1999.3.8 KEKB Review Committee
Atsushi ENOMOTO (Accelerator Laboratory)

COMMISSIONING SUMMARY OF THE INJECTOR LINAC

1. Introduction

The KEK electron injector linac was constructed during 1978-1981 for injecting a full energy beam to the 2.5-GeV Photon Factory storage ring. Then a positron generator linac was added beside the electron injector during 1982-1984 for the TRISTAN project. This electron/positron linac has been reconstructed to an 8-GeV linac since 1994 for KEKB.

The main goal s of the linac reconstruction were upgrading the energy from 2.5 GeV to 8 GeV and increasing positrons from 0.03 nC/pulse to 0.64 nC/pulse (single bunch). For the energy upgrade, the energy gain of the accelerating modules* in the existing linac were increased from 8 MeV/m to 20 MeV/m, and the number of accelerator modules from 40 to 56. For the positron increase, the positron radiator was moved to a higher energy point of 3.7 GeV from 0.2 GeV. (**Fig.1**)

*An accelerator module comprises four 2-m accelerator sections fed by a 40-MW klystron with a SLED.

The reconstruction was almost finished by the end of March 1998; the old linac and the extension part were combined; and, full commissioning of the linac was done in May, June, October, and November, while continuing routine injection for the PF. Since December 1998, the linac has been running for the KEKB commissioning.

2. Progress of the linac commissioning

2-1 Linac energy

The linac energy is tuned by measuring beam energy of the 1-nC electron beam at the linac arc and at the end of the linac. (**Fig.2**) The linac energy of 8 GeV was achieved on April 24. Because the energy margin was not enough, operation energy of the linac arc was increased from 1.5 to 1.7 GeV in autumn. Then the linac maximum energy became to be about 8.6 GeV. (**Fig.3**) An energy margin of 0.6 GeV is enough for having two modules for energy adjusting as well as one or two standby modules for trouble. The designed maximum energy is 8.96 GeV for more stable linac operation. The reasons of slight lack of energy are as follows:

1) One accelerator module is still utilized for the independent pre-injector to accelerate 2.5-GeV electron beam for the PF/AR SOR facilities (-80 MeV).
2) One accelerator module is used for the energy compression system (-160 MeV).
3) Full power could not be fed in three accelerator modules (-120 MeV).

These will gradually be improved from this summer shutdown.

2-2 Single bunch beam

Producing single-bunch beams for the linac fundamental frequency (2856 MHz) was also a new requirement for the KEKB injector. The gun beams with a pulse width of about 2.8 ns are bunched with the 25th subharmonic (114.24-MHz) buncher, the 5th subharmonic (571.2-MHz) buncher, and the fundamental pre-buncher and buncher. The bunch length of the well-tuned beams were about 10 ps (FWHM). (**Fig.4**) However, the bunch tuning has been performed frequently, because the rf system of the buncher system has not been stable. A streak-camera system was then very useful to monitor bunch shape.

2-3 Transmission of the 8-GeV, 1-nC bunches

During FY1997, the beam-transport system of the sectors A, B, the linac arc, and the sector C had been tuned. At the end of March 1998, the beam-transport between the sector C and the sector 1 was combined, and the beam from the extended linac was transported along the entire linac. Transmission of the 1-nC bunch is nearly 100% from the buncher exit to the end of the linac. (**Fig.5**)

2-4 Tuning of the positron beam

In June 1998, more than 0.64 nC (4 x 10^9 e+) /bunch were accelerated to the linac end. At that time, the primary electron beam was 6 to 7 nC/bunch due to beam loss after the arc. (**Fig.6**) During the 1998 summer shutdown, the linac alignment upstream of the positron target was corrected, and the energy gain of two accelerator sections just after the buncher was increased from 40 to 60 MeV. This decreased the beam breakup of the high-current beam: The orbit bump to suppress BBU became not necessary, and finally 10 nC (6.25 x 10^10 e-) hit the target in November. The positron intensity at the linac end reached about 0.8 nC/bunch at maximum. (**Fig.7**)
In order to decrease energy spread of the positron beam, the bunch compressor (BCS) for the primary beam and the energy compressor (ECS) for the output positron were used. It turned that about 90% of the positrons were inside the energy width of 0.5%. However, the beam transmission in the ECS is not perfect (maximum 80%) and still necessary to be tuned. (**Fig.8**)

2-5 Trouble

In November 1998, vacuum leak was found in the positron vacuum chamber after the repetition rate was increased 25 to 50 pps. Though the exact source of the leak was not determined, it was guessed it was caused by insufficient squeeze of the chamber-flange screw and eddy-current effect of the pulsed solenoid. The old flange was replaced by a new one with water-cooling pipe. (**Fig.9**)

3. Linac operation for the KEKB commissioning

3-1 Injection beam status

The linac high-power rf has been operated at an constant pulse repetition rate of 50 pps since last autumn. In the linac tuning, the linac beam was usually repeated at 5 pps. After the KEKB injection started, the beam repetition rate was changed according the ring request. The typical beam parameters are listed below together with the achieved maximum values and the designed values:

	design goal	max.	operation
8-GeV electron			
energy	8.9 GeV	8.6 GeV	8 GeV
charge	1.2 nC	>2. nC	1 nC
energy width	<0.125%	~0.125%	
emittance	<0.1 mm	0.06 mm	
transmission			
buncher exit	1.2 nC		1 nC
linac end	1.2 nC		1 nC
3.5-GeV positron			
energy	4.0 GeV	4.0 GeV	3.5 GeV
charge	0.64 nC	0.6 nC	0.4
energy width	0.125%	0.15%	
emittance	<0.25 mm	0.4 mm	
transmission			
buncher exit	10 nC	12 nC	12 nC
e+ target	10 nC	10 nC	6-8 nC
linac end	0.64 nC	0.8 nC	0.4-0.6 nC
ECS exit	0.64 nC	0.6 nC	0.3-0.4 nC

3-2 Stability and Reproducibility of the linac beam

After the KEKB commissioning started, it turned that though well-tuned linac beam was tolerable for the KEKB injection but it could not be kept stable long time. (**Fig.10**) Therefore feedback software regarding below was immediately supplemented on the linac-control host-computer as a temporary cure until the trouble sources are removed. (**Fig.11**)

1) Energy at the linac arc.
2) Energy at the end of the linac (e- and e+).
3) Orbit at the end of the linac.
4) Gun high-voltage.
5) 114-MHz SHB power.
6) 571-MHz SHB power.

Consequently short-term reproducibility of the linac beam became tolerable and the feedback system maintained the injection beam. However long-term stability is still intolerable. Especially, the positron beam, if it is well tuned, cannot be kept long time and drift . This is the most important subject to be improved (**reported to MAC independently by H. Kobayashi**).

3-4 Beam switching

The linac must inject four kinds of beam:

1) KEKB 8-GeV electron.
2) KEKB 3.5-GeV positron.
3) PF 2.5-GeV electron.
4) AR 2.5-GeV electron.

The changed parameters and devices are

1) Gun parameters,
2) Positron devices (target, chicane),
3) BT parameters (using hysteresis loop for Q and B),
4) Rf phase,
5) Standby module,
4) BPM range,
5) Beam repetition.

Switching procedure was tested and proved to be sufficient. At present these are changed serially in order to monitor each process, and to be changed to a parallel sequence less than 1 minute. (**Fig.12**)

4. Summary

(1) Well-tuned linac beam is sufficient (e-) or tolerable (e+) for the KEKB injection.

(2) However long-term stability is intolerable and the improvement is urgent.

