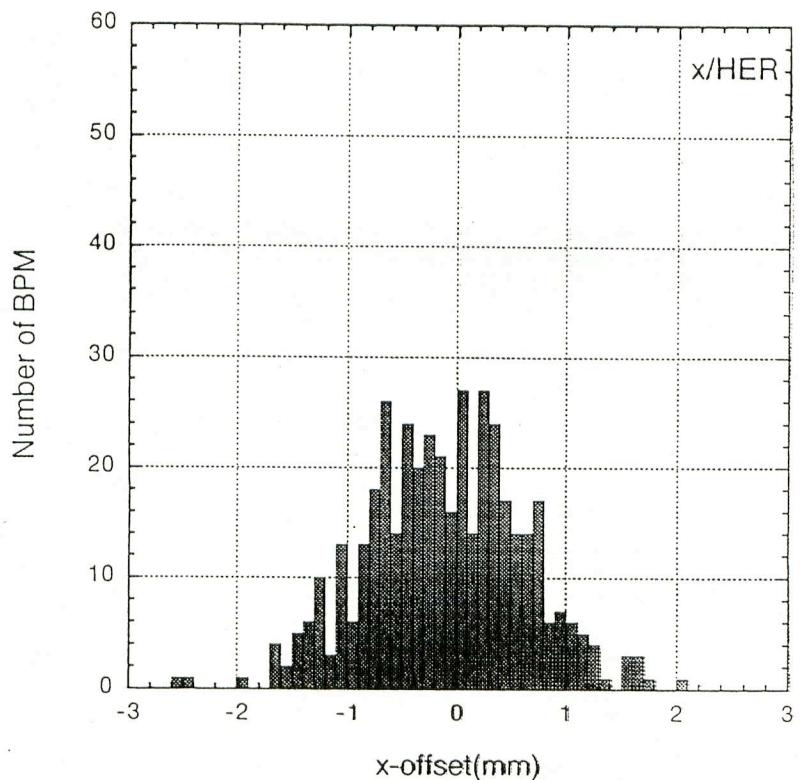


Function = (a Exp[(-.5 (sigma^-2) ((x+(-c))^2))])

Beam based Calibration: BPM/LER Offset Distribution (Quad/BPM-response)



Beam based Calibration: BPM/HER Offset Distribution
(Quad/BPM-response)



LER Orbit Correction

2.463 mA

measured 12/26/1999 10:04:43

46/40 2.5x1000-7

BPM K3.18

rms(m)=.299 mm

max(m)=1.098 mm

@ M001QCSLP

min(m)=-.353 mm

@ M043QF2P

rms(m-r)=.024 mm

~.135 fm

@ M030QZ2_P

(~.272±.442 mm)

rms(m)=.349 mm

max(m)=.3422 mm

@ M003QCSLP

min(m)=-.1841 mm

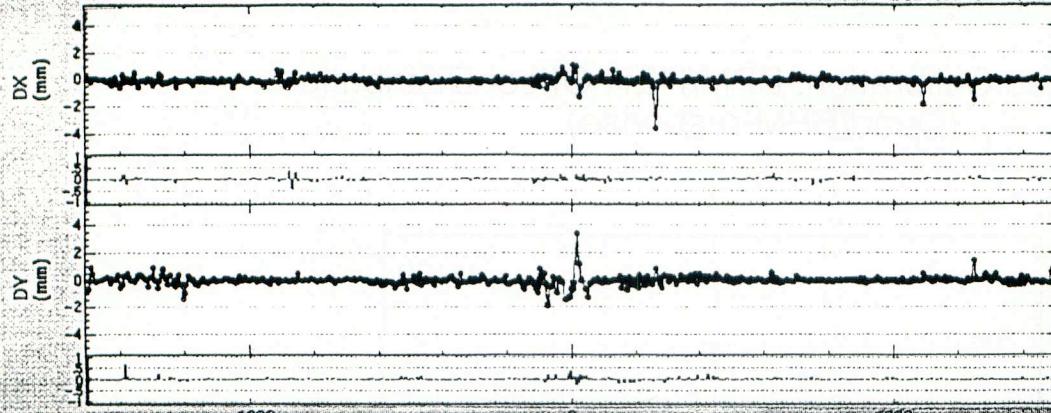
@ M446QB1RP

rms(m-r)=.088 mm

~.235 fm

@ M030QZ2_P

(~.567±.192 mm)



CCC Stop : GOLD_12_26_1999_08:54:38

range DX Auto Fix (S) ▲ ▼ DV Auto Fix (S) ▲ ▼ Report

Ring ✓ -T- ✓ T-N ✓ -N- ✓ N-F ✓ -F- ✓ F-0 ✓ -O- ✓ O-T ✓ @BPMx ✓ @BPMy

[mea] [sta] [ref] [m-r] [s-r] [cal] [gold] [m-g] [mea->] [ref] [gold] [Save mea] [ref] [m-r] [gold] [Clear Stat.] [Standard Size]

Correction Panel

Conditions

◆ mea ✓ mea-ref ✓ mea-gold

■ Horizontal ■ Vertical

SVD: MICADO

Tolerance .01

◆ normal ✓ fast

v_x 45.57963 45.57548 45.57963v_y 44.13023 44.14141 44.13023

Correction

Calculate

Set Correctors

Damping Factor .5

Start CCC

Stop CCC

■ Correction

■ Display Results

Clear Inhibit Flags

Orbit

Measure

BPM NG: 016 30

[Use NG BPMs]

Recall ->

[mea] [ref] [gold]

Factor 1

TBT->COD

Forget Old Bump

Steering

Reset

Back

IP Kick

Set QCS

Synch Set

Adjust Kick

Saved to COD_12_26_1999_10:05:44

COD/LER (after BPM offset correction)

x_{COD} 0.3 mm rmsy_{COD} 0.35 mm rms

* Offset correction of 37 BPMs around IR has not been done yet.

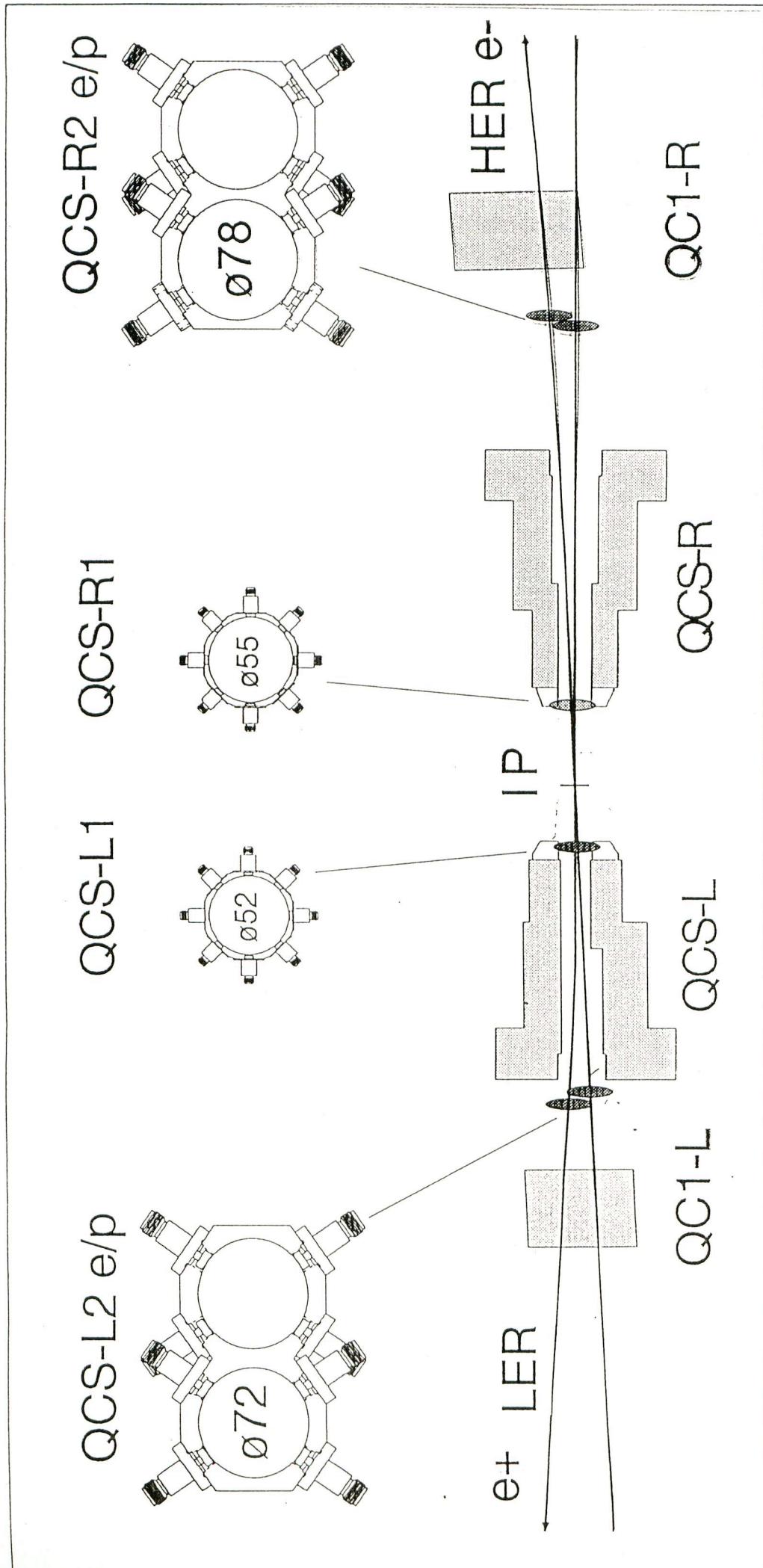
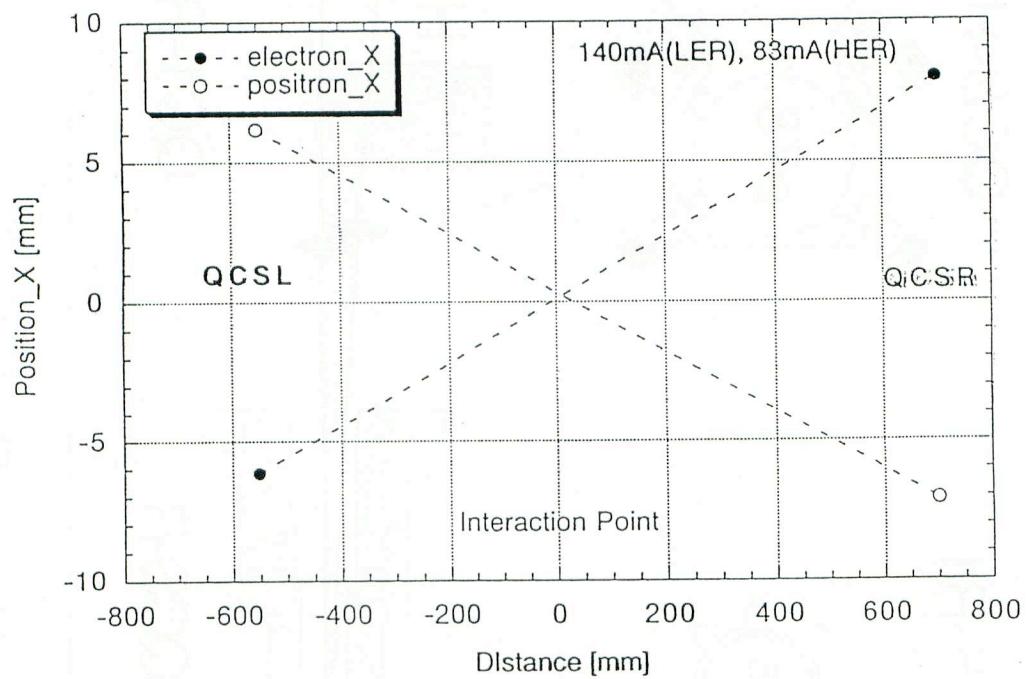
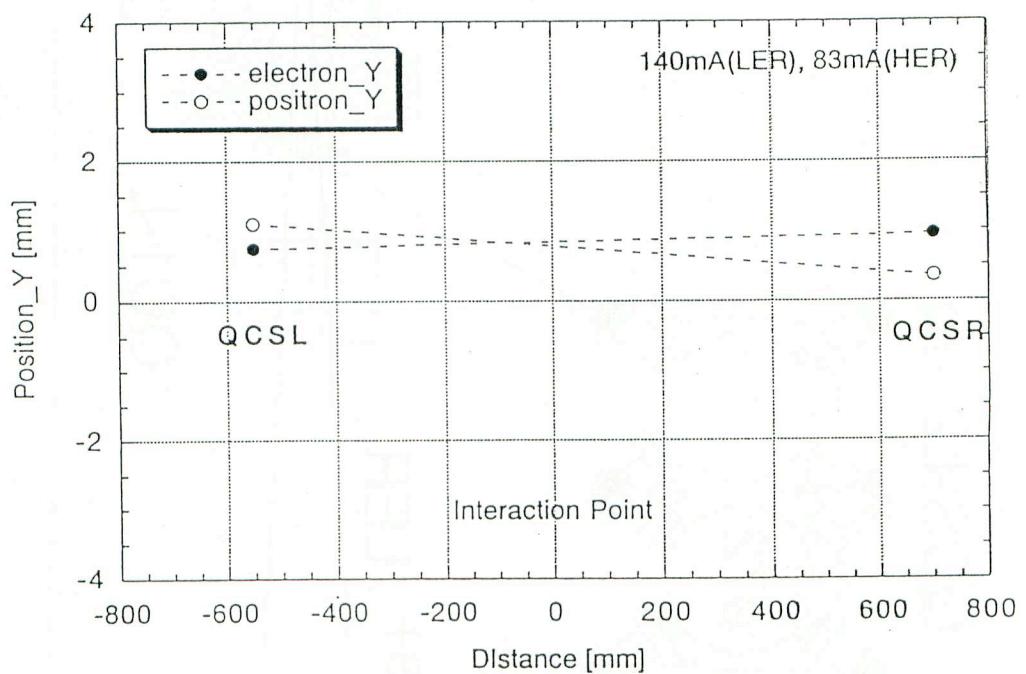


