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KEK/SLAC X-Band Collider Design Mini-workshop

December 5–9, 1994

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Stanford, California

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SLAC
December 5-9, 1994

KEK and SLAC have long enjoyed an exciting and fruitful collaboration for the development of electron-positron colliders. Joint research on the accelerator physics and technologies required for a future high-energy linear collider has included important collaboration on all major areas of R&D – parameters, particle sources, damping rings, high-power rf sources, accelerating structures and dynamics, final focus systems, instrumentation, as well as study of goals for particle physics and experimentation. Particularly close collaborations exist between KEK and SLAC on the development of a linear collider based on acceleration of beams with X-Band frequency (11.4 GHz) microwaves. Physicists from the two institutions met at SLAC during the week of Decmeber 5-9, 1994 to review and compare their progress, designs, and plans for such a collider.

The goal of the workshop was to discuss and compare the KEK JLC and SLAC NLC collider designs and technologies, to discuss important similarities and differences, and to identify and discuss ways to further enhance and strengthen collaboration between the two laboratories.

The first day of the workshop was used for presentations by people from each laboratory. Individual and small group meetings were held on Tuesday and Wednesday, and reports from the working groups were presented on Thursday afternoon and Friday morning. Many interesting and important topics were covered during the review, and the detailed comparisons of the two X-Band designs added insight to our understanding of each of them.

Although the basic approach and parameter sets of the KEK JLC and SLAC NLC X-Band designs are similar, a number of important and interesting differences were found during the workshop. The JLC scheme to compensate for beam loading in the injector uses pairs of klystrons operating at frequencies shifted slightly from the central band, while the NLC plan is to shape the applied rf by controlling the klystron phase at input to the compression stage. Neither technique has been fully tested yet. The rf systems for the main linac are also slightly different. The JLC design calls for a 130 MW klystron with a 500 ns output pulse that is compressed a factor 2 with a 3 db coupler and the transit time delay of the accelerated bunches. By contrast, the NLC design leans more heavily on the use of pulse compression to allow use of a lower power (50 MW) pulse 1.5 µs long. A more elaborate SLED II system amplifies the peak power by a factor nearly five. Work at both laboratories continues to improve the overall efficiency of rf power systems through such developments as PPM focused klystrons, superconducting focusing coils, and Blumlein modulators. Both groups will use detuned accelerating structures, and a very healthy diversification exists in fabrication methods being developed at the two laboratories – KEK is exploring diffusion bonding techniques while SLAC is working on precision brazing. A very interesting comparison was made of the final focus designs. The JLC incorporates a new "double bend" layout that minimizes the crossing angle of the beams at the interaction point. This has the advantage that no crab cavity is required, and most probably could also be designed to minimize muon backgrounds at the detector. The NLC design maintains a relatively large 40 mr crossing angle at the collision point, and corrects for the skew angles of the beams with a pair of crab cavities. Tolerances on the phase difference of such cavities are tight.

These are only some highlights of the KEK/SLAC miniworkshop on X-Band colliders. The meeting proved to be a useful stimulus for both teams, and the discussions of the week will strengthen each design. It was agreed that follow-on workshops will certainly be beneficial, and we look forward to getting together again in Tsukuba next Fall.

D. Burke
G. Loew
T. Matsui
K. Takata

KEK/SLAC X-Band Design Mini-workshop
SLAC Dec 5 - 9, 1994

The goal of this workshop is to discuss and compare the KEK JLC and SLAC NLC collider designs and technologies, to discuss important similarities and differences, and to identify and discuss ways to further enhance and strengthen our collaborations.

Working Groups

Parameters	Yokoya/Ruth
Sources, Injectors, and Prelinacs	Takeda/Miller
Damping Rings and Compressors	Urakawa/Raubenheimer
RF Power Systems	Mizuno/Wilson
Accelerator Structures	Higo/Wang
Final Focus and Collimation	Oide/Irwins
Instrumentation	Hayano/Ross
Experimentation	Matsui/Markiewicz