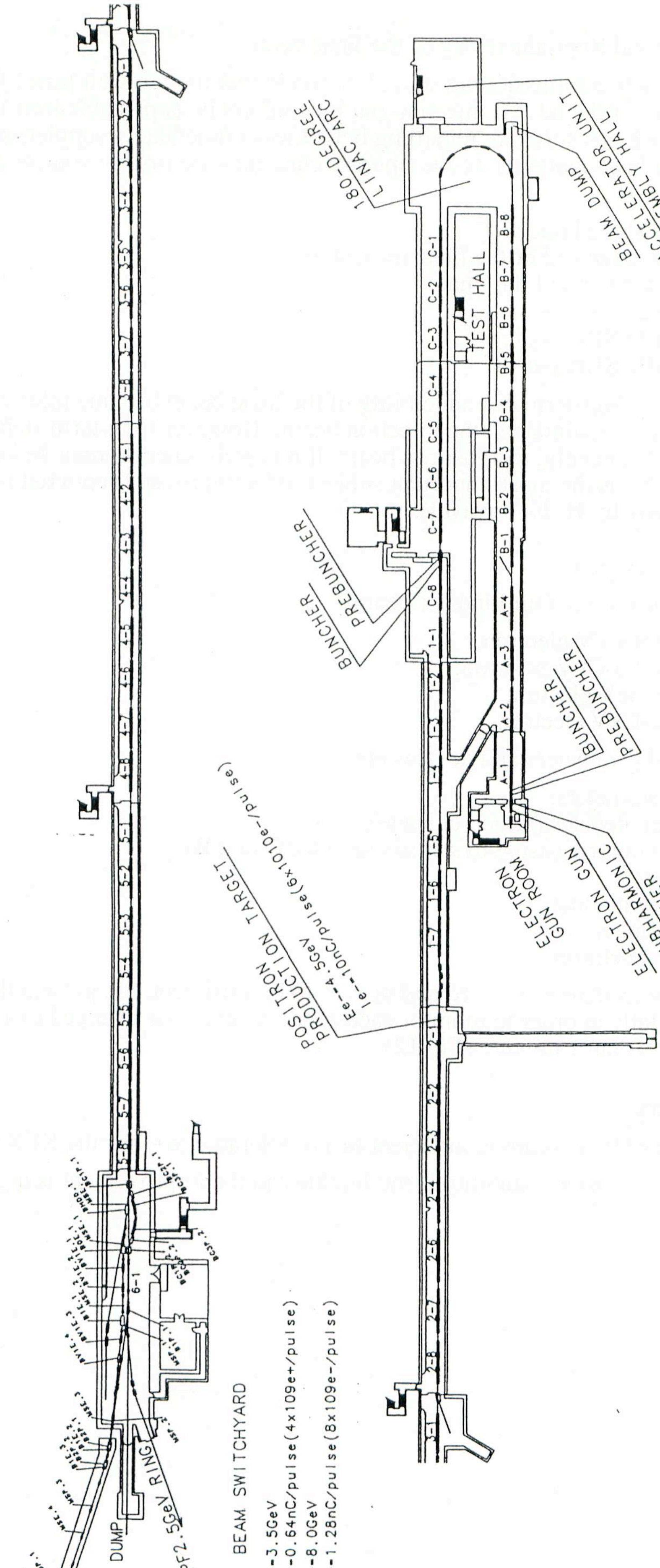
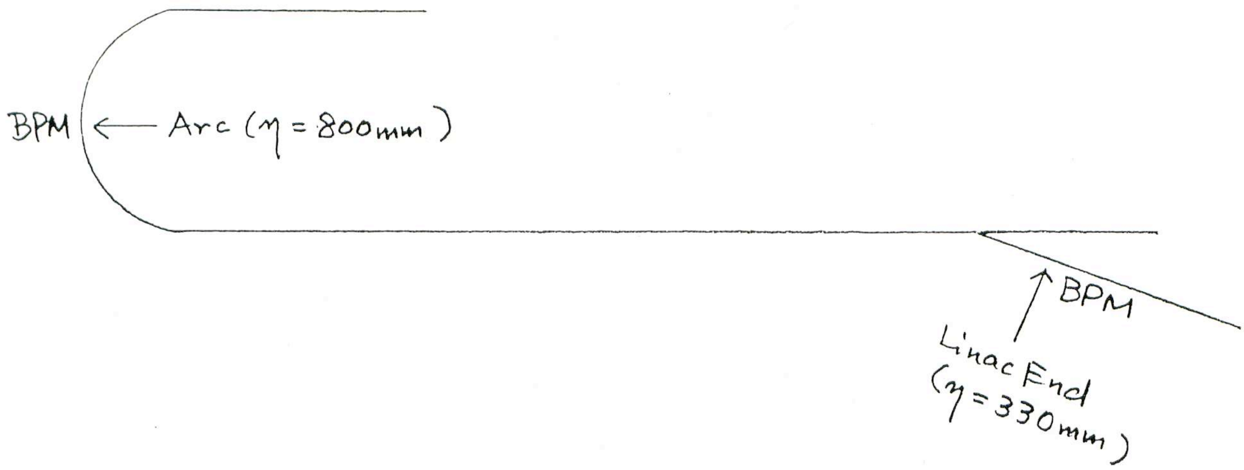
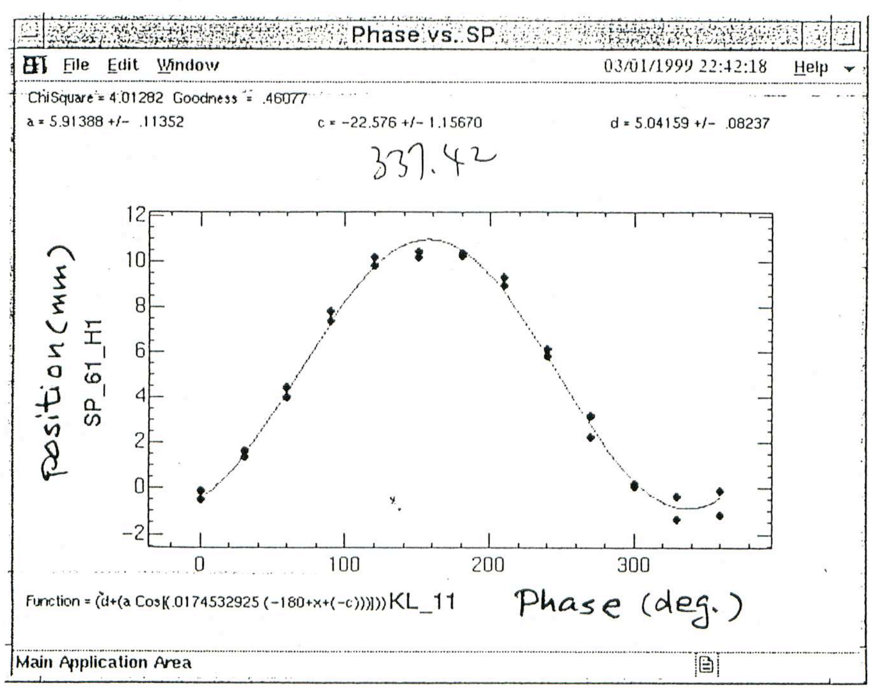

180-DEGREE LINAC ARC
BEAM DUMP UNIT
ACCELERATOR HALL
ASSEMBLY HALL
TEST HALL
PREBUNCHER
BUNCHER
BUNCHER
PREBUNCHER
ELECTRON GUN ROOM
ELECTRONIC GUN
SUBHARMONIC BUNCHER
POSITRON PRODUCTION TARGET
Ee-=4.5GeV
Ie-=10nC/pulse(6x1010e-/pulse)
BEAM SWITCHYARD
Ee+=3.5GeV
Ie+=0.64nC/pulse(4x109e+/pulse)
Ee-=8.0GeV
Ie-=1.28nC/pulse(8x109e-/pulse)
BEAM DUMP
PF2.5GeV RING

Fig. 1



BPM
Arc (η = 800mm)
BPM
Linac End
(η = 330mm)



Phase vs. SP
File Edit Window
03/01/1999 22:42:18
Help
ChiSquare = 4.01282 Goodness = .46077
a = 5.91388 +/- .11352
c = -22.576 +/- 1.15670
d = 5.04159 +/- .08237
337.42
Position (mm)
SP_61_H1
Function = (d+(a Cos((.0174532925 (-180+x+(-c)))))) KL_11
Phase (deg.)
Main Application Area