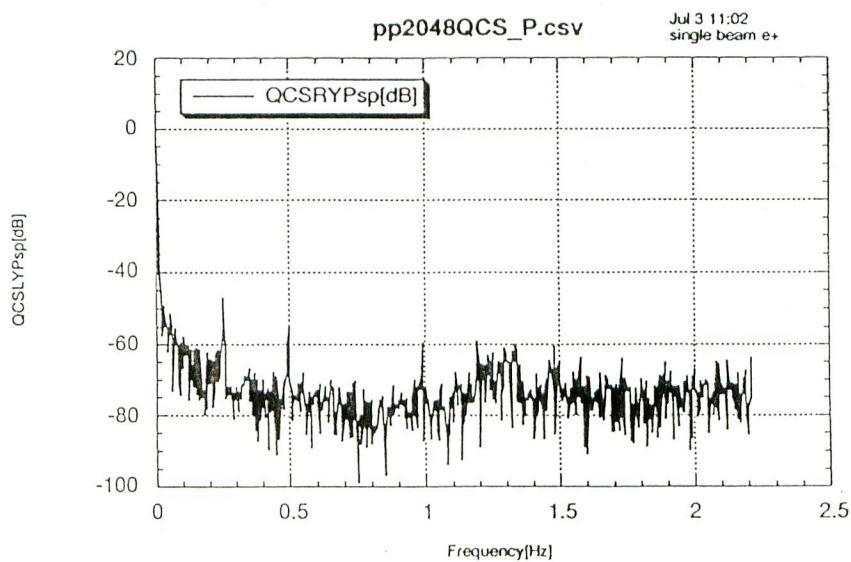
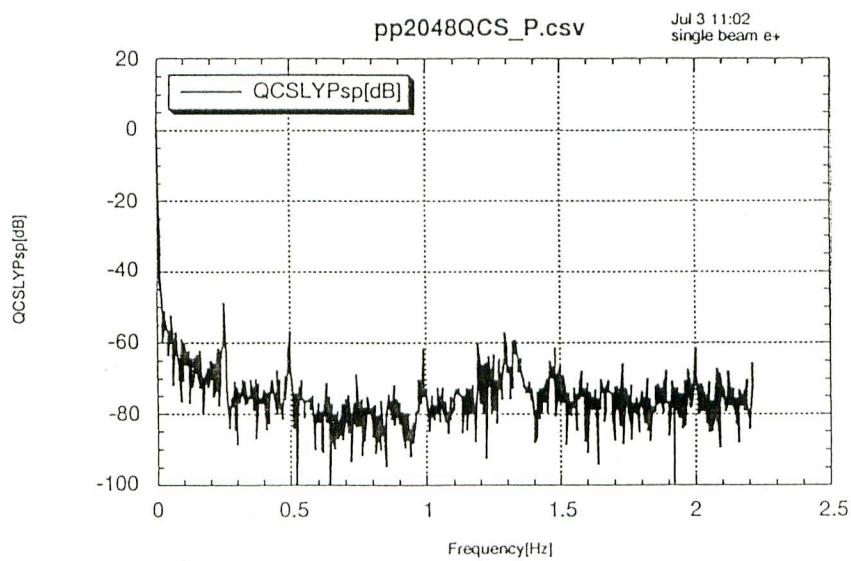
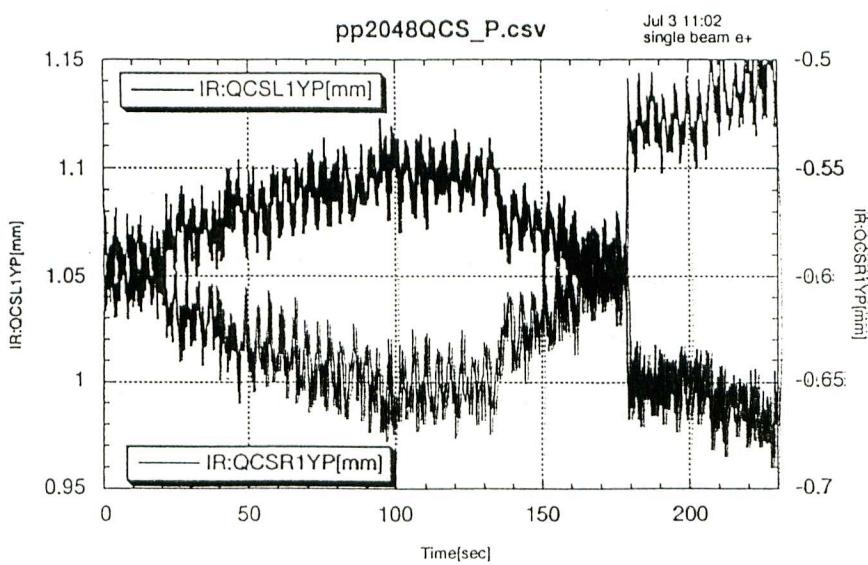
Figure 12 BPMs around Interaction Point