Fig. 2

not calibrated exactly ↙

99.3.1 Phasing by FURUKAWA program														
		phase (degree)			330mm=8000Me			phase (degree)					MeV	
se	uni	Sbnew	KLYnew	sum-φ	mm	gain		Sbold φ	KLYold φ	sum-φ	δ φ	gain	δ gain	
A	1								112.6	112.6		0.0	0.0	
	2	208.7	306.1	514.8				208.7	295.5	504.2	10.6	0.0	0.0	
	3	208.7	153.5	362.2				208.7	145.0	353.7	8.5	0.0	0.0	
	4	208.7	294.3	503.0				208.7	296.0	504.7	−1.7	0.0	0.0	
B	1	339.4	208.1	547.5				339.4	209.0	548.4	−0.9	0.0	0.0	
	2	339.4	36.4	375.8				339.4	35.5	374.9	0.9	0.0	0.0	
	3	339.4	190.7	530.1				339.4	182.5	521.9	8.2	0.0	0.0	
	4	339.4	279.2	618.6				339.4	278.5	617.9	0.7	0.0	0.0	
	5	339.4						339.4	263.5	602.9		0.0	0.0	
	6	339.4						339.4	215.0	554.4		0.0	0.0	
	7	339.4	36.5	375.9				339.4	41.0	380.4	−4.5	0.0	0.0	
	8	339.4	156.5	495.9				339.4	156.0	495.4	0.5	0.0	0.0	← arc.(1.7GeV)
C	1	344.7	178.7	523.4	7.43	180.1		0.9	180.5	181.4	342.0	171.1	9.0	
	2	344.7	158.1	502.8	6.85	166.0		0.9	149.0	149.9	352.9	164.7	1.3	
	3	344.7	306.9	651.6	5.75	139.4		0.9	280.0	280.9	370.7	137.1	2.3	
	4	344.7	112.4	457.1	6.47	156.7		0.9	108.0	108.9	348.2	153.3	3.4	
	5	344.7	235.9	580.6	6.37	154.4		0.9	231.5	232.4	348.2	151.1	3.4	
	6	344.7	263.4	608.1	6.49	157.3		0.9	256.0	256.9	351.2	155.4	1.9	
	7	344.7		344.7		0.0		0.9	73.5	74.4	270.3	0.0	0.0	← X temporary pre-injector for PF
	8	344.7	268.0	612.7	5.18	125.6		0.9	270.5	271.4	341.3	118.9	6.7	
1	1	325.2	337.4	662.6	5.91	143.4		334.8	323.5	658.3	4.3	143.0	0.4	
	2	325.2	232.7	557.9	6.17	149.5		334.8	205.0	539.8	18.1	142.1	7.4	
	3	325.2	19.8	345.0	6.60	159.9		334.8	0.5	335.3	9.7	157.6	2.3	
	4	325.2	323.8	649.0	6.01	145.7		334.8	309.0	643.8	5.2	145.1	0.6	
	5	325.2	231.2	556.4	5.60	135.7		334.8	216.0	550.8	5.6	135.1	0.7	
	6	325.2	214.2	539.4	5.41	131.2		334.8	196.5	531.3	8.1	129.9	1.3	
	7	325.2	277.2	602.4	6.16	149.3		334.8	274.5	609.3	−6.9	148.2	1.1	
2	1		51.2	51.2	2.77	67.1		65.3	153.3	218.6				← X e+ radiator
	2	63.3	143.2	206.5	6.43	155.8		65.3	126.0	191.3	15.2	150.4	5.4	
	3	63.3	160.5	223.8	6.57	159.2		65.3	149.5	214.8	9.0	157.2	2.0	
	4	63.3	353.6	416.9	6.47	156.8		65.3	5.0	70.3	346.6	152.4	4.4	
	6	63.3	25.1	88.4	6.24	151.2		65.3	16.0	81.3	7.1	150.0	1.2	
	7	63.3	46.3	109.6	5.89	142.8		65.3	40.5	105.8	3.8	142.5	0.3	
	8	63.3	0.8	64.1	5.95	144.2		65.3	352.5	417.8	−353.7	143.3	0.9	
3	1	122.3	65.5	187.8	6.20	150.3		126.1	51.0	177.1	10.7	147.7	2.6	
	2	122.3	199.6	321.9	6.42	155.6		126.1	183.5	309.6	12.3	152.1	3.5	
	3	122.3	293.7	416.0	5.96	144.5		126.1	300.0	426.1	−10.1	142.2	2.2	
	4	122.3	150.0	272.3	5.37	130.1		126.1	134.0	260.1	12.2	127.2	2.9	
	5	122.3	318.4	440.7	6.08	147.4		126.1	306.0	432.1	8.6	145.8	1.6	
	6	122.3	212.9	335.2	5.78	140.1		126.1	210.5	336.6	−1.4	140.0	0.0	
	7	122.3	273.9	396.2	5.79	140.4		126.1	253.5	379.6	16.6	134.6	5.8	
	8	122.3	340.0	462.3	5.71	138.4		126.1	320.5	446.6	15.7	133.3	5.2	
4	1	139.9				0.0		133.2	194.5	327.7	−327.7	0.0	0.0	← X
	2	139.9	199.0	338.9	5.87	142.3		133.2	194.5	327.7	11.2	139.5	2.7	
	3	139.9	8.3	148.2	6.00	145.5		133.2	12.5	145.7	2.5	145.3	0.1	
	4	139.9	216.4	356.3	5.07	122.9		133.2	205.0	338.2	18.1	116.8	6.1	◁
	5	139.9	280.3	420.2	5.97	144.7		133.2	260.0	393.2	27.0	129.0	15.7	
	6	139.9	145.1	285.0	5.25	127.4		133.2	141.0	274.2	10.8	125.1	2.3	
	7	139.9	292.8	432.7	5.91	143.3		133.2	288.0	421.2	11.5	140.4	2.9	
	8	139.9	343.0	482.9	6.09	147.6		133.2	338.0	471.2	11.7	144.6	3.1	
5	1	351.4	228.7	580.1	5.32	129.1		2.0	276.5	278.5	301.6	67.4	61.7	
	2	351.4	327.3	678.7	6.16	149.2		2.0	271.5	273.5	405.2	105.5	43.8	
	3	351.4	78.3	429.7	5.59	135.5		2.0	66.5	68.5	361.2	135.4	0.0	
	4	351.4	207.4	558.8	6.17	149.6		2.0	204.0	206.0	352.8	148.3	1.2	
	5	351.4	7.3	358.7	4.95	120.1		2.0	10.5	12.5	346.2	116.5	3.6	
	6	351.4						2.0	256.0	258.0	−258.0	0.0	0.0	← X
	7	351.4	190.0	541.4	5.90	143.0		2.0	194.5	196.5	344.9	137.9	5.1	
						6018.1						5722.8	228.2	

↑ sum after the arc.

Fig. 3

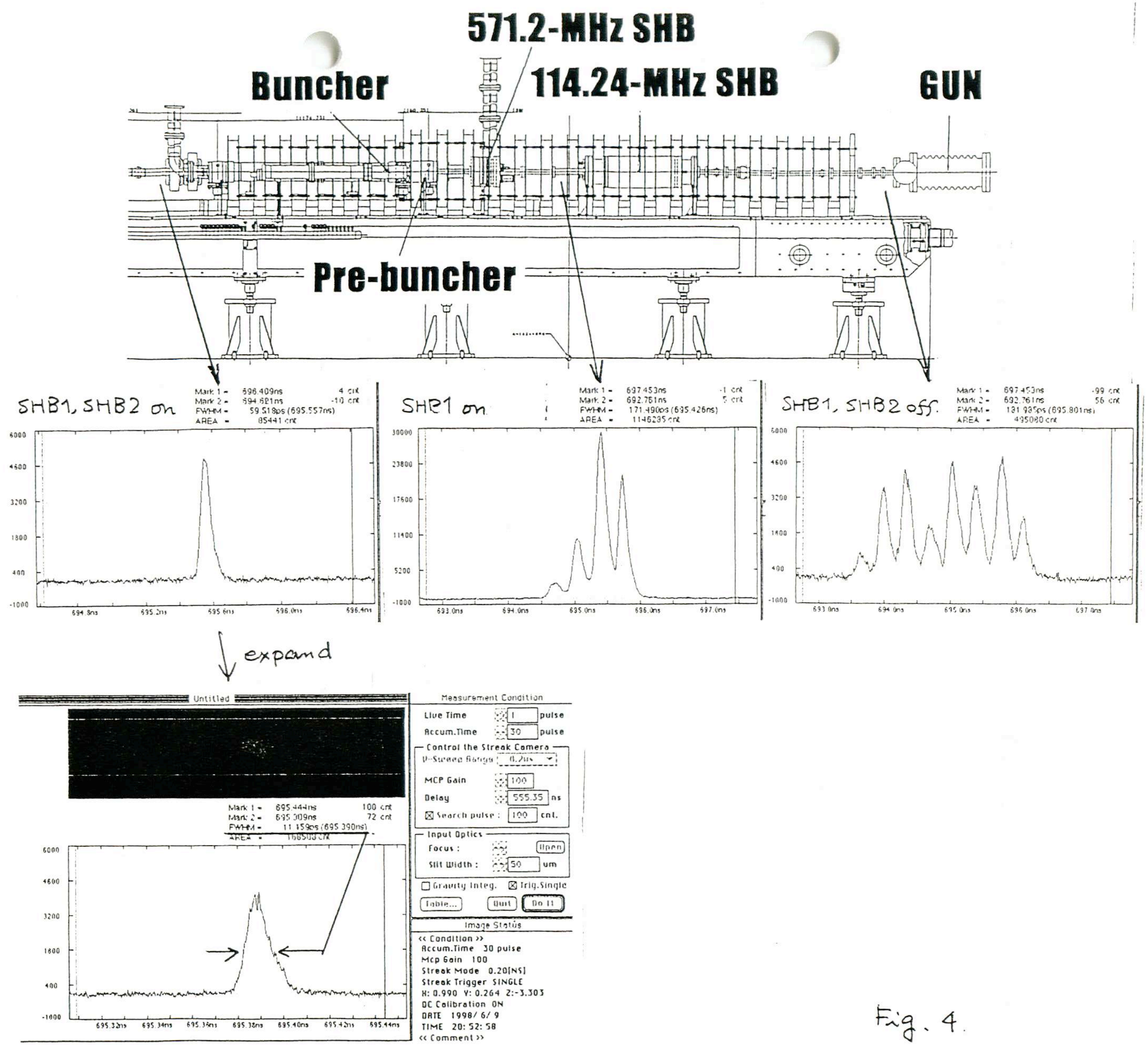

571.2-MHz SHB
114.24-MHz SHB
Buncher
GUN
Pre-buncher
SHB1, SHB2 on
SHB1 on
SHB1, SHB2 off.
expand
Untitled
Measurement Condition
Live Time
Accum.Time
Control the Streak Camera
MCP Gain
Delay
Search pulse
Input Optics
Focus :
Slit Width :
Gravity Integ.
Trig.Single
Image Status
<< Condition >>
Accum.Time 30 pulse
Mcp Gain 100
Streak Mode 0.20[NS]
Streak Trigger SINGLE
X: 0.990 Y: 0.264 Z:-3.303
DC Calibration ON
DATE 1998/ 6/ 9
TIME 20: 52: 58
<< Comment >>

Fig. 4.

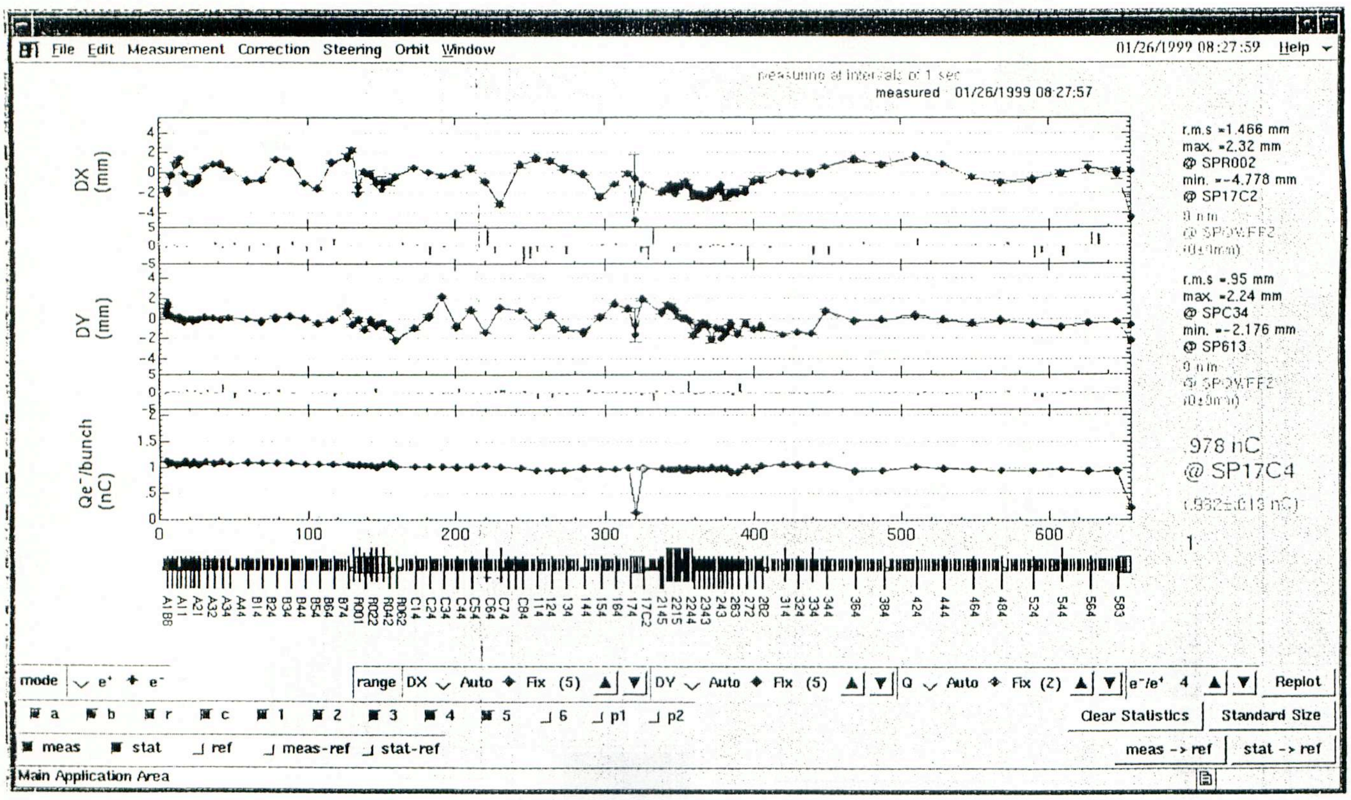
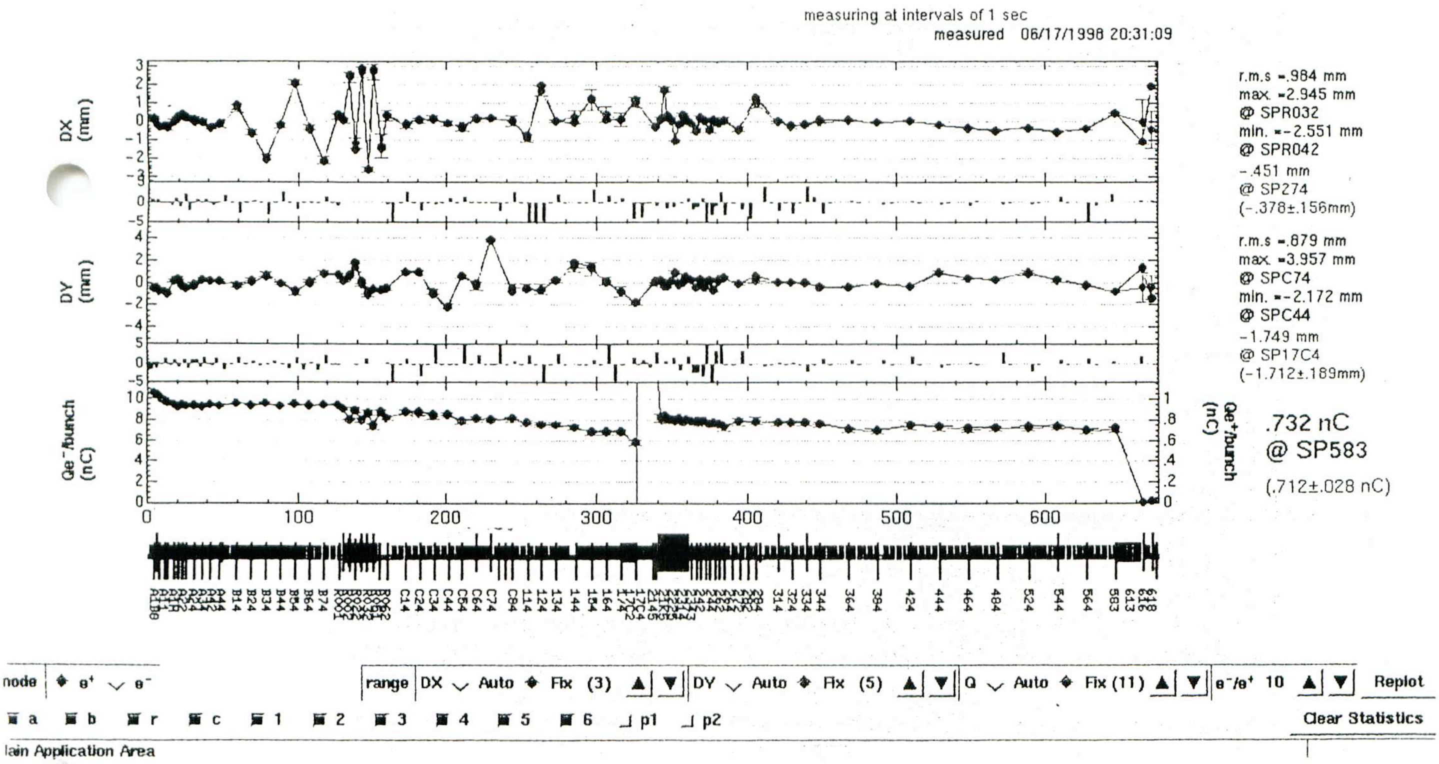