Measurement by OCTPOS

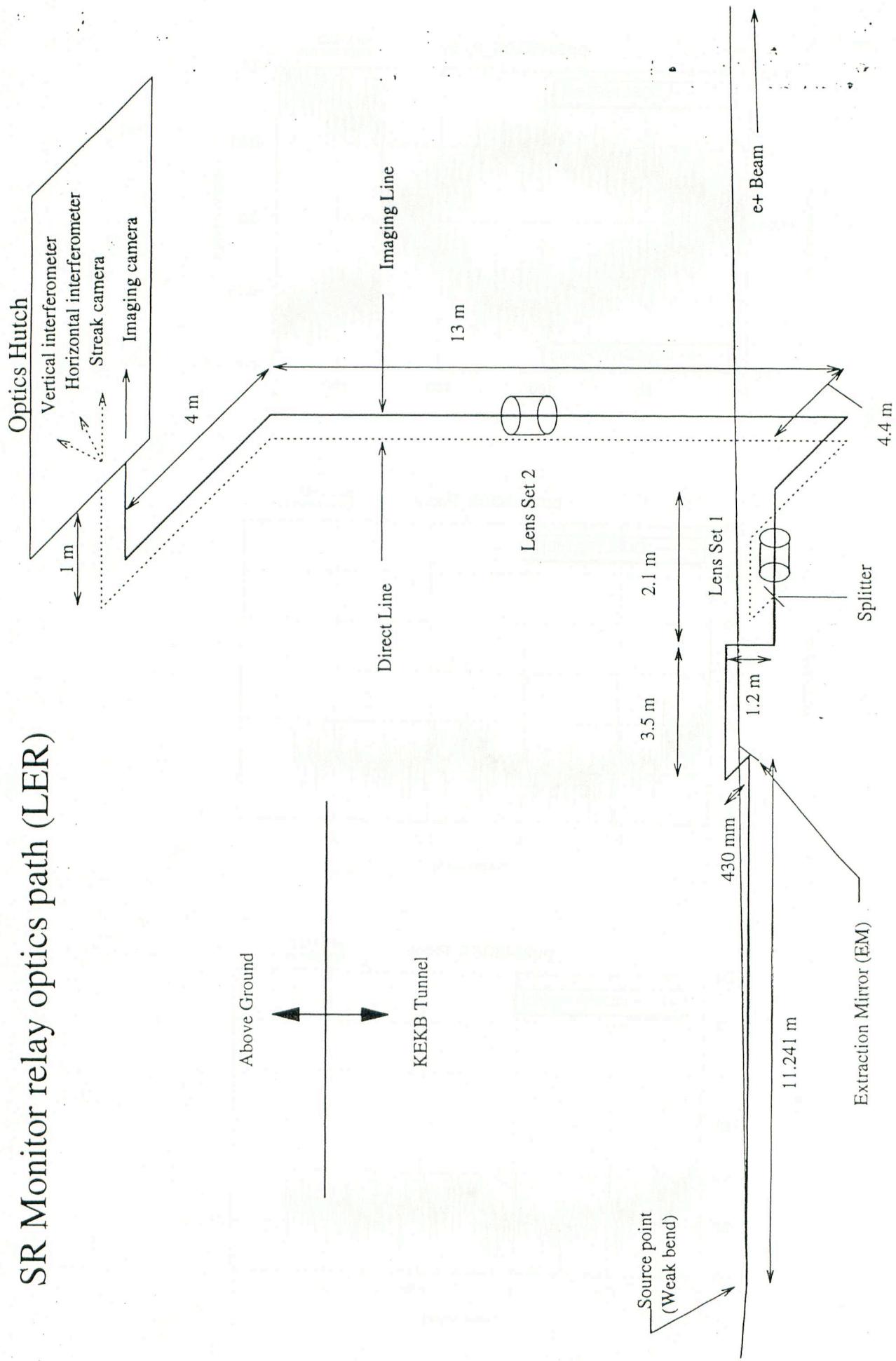


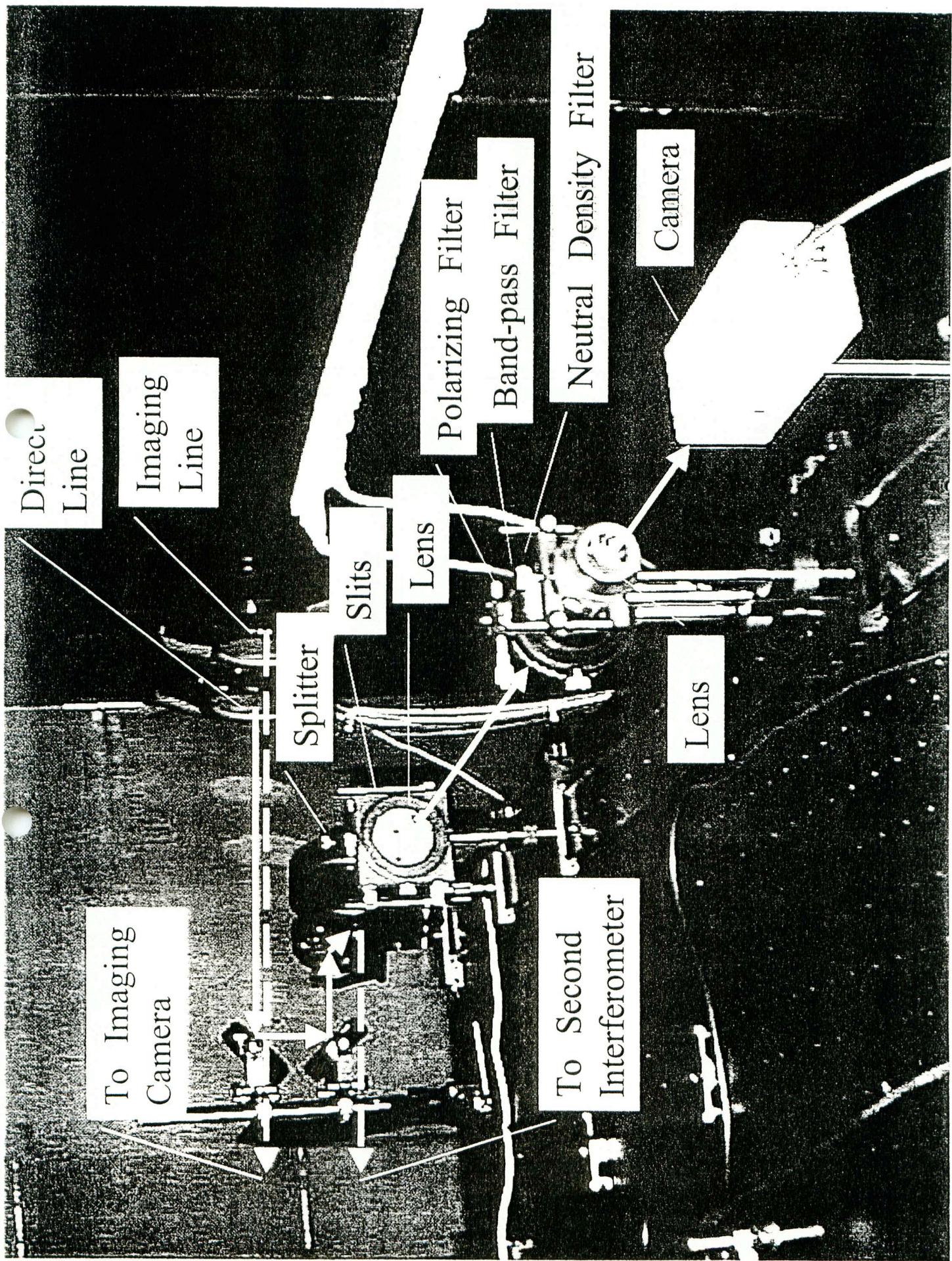
Measurement by OCTPOS





SR Monitor relay optics path (LER)





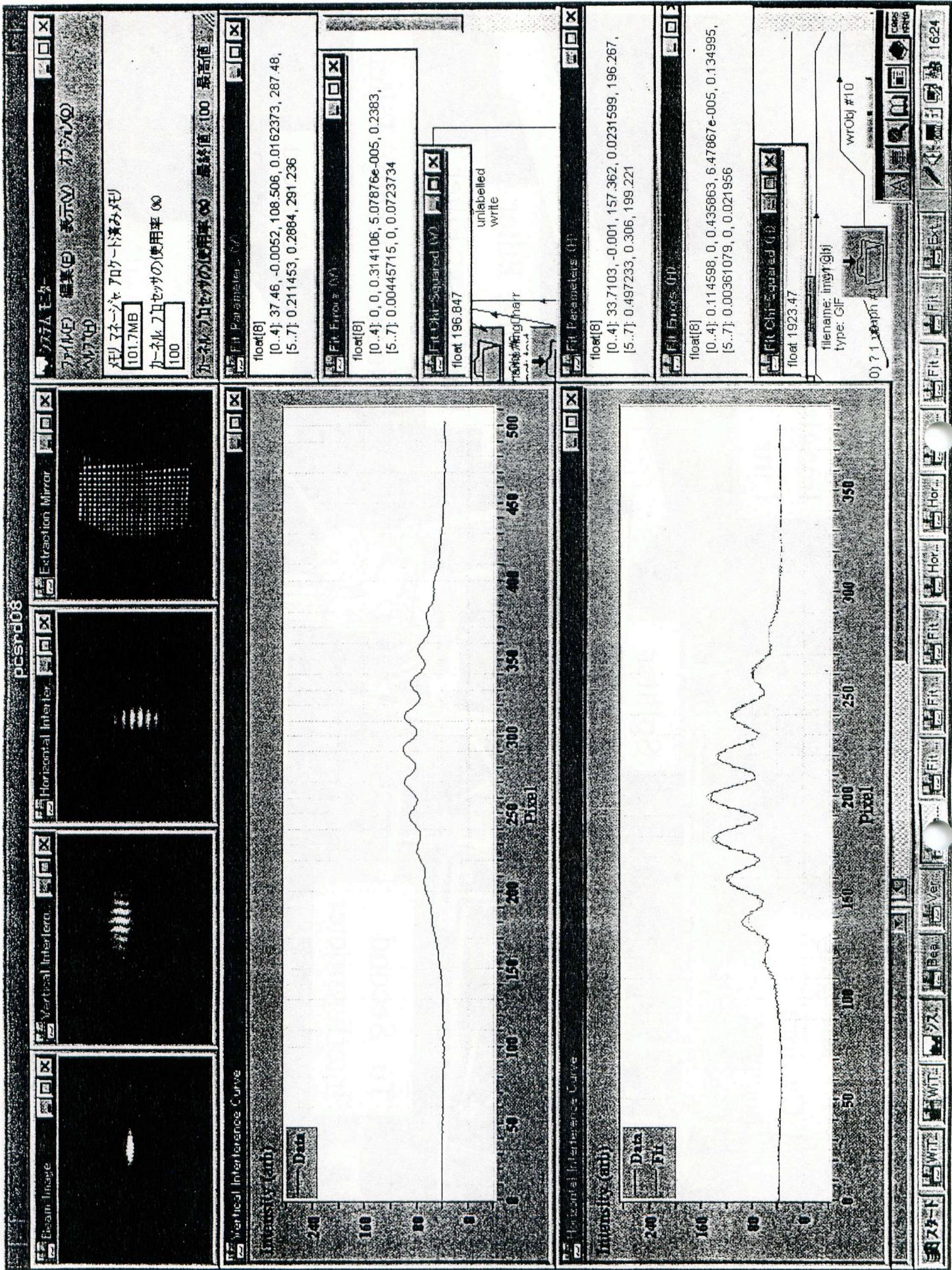
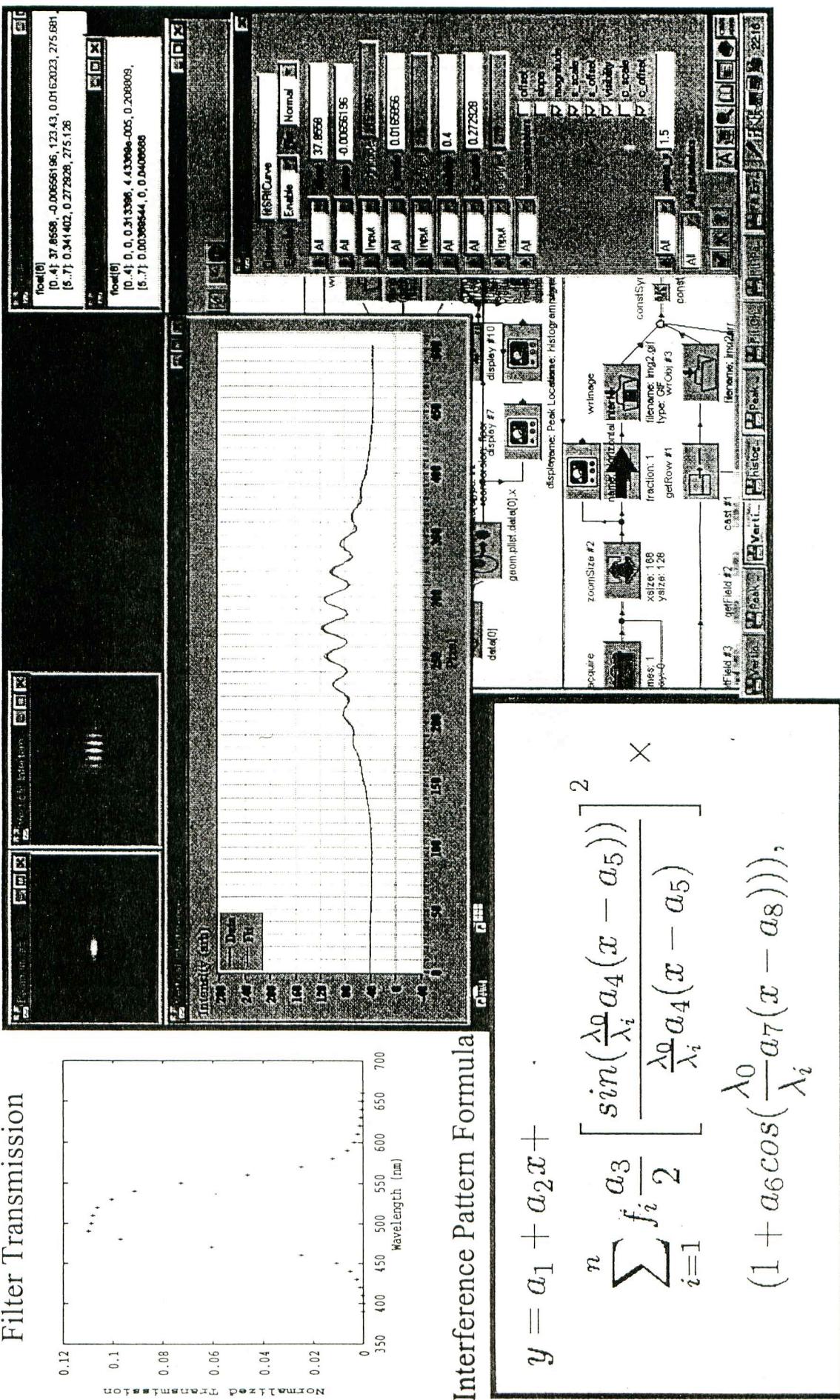