File Edit Measurement Correction Steering Orbit Window
01/26/1999 08:27:59 Help
measured 01/26/1999 08:27:57
DX (mm)
DY (mm)
Qe⁻/bunch (nC)
r.m.s =1.466 mm
max. =2.32 mm
@ SPR002
min. =-4.778 mm
@ SP17C2
r.m.s =.95 mm
max. =2.24 mm
@ SPC34
min. =-2.176 mm
@ SP613
.978 nC
@ SP17C4
mode
range
Replot
Clear Statistics
Standard Size
meas -> ref
stat -> ref
meas
stat
ref
meas-ref
stat-ref
Main Application Area

Fig. 5



measuring at intervals of 1 sec
measured 06/17/1998 20:31:09
DX (mm)
DY (mm)
Qe⁻/bunch (nC)
Qe⁺/bunch (nC)
r.m.s =.984 mm
max. =2.945 mm
@ SPR032
min. =-2.551 mm
@ SPR042
-.451 mm
@ SP274
(-.378±.156mm)
r.m.s =.879 mm
max. =3.957 mm
@ SPC74
min. =-2.172 mm
@ SPC44
-1.749 mm
@ SP17C4
(-1.712±.189mm)
.732 nC
@ SP583
(.712±.028 nC)
node
range DX Auto Fix (3)
DY Auto Fix (5)
Q Auto Fix (11)
e⁻/e⁺ 10
Replot
a b r c 1 2 3 4 5 6 p1 p2
Clear Statistics
lain Application Area

Fig. 6

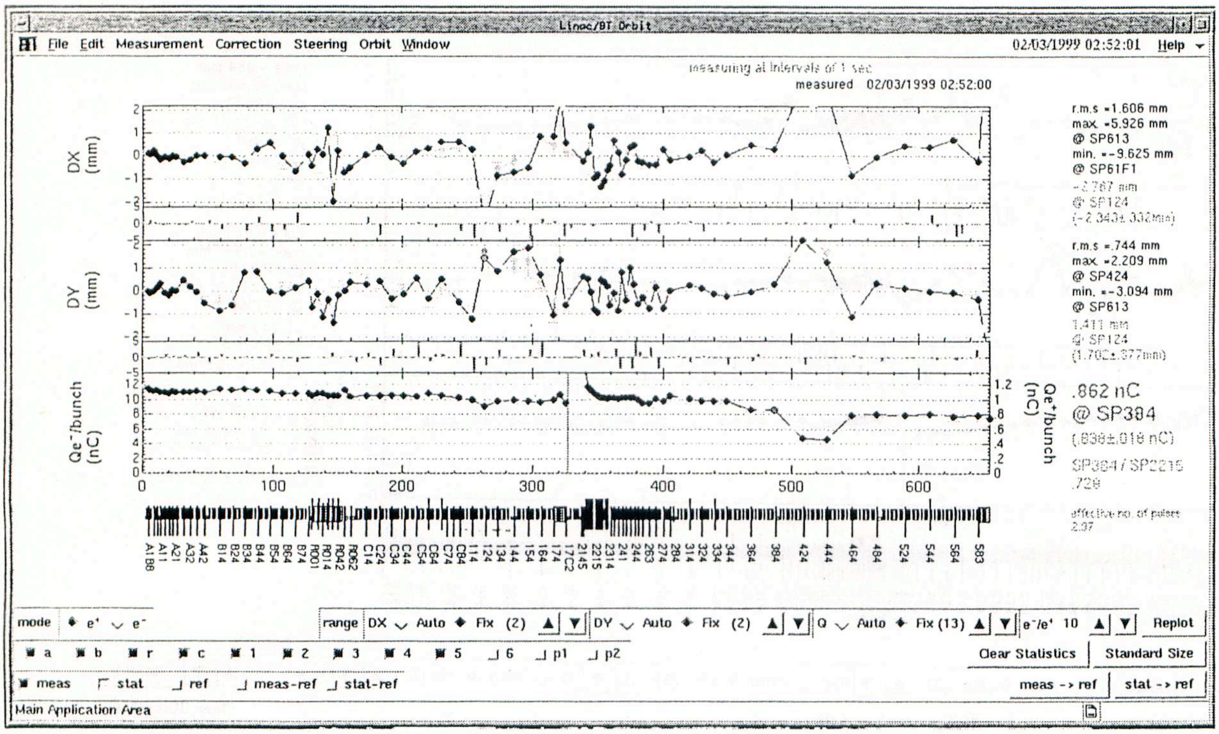
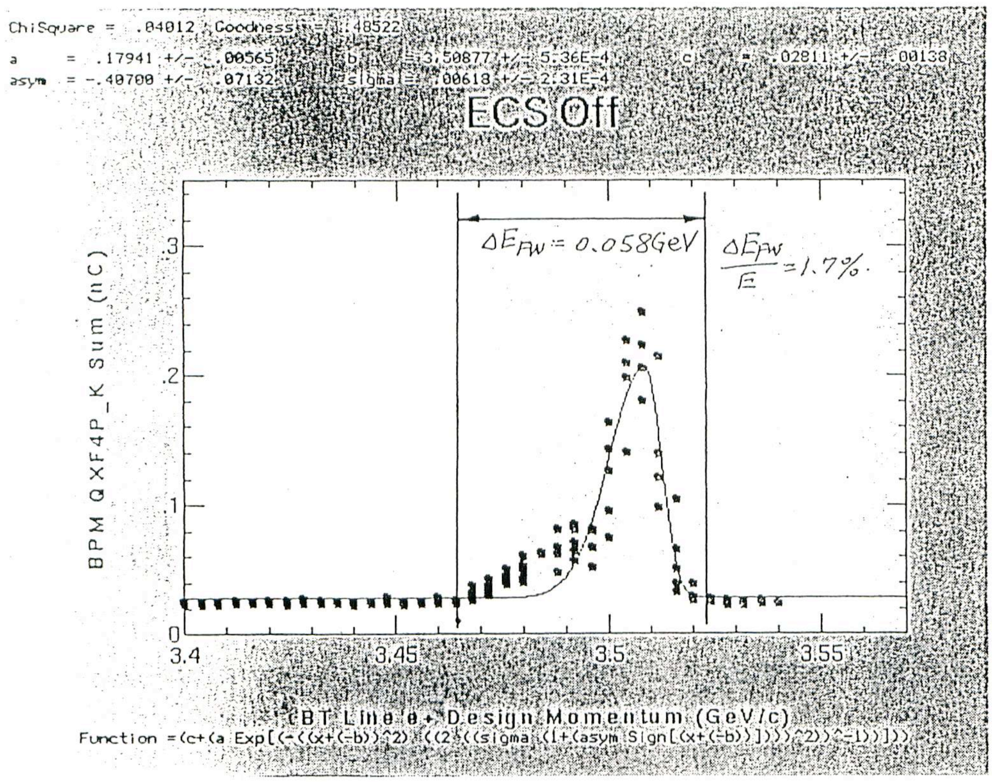

Linac/BT Orbit
File Edit Measurement Correction Steering Orbit Window
02/03/1999 02:52:01 Help
measuring at intervals of 1 sec
measured 02/03/1999 02:52:00
DX (mm)
DY (mm)
Qe⁺/bunch (nC)
r.m.s =1.606 mm
max. =5.926 mm
@ SP613
min. =-9.625 mm
@ SP61F1
r.m.s =.744 mm
max. =2.209 mm
@ SP424
min. =-3.094 mm
@ SP613
.862 nC
@ SP384
mode
range
Replot
Clear Statistics
Standard Size
meas -> ref
stat -> ref
Main Application Area

Fig. 7.


ChiSquare = .04012 Goodness = .48522
a = .17941 +/- .00565 b = 3.50877 +/- 5.36E-4 c = .02811 +/- .00138
asym = -.40700 +/- .07132 sigma = .00618 +/- 2.31E-4
ECS Off
ΔE_{FW} = 0.058GeV
$\frac{\Delta E_{FW}}{E}$ = 1.7%
BPM QXF4P_K Sum (nC)
BT Line e+ Design Momentum (GeV/c)
Function = (c+(a Exp[(-((x+(-b))^2) ((2 ((sigma (1+(asym Sign[(x+(-b))])))^2))^-1))])))

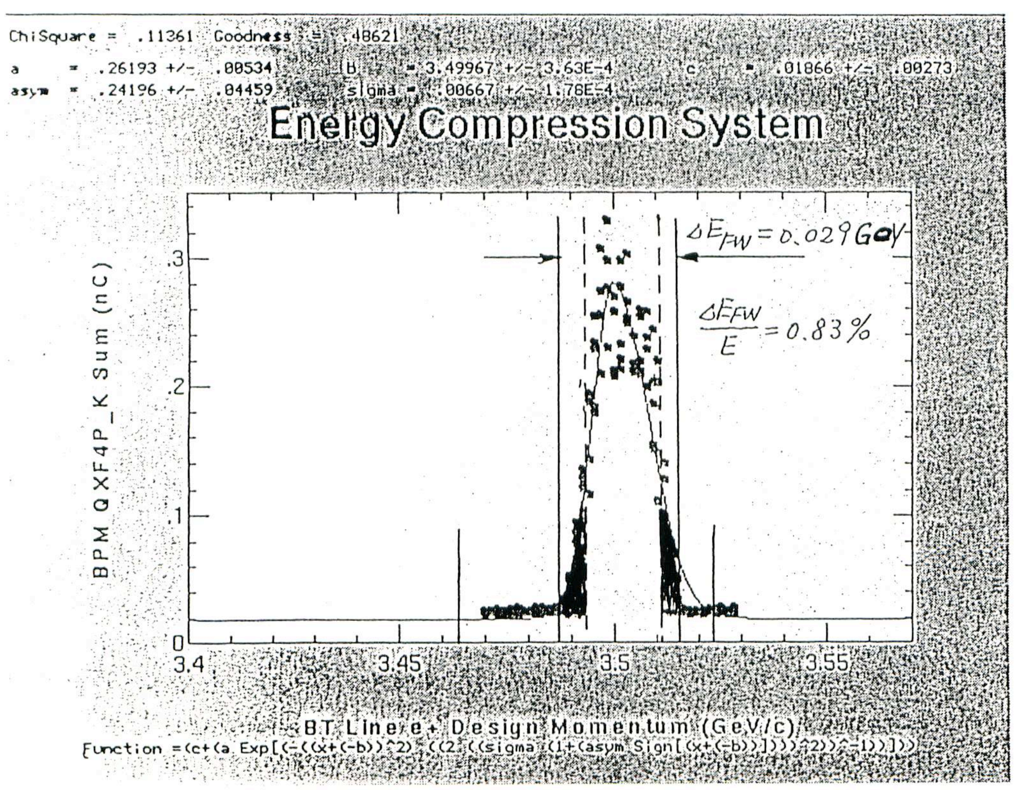
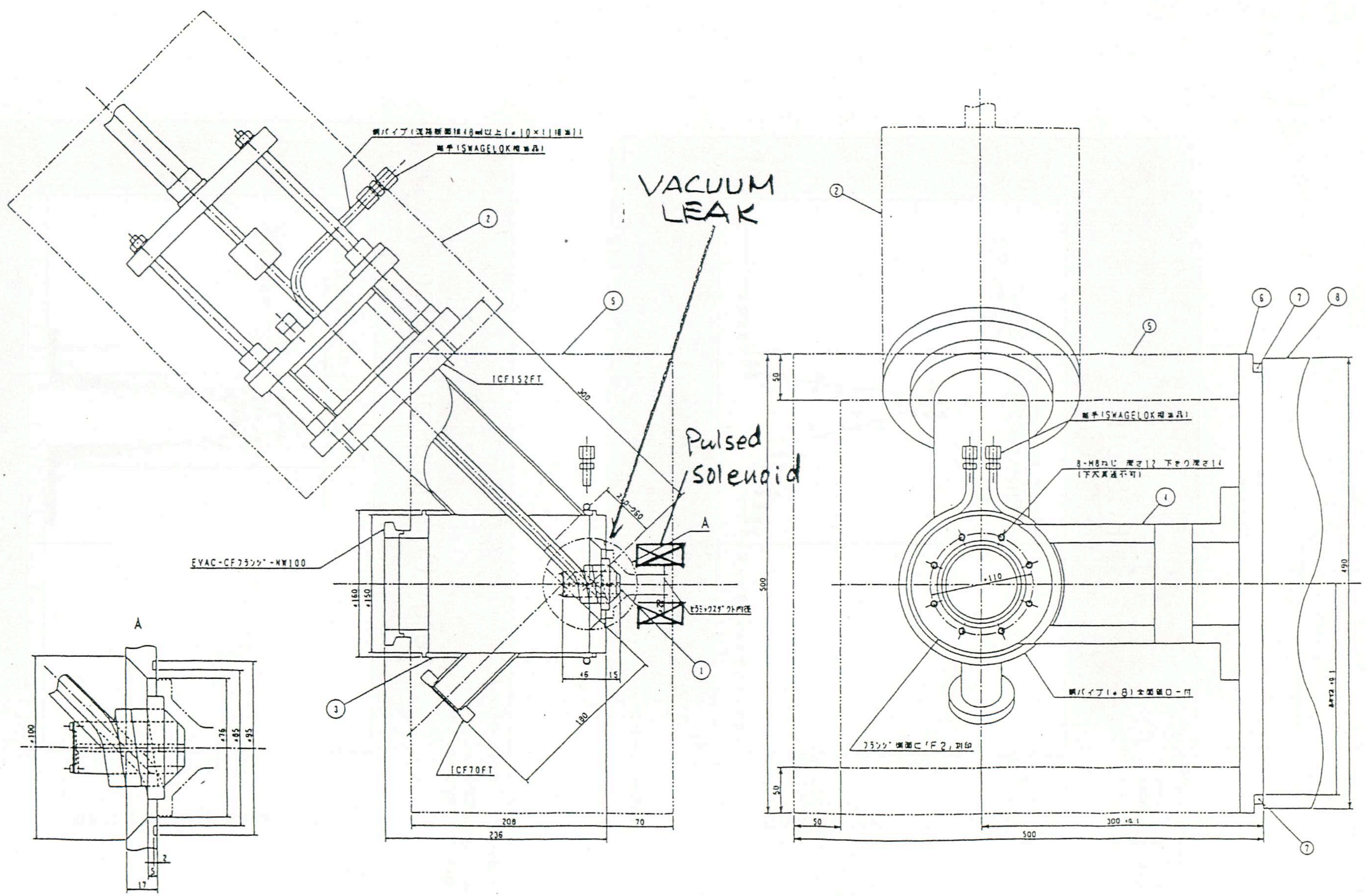