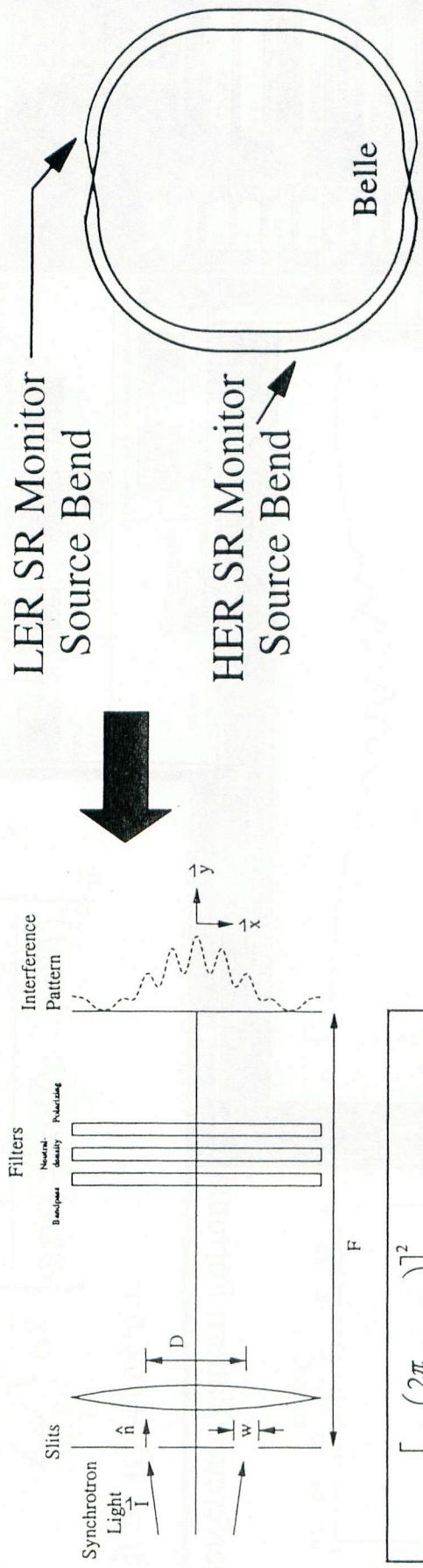
Image Processing System

Online Fitting



SR Interferometry

Beam-Size Monitor



$$y(x) = I_0 \left[\frac{\sin\left(\frac{2\pi}{\lambda} F_w \Phi x\right)}{\frac{2\pi}{\lambda} F_w \Phi x} \right]^2 \left(1 + \gamma \cos\left(\frac{2\pi}{\lambda} D x\right) \right)$$

where:
 λ = wavelength
 $\Phi \propto \vec{I} \cdot \hat{n}$
 γ = Visibility

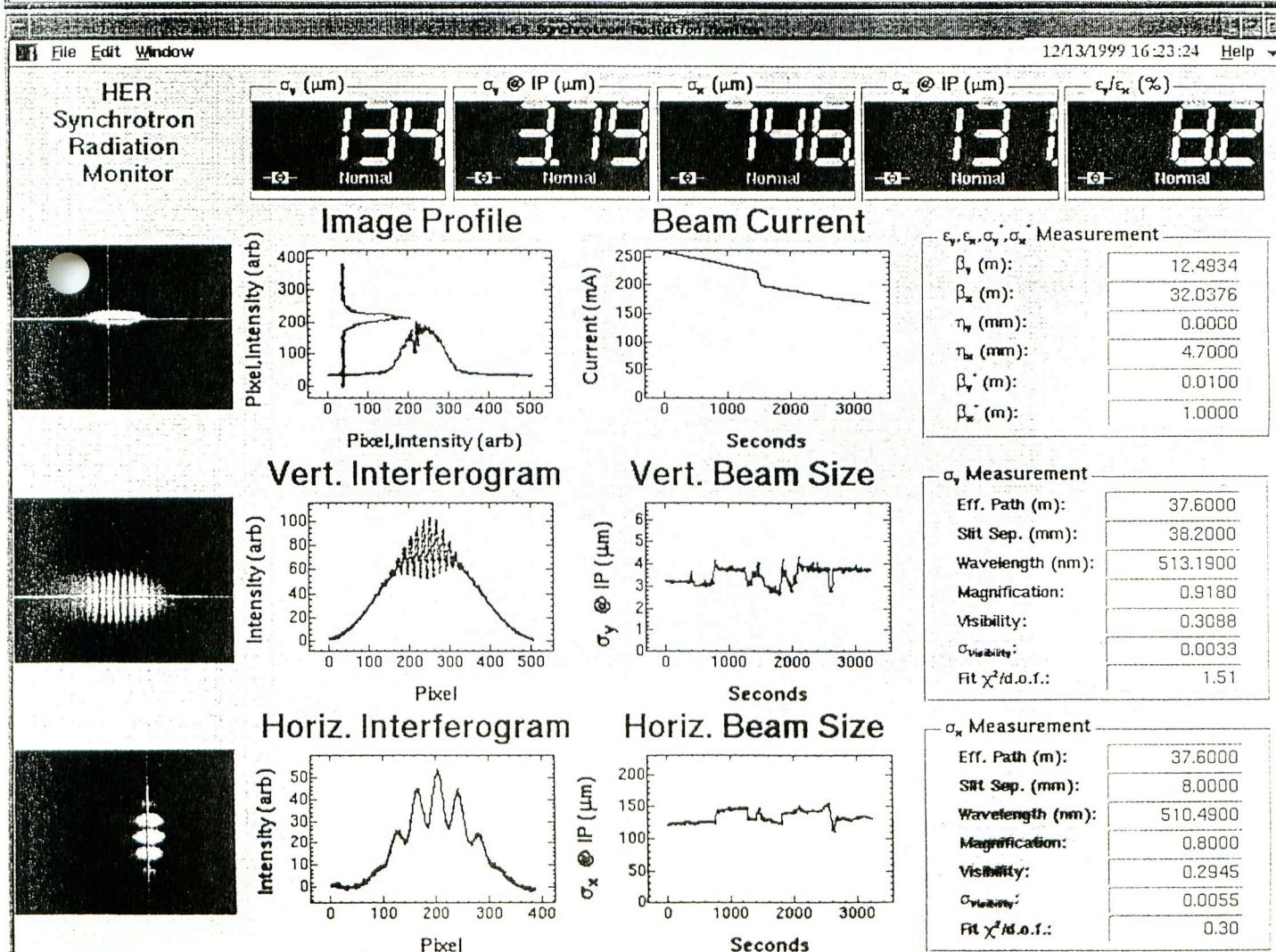
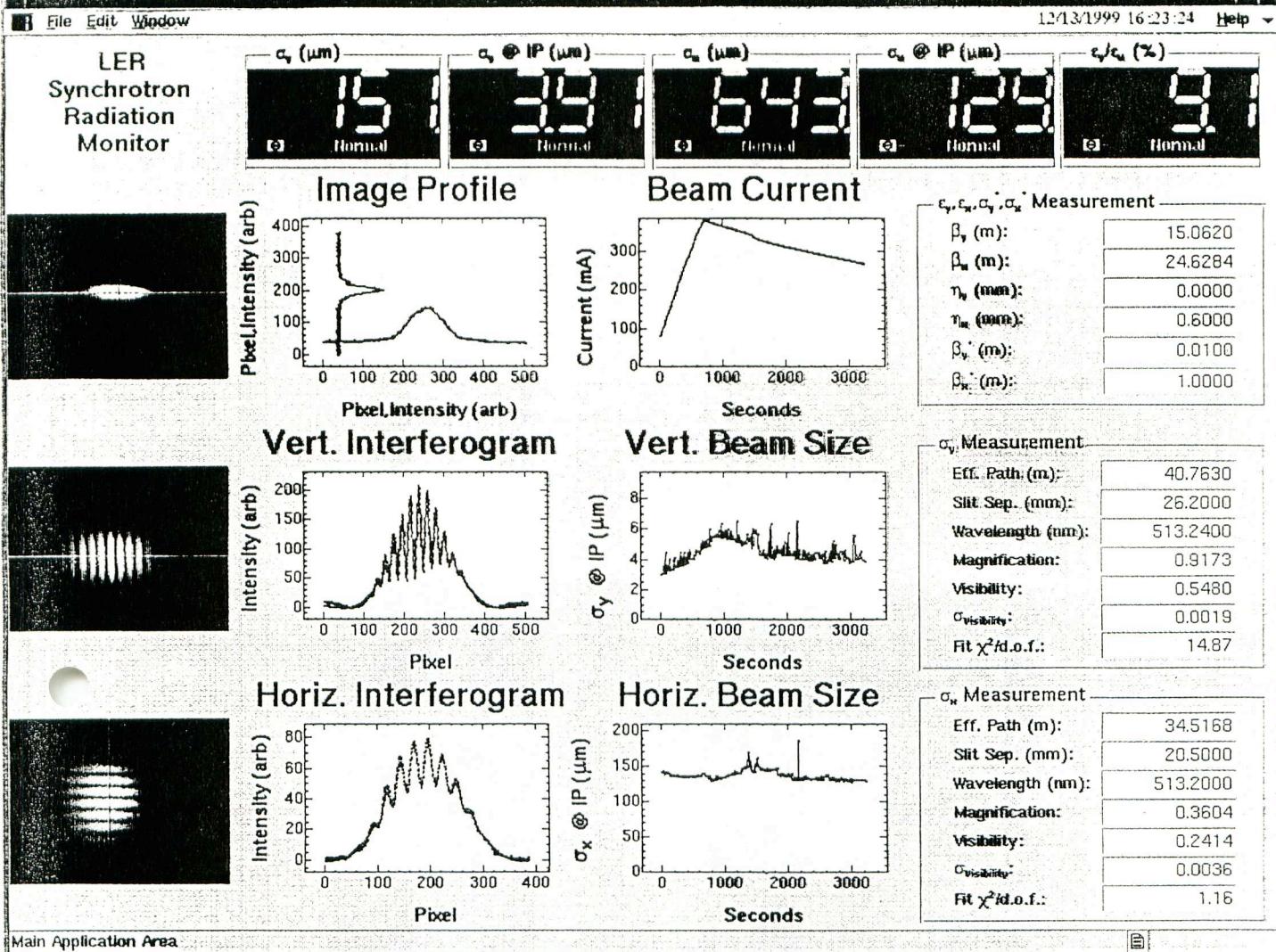
$$\sigma_{beam} = \frac{\lambda L}{\pi D M} \sqrt{\frac{1}{2} \ln \frac{1}{\gamma}}$$

where:
 L = distance from source
 M = magnification

↑ Translate
to I.P.

Find Visibility

$$\sigma^* = \sigma(SRMon) \sqrt{\frac{\beta^*}{\beta(SRMon)}}$$

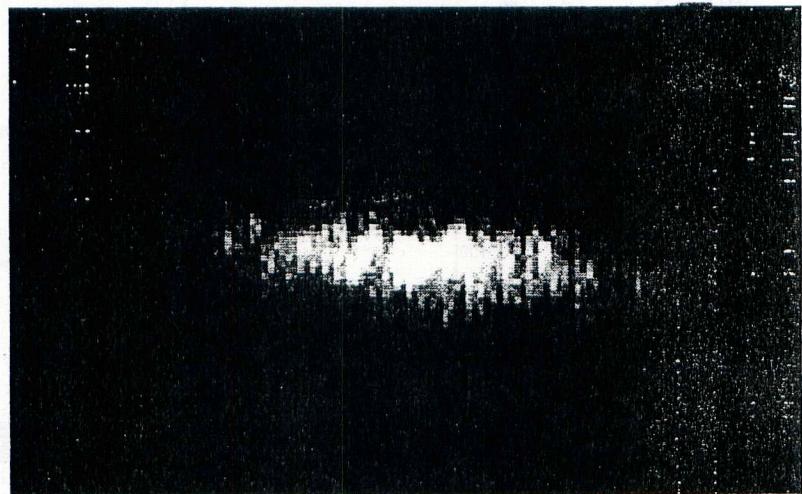


High-Speed Gated Camera Observations

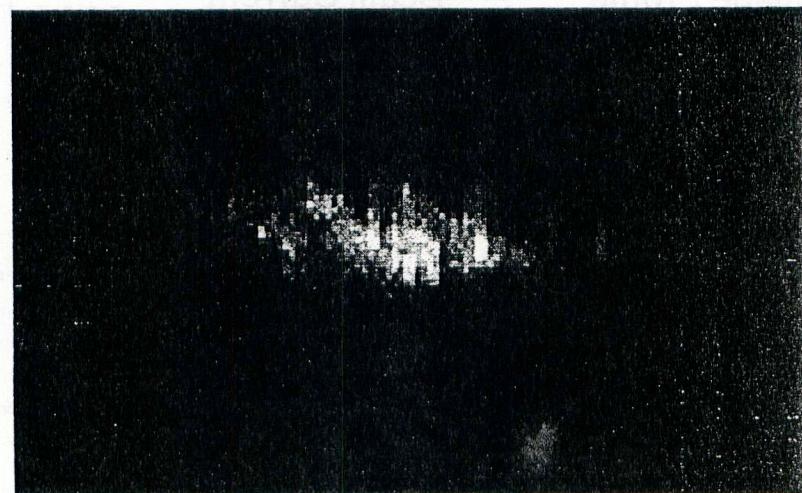
Train: 120 bunches, 0.4 mA/bunch

Bunch Spacing: 8 ns (4 buckets)

Gate Width: 10 ns (single bunch)



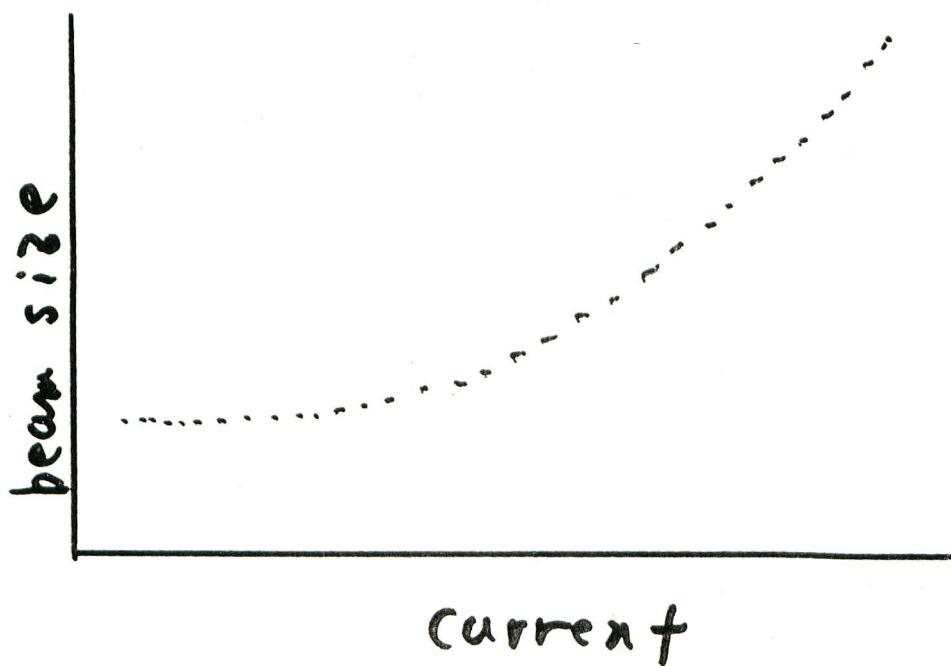
Head Bunch



Tail Bunch

Observation of beam blow up
in LER

A result of SR interferometer



Can we observe this blow up
by imaging?

Problems :

1. Wavefront error
2. Diffraction .

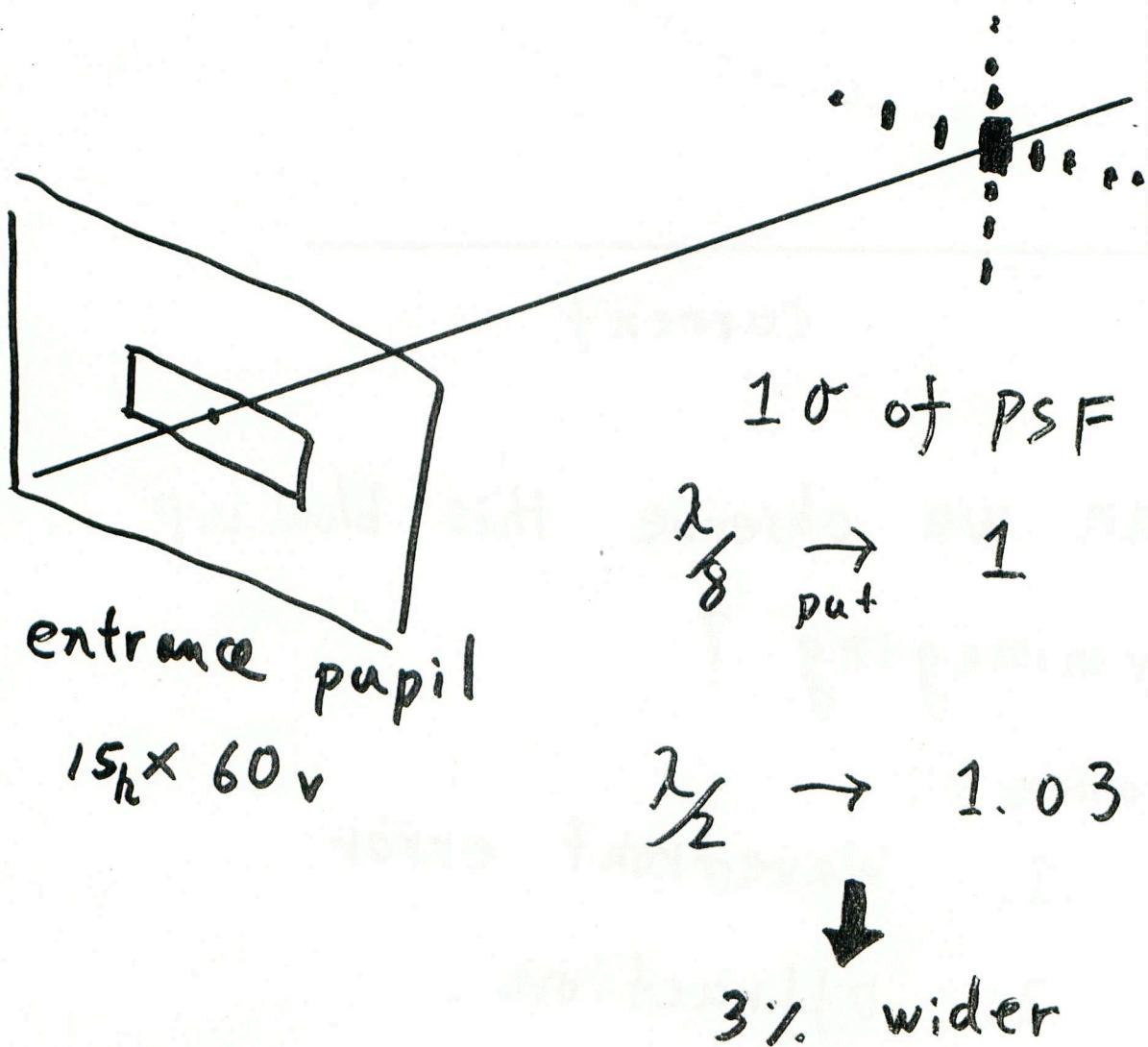
2. Diffraction

- Difference between

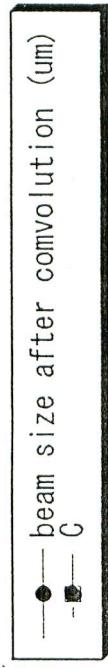
$\frac{\lambda}{2}$ diffraction limited PSF