ChiSquare = .11361 Goodness = .48621
a = .26193 +/- .00534 b = 3.49967 +/- 3.63E-4 c = .01866 +/- .00273
asym = .24196 +/- .04459 sigma = .00667 +/- 1.78E-4
Energy Compression System
ΔE_{FW} = 0.029GeV
$\frac{\Delta E_{FW}}{E}$ = 0.83%
BPM QXF4P_K Sum (nC)
BT Line e+ Design Momentum (GeV/c)
Function = (c+(a Exp[(-((x+(-b))^2) ((2 ((sigma (1+(asym Sign[(x+(-b))])))^2))^-1))])))

Fig. 8

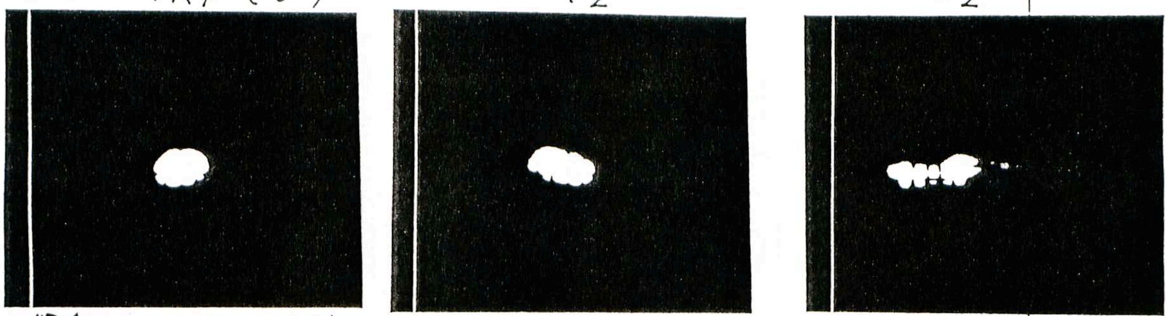
Fig. 9



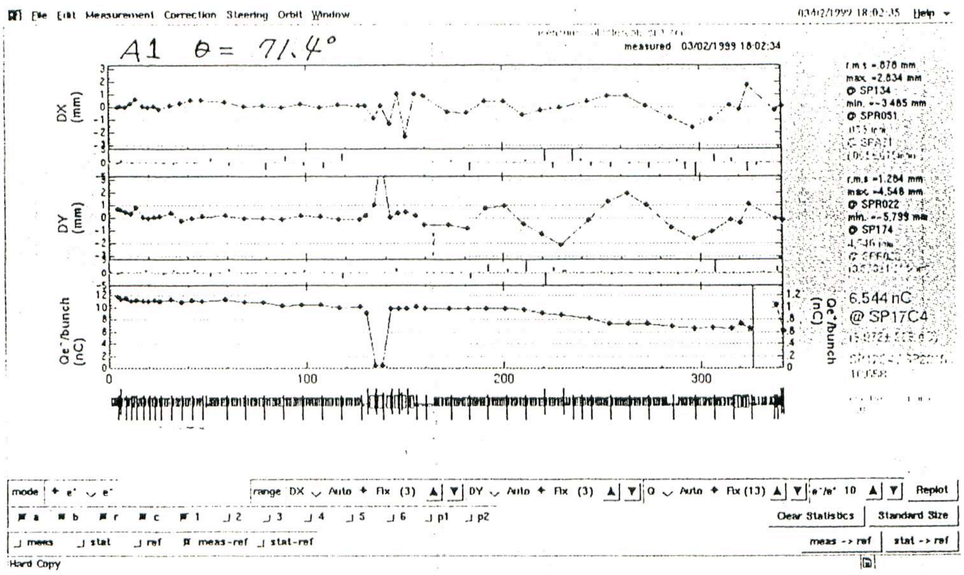
VACUUM LEAK
Pulsed solenoid
ICF152FT
ICF70FT
A
300
180
46
15
208
70
236
500
50
300
490

fundamental (2856 MHz) buncher phase vs. spectrum observed at the arc (η = 800 mm)

A1 θ = 71.4° (0°) +2° −2°



$\Delta E/E$ →| |← 0.6%



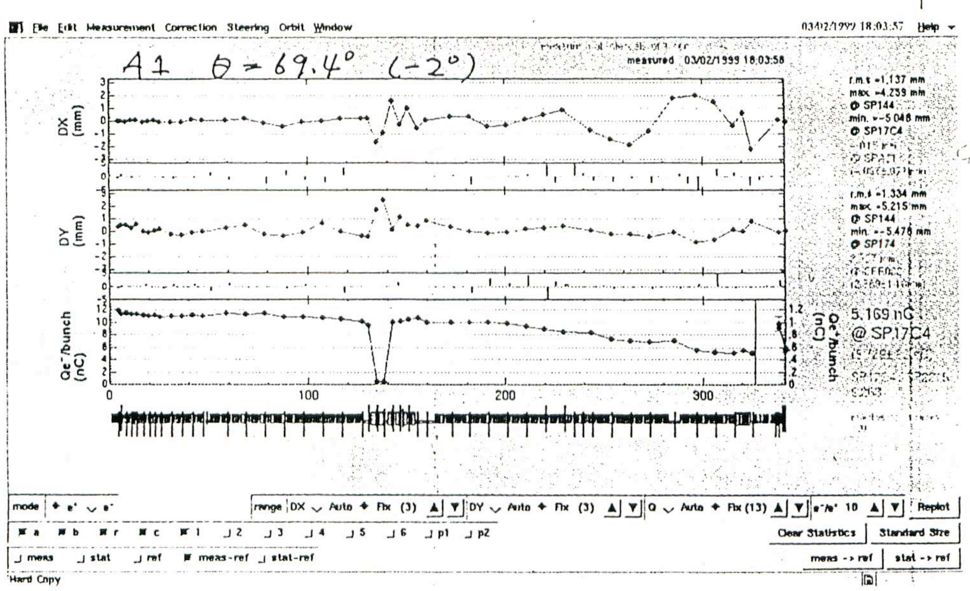
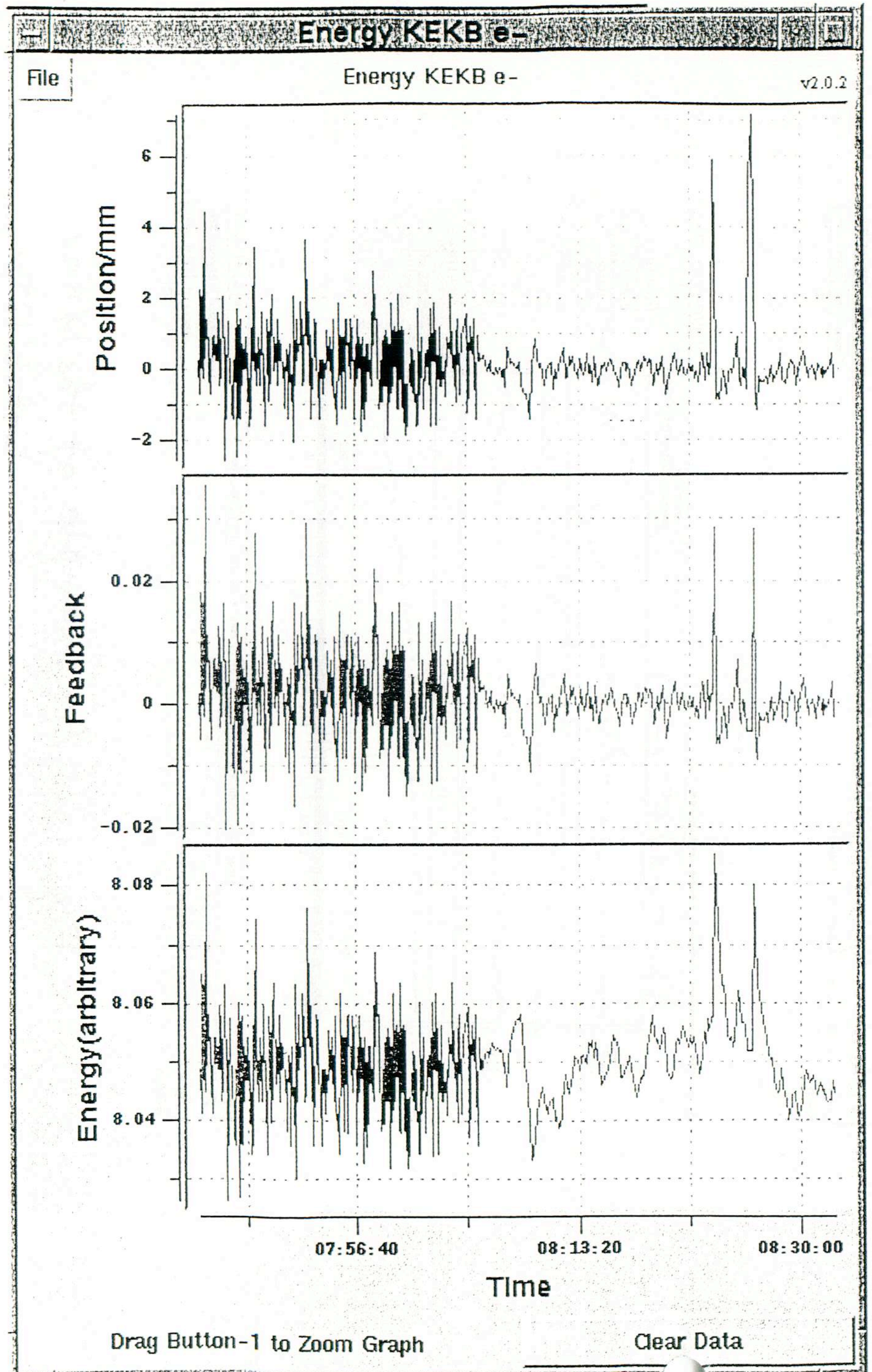