and

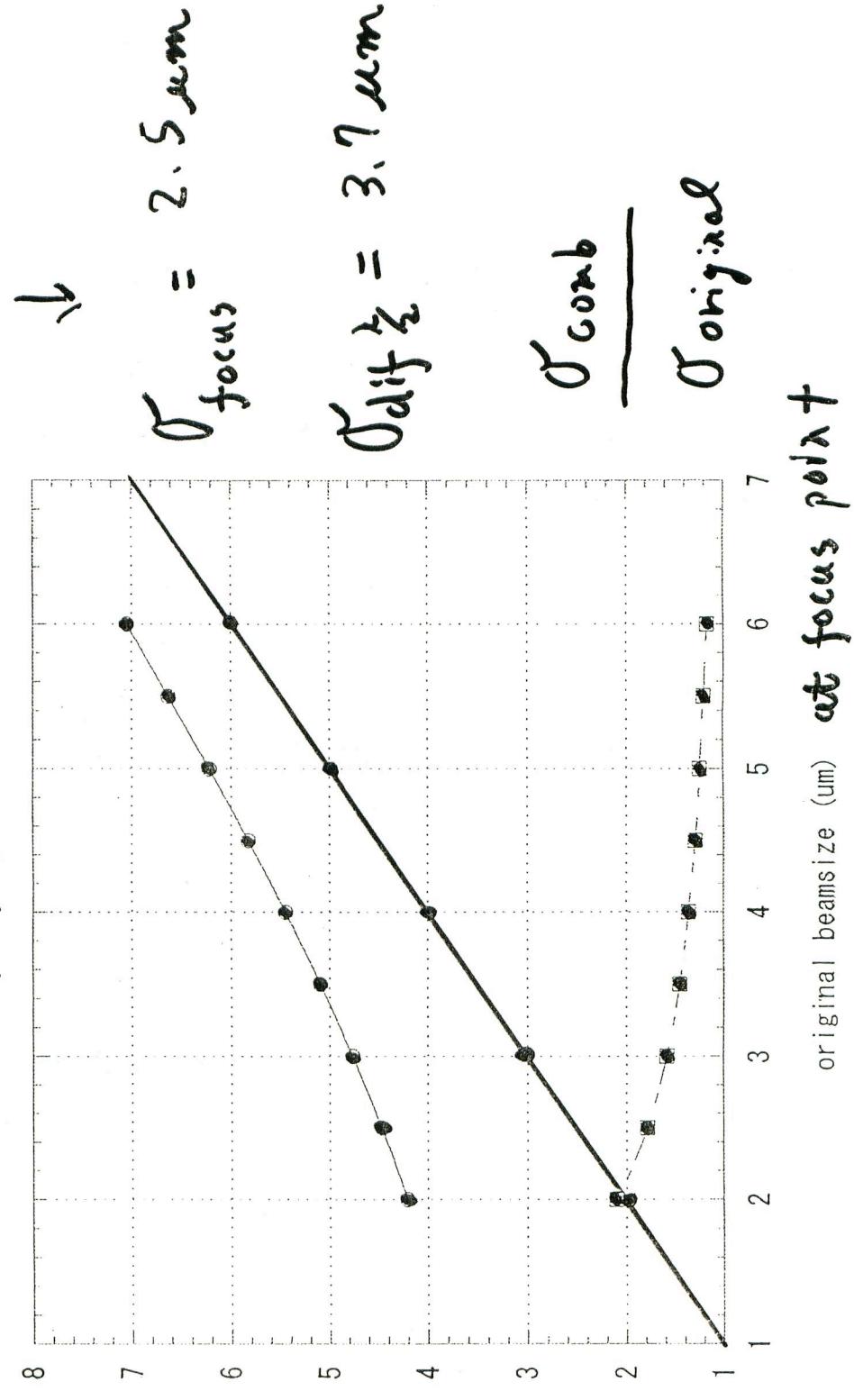
$\frac{\lambda}{8}$ diffraction limited PSF



— without diffraction



$$\sigma_y^{\text{out}} = 100 \mu\text{m}$$



beam size after convolution (um)

Results

1. Wavefront distortion

$\lesssim \frac{\lambda}{2}$ by spatial filtering.

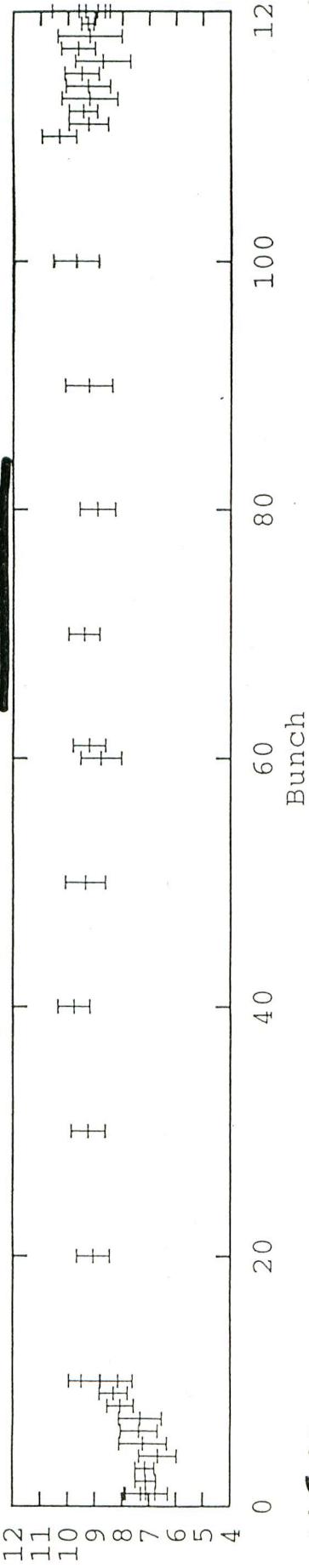
→ No deformation of PSF.

2 Diffraction

After a convolution by
PSF, we can observe
beam size blow up.

HIGH-SPEED GATED CAMERA OBSERVATION OF LEAK ALONG TRAIL

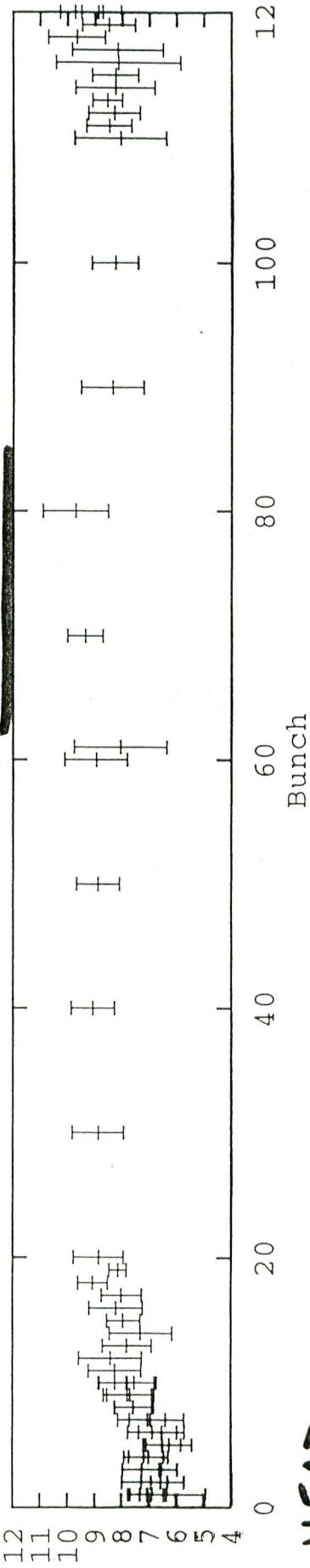
4/120/4 at 150 mA w/out magnets



HEAD

TAIL

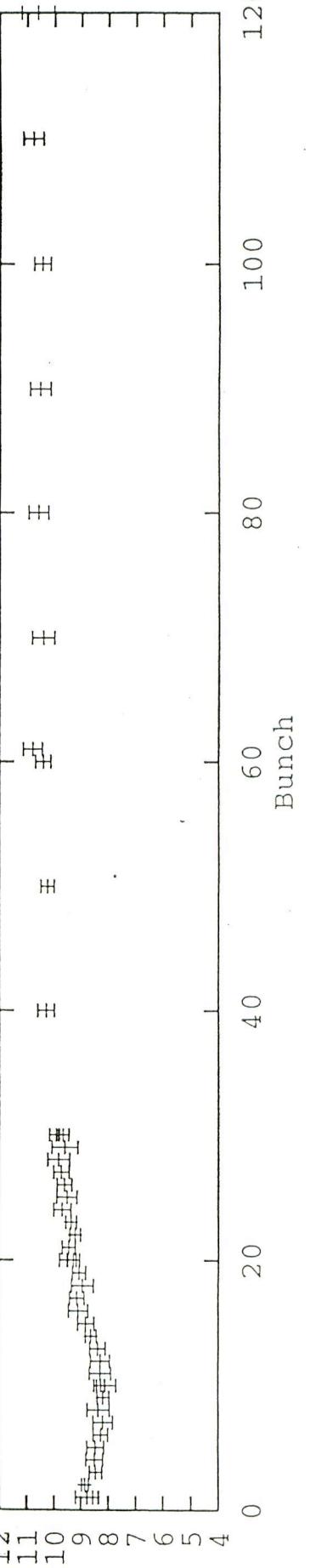
4/120/4 at 150 mA w/perm. magnets



HEAD

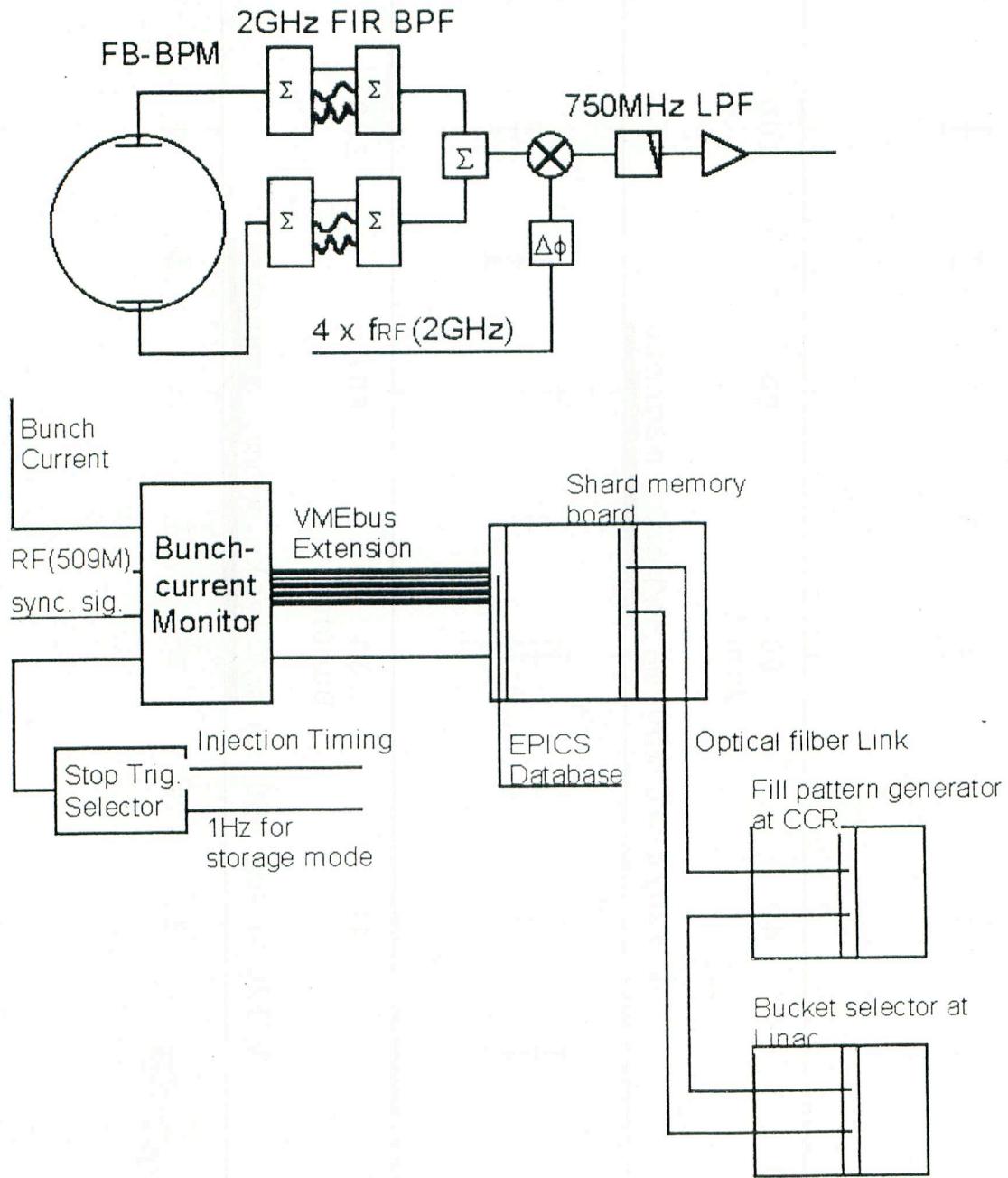
TAIL

4/120/4 at 150 mA w/c-yoke perm. magnets



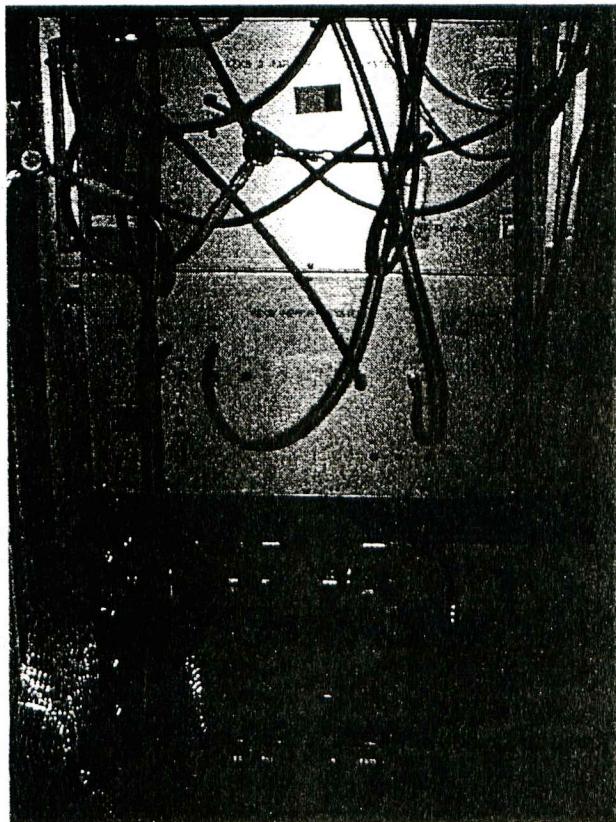
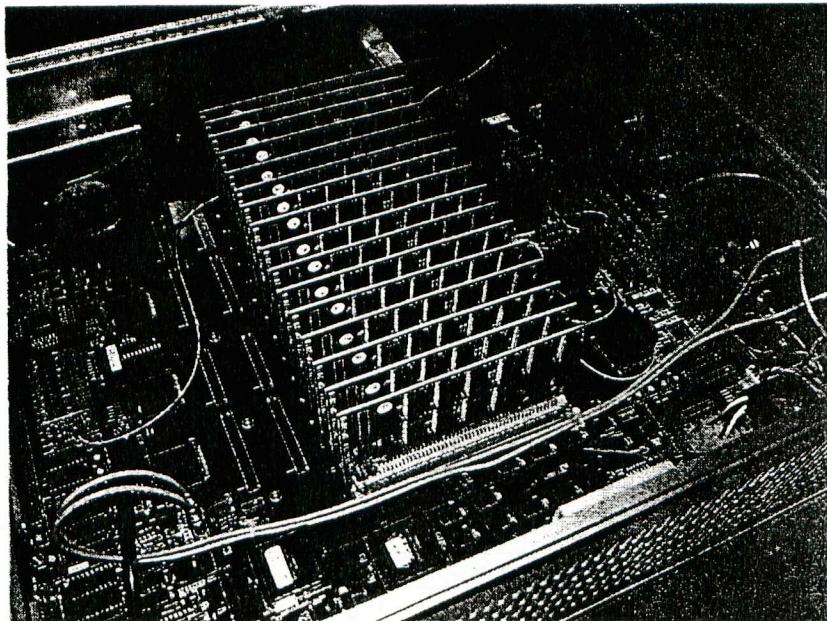
Sig-Y (arb, uncorr.) Sig-Y (arb, uncorr.) Sig-Y (arb, uncorr.)

Bunch-Current Monitor System



- ☆ 1.4ms/5120 data transfer
- ☆ Up to 100Hz trigger for both LER and HER data transfer available.

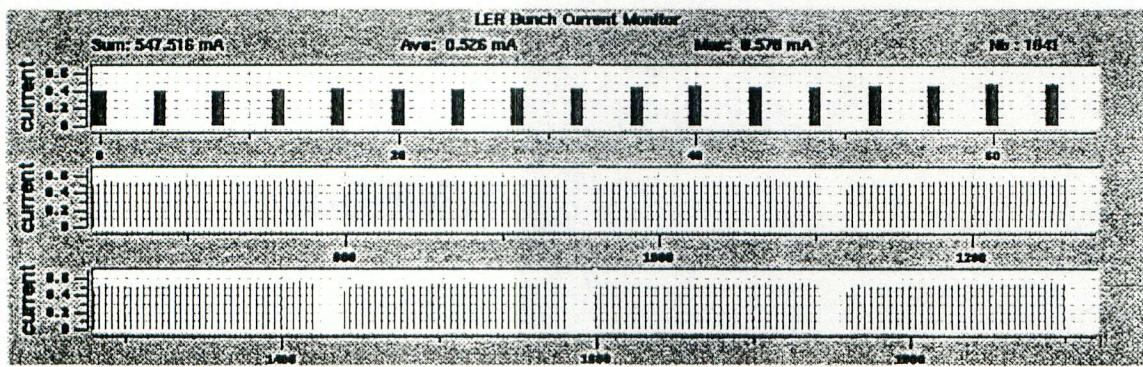
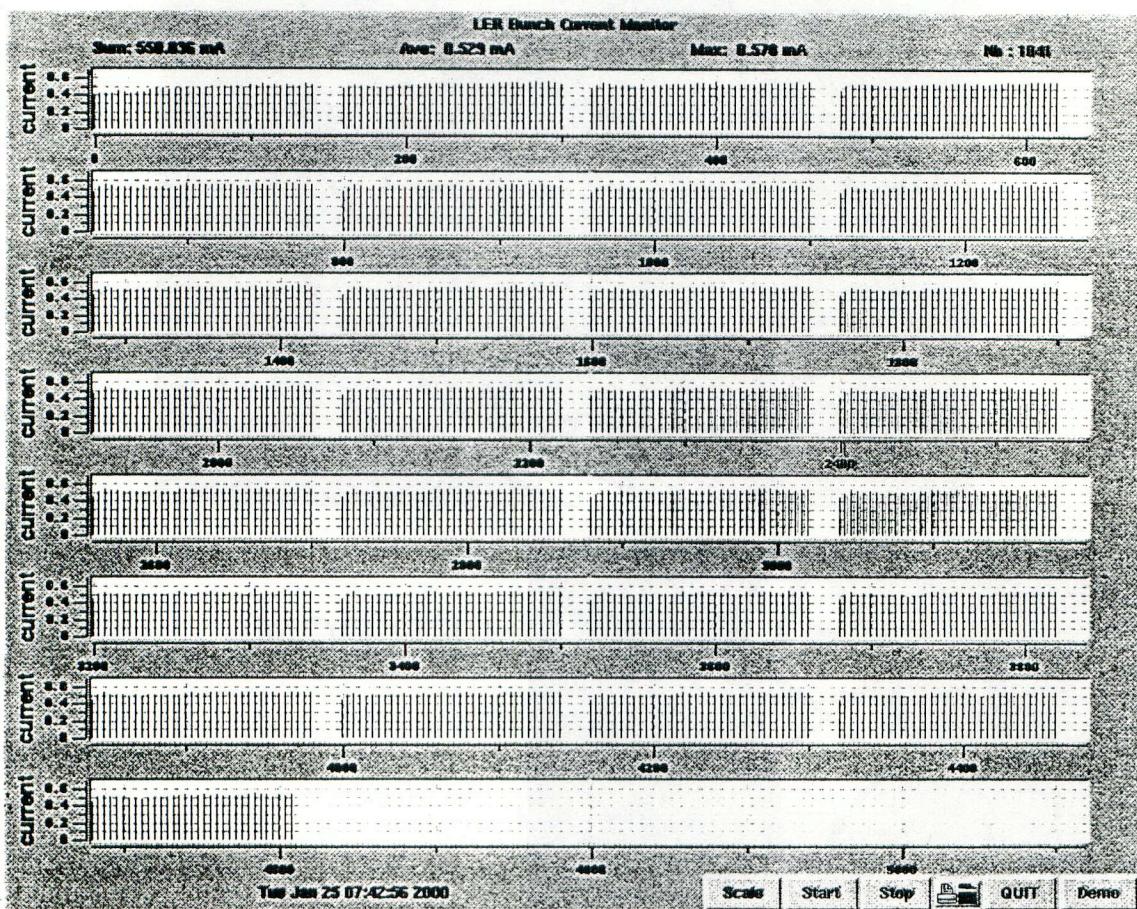
Bunch-current Monitor/ Large-scale memory board system