Fig. 10 An example of the linac instability



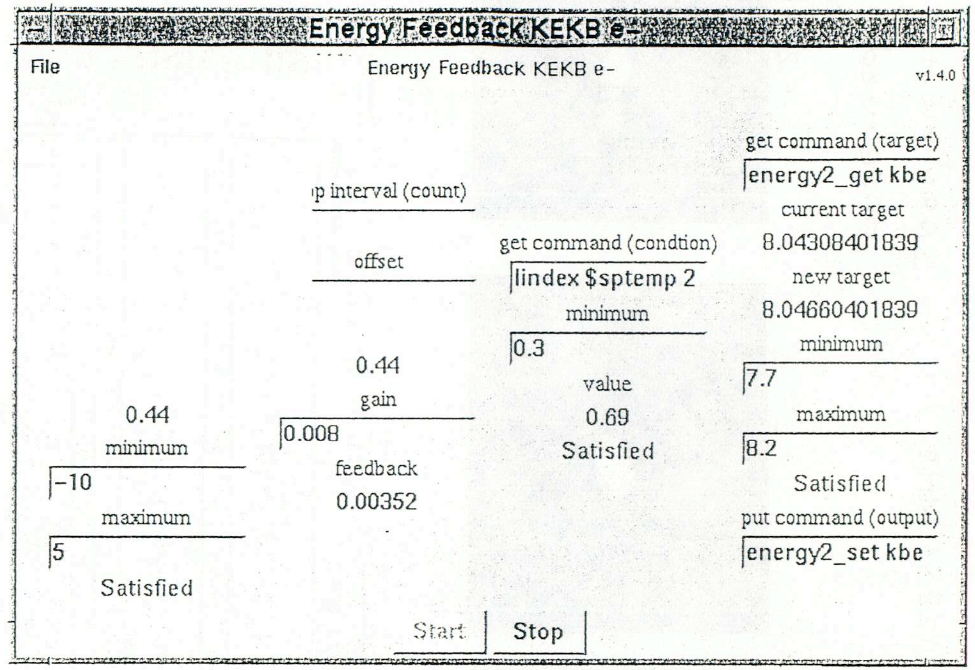


Fig. 11 Enery Feedback Software.

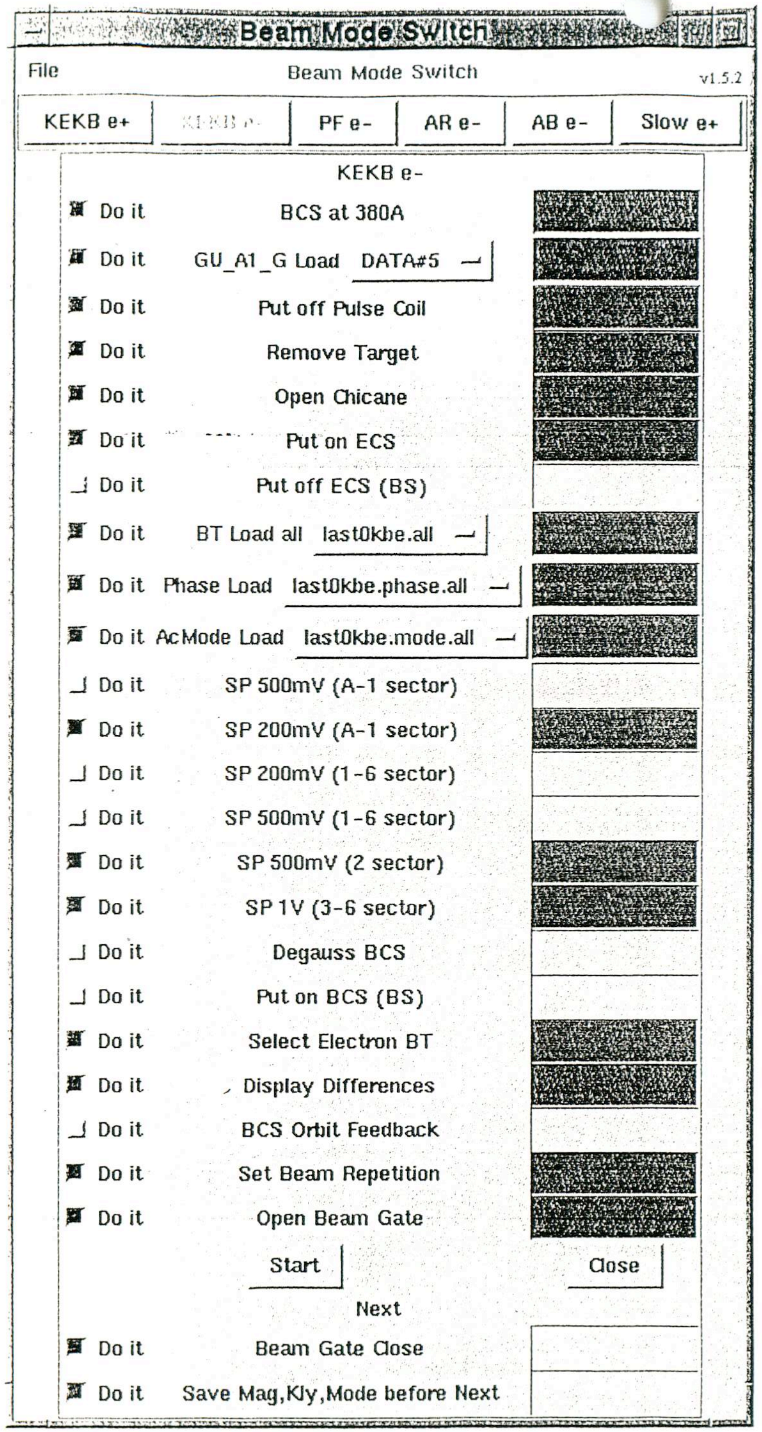


Fig. 12 Beam mode switch Software