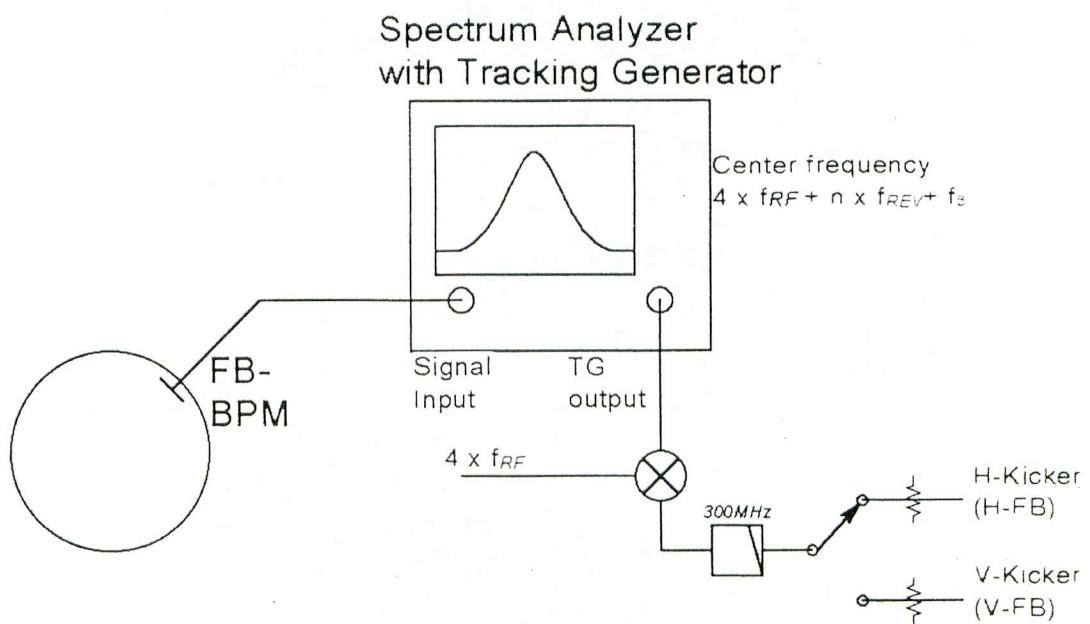
LER BCM

HER BCM

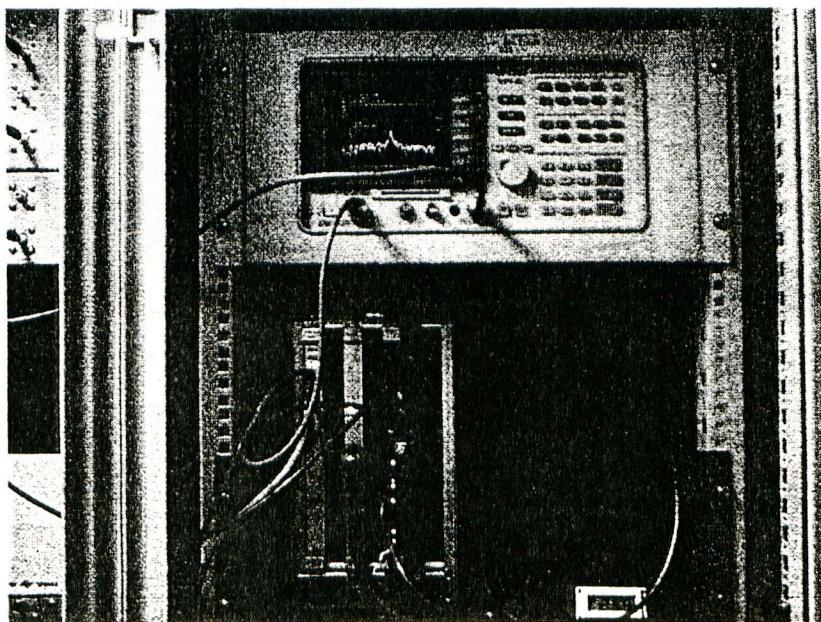
An Example of Bunch Current Monitor View
32 Trains (36 bunches/train) with 8ns spacing
(1040 bunches in total)



Tune Measurement System



- ☆ EPICS controlled (GP-IB/VME)
- ☆ Video image available at CCR



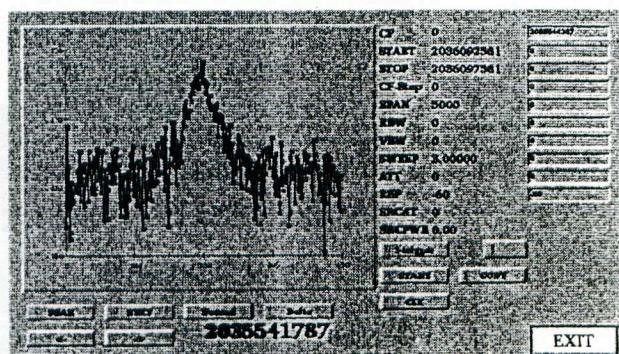
EPICS(MEDM) Operation Panel

LER Tune

X	45.5619	25	PWR	-20 dBm
Y	44.1541	25	negative value	
RF counter	508886081			
RF(SA)	508886064 OK			
Threshold(dBm)				
Measure	-105	Fine set	TV	SA
		2035544258	49.6300	
RF Measure		0.5619		
Ref level	-60	dBm	0.1541	
RF level	0	dBm	To Tune Set Panel	

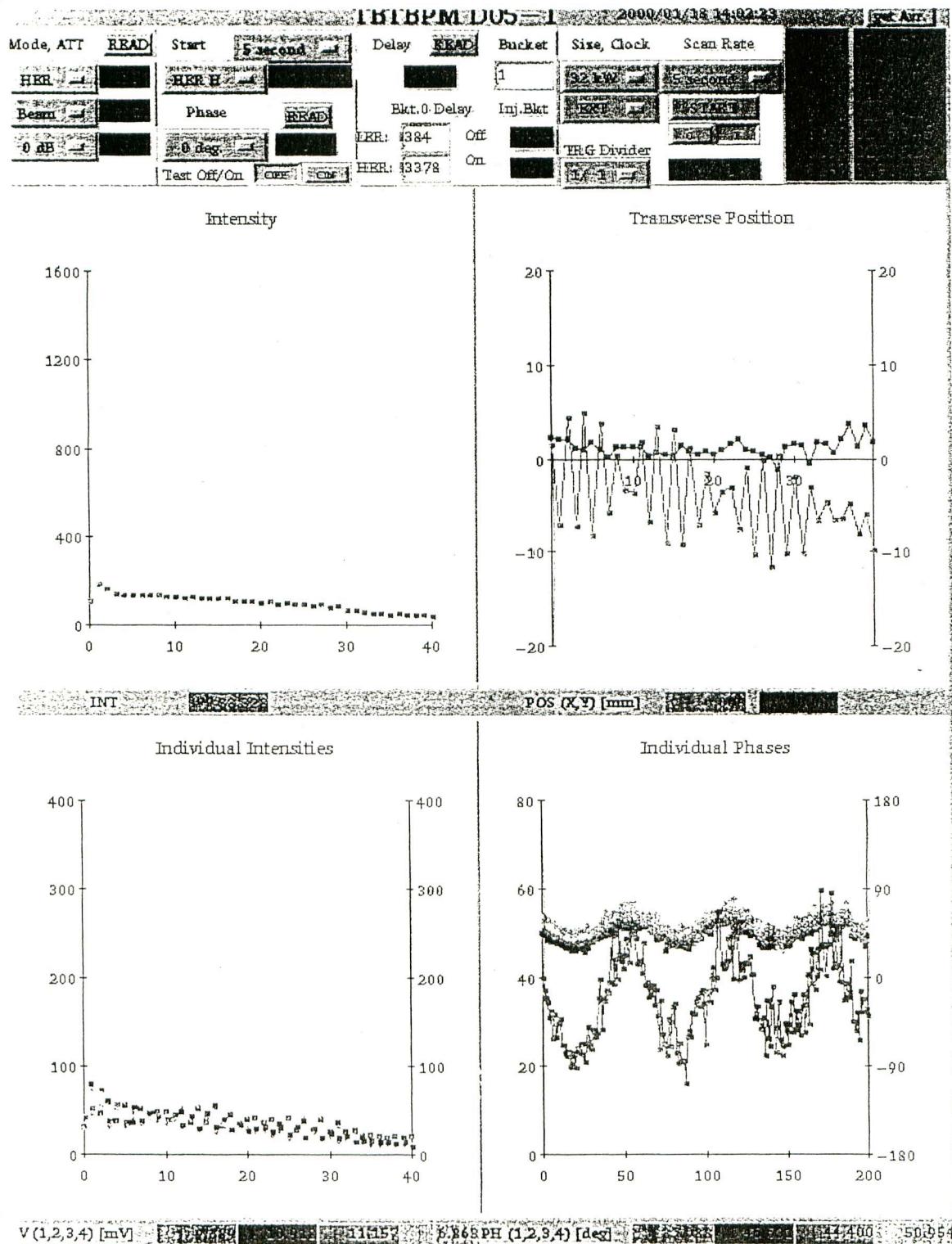
Calibrate LER tune server

ΔV_x	-0.0000	45.5619
ΔV_y	0.00500	44.1541
Differences SET		
V_x	45.53000	45.53500
V_y	44.11000	44.12100
Direct SET		



Turn-by-Turn Monitor (4D-BPM)

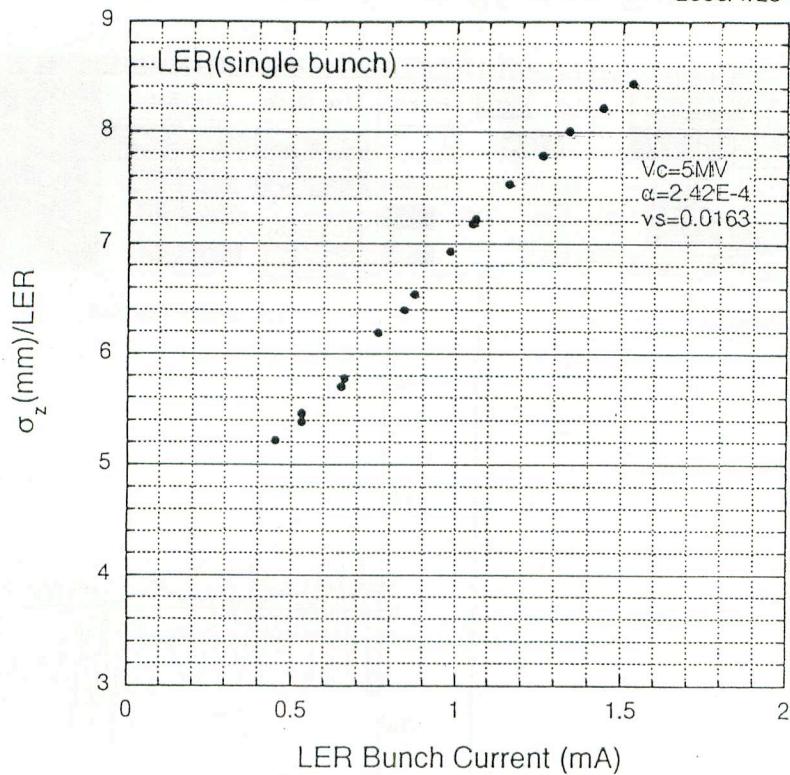
- used for Monitoring energy and phase of injected beam.



Synchrotron oscillations show beam energy injected is a little higher than accepted ring energy.

Bunch Length vs. Bunch Current

2000/1/25



2000/1/25