Committee: D. Burke G. Loew T. Matsui K. Takata

KEK/SLAC X-Band Design Mini-workshop
Program

Monday, December 5 **Presentations of JLC and NLC**
Orange Room

Morning Session Chair: Burke

	Welcome	Drell	
0900-0940	**Parameters**	Yokoya/Ruth	1
0945-1030	**Sources,etc.**	Takeda/Miller	23
1030-1100	Coffee Break		
1100-1140	**Damping Rings/Compressors**	Urakawa/Raubenheimer	57
1145-1230	**Instrumentation**	Hayano/Ross	115

Afternoon Session Chair: Takata

1400-1440	**RF Power**	Mizuno/Wilson	145
1445-1530	**Structures**	Higo/Wang	191
1530-1600	Coffee break		
1600-1640	**Final Focus**	Oide/Irwin	259
1645-1730	**Experimentation**	Matsui/Markiewicz	305

Tuesday-Wednesday: Working Group Meetings and Preparation

Thursday, December 8 **Working Group Reports**
Orange Room

Afternoon Session Chair: Takata

1400-1440	**Parameters**	345
1445-1530	**Sources, etc**	351
1530-1600	Coffee break	
1600-1640	**Damping Rings/Compressors**	363
1645-1730	**Instrumentation**	383

Friday, December 9 **Working Group Reports**
Orange Room

Morning Session Chair: Loew

0900-0940	**RF Power**	401
0945-1030	**Structures**	413
1030-1100	Coffee break	
1100-1140	**Final Focus**	419
1145-1230	**Experimentation**	443

Afternoon Session Chair: Loew/Takata

1400-1515	Discussions
1515	Monbusho Visit

Parameters at E_{CM}=0.5, 1.0, and 1.5 TeV with X-Band

version Dec.1.1994

——- Basic Parameters ——-					
Beam Energy	E	GeV	250	500	750
Main accelerating frequency	f_{rf}	GHz	11.424	11.424	11.424
Number of particles per bunch in main linac	N	10^{10}	0.753	0.753	0.770
Number of bunches per pulse	m_b		72	72	72
Bunch spacing	t_b	nsec	1.40	1.40	1.40
Repetition frequency	f_{rep}	Hz	150	150	150
Normalized emittance at damping ring	ε_x	rad.m	3×10^{-6}	3×10^{-6}	3×10^{-6}
	ε_y	rad.m	3×10^{-8}	3×10^{-8}	3×10^{-8}
R.m.s. bunch length	σ_z	μm	89.1	90.2	98.3
——- Parameters related to Main Linac RF ——-					
Nominal accelerating gradient	G_0	MeV/m	71.4	71.4	71.4
Effective gradient in cavities	G_{eff}	MeV/m	53.5	53.5	53.5
Active length of main linac per beam	L_{ac}	m	4296	8966	13635
Length of a cavity unit	l_{cav}	m	1.31	1.31	1.31
Number of cavity units per beam			3279	6844	10409
Iris radius/Wave length	a/λ		0.1658	0.1658	0.1658
Cavity filling time (CG)	T_f	nsec	102.8	102.8	102.8
Attenuation parameter	τ		0.553	0.553	0.553
Q-factor	Q		6671	6671	6671
Average group velocity	$\bar{v}_g/c$		0.0425	0.0425	0.0425
Loss parameter	k_1	10^{14} V/C/m	2.06	2.06	2.06
Total average power into cavities for two linacs		MW	25.8	53.8	81.2
Wall-plug power for two linacs		MW	86	179	271
Assumed efficiency from AC to RF		%	30	30	30
Peak power per cavity	P_{peak}	MW	130	130	130
Single-bunch extraction efficiency	η_1	%	1.40	1.40	1.43
Multibunch energy compensation by filling time shift		%	2	2	2
fraction of cavities of zero and full timimg shift		%	49	49	48

———- Parameters Related to Main Linac Beam Dynamics ———-					
Beta function scale ($\beta = \beta_0 \sqrt{E/1\mathrm{GeV}}$)	β_0	m	0.95	0.95	0.95
Total number of betatron oscillation in main linac			88.7	139.9	179.3
Phase shift from the crest	ϕ_{rf}	deg	16.3	16.3	15.1
Single bunch full energy spread after off-crest correction		%	0.50	0.50	0.50
Single-bunch energy slope due to wake	$\langle \sigma_z d\epsilon/dz \rangle$	%	-0.738	-0.768	-0.780
Energy slope for BNS damping		%	-0.295	-0.299	-0.329
———- Parameters Related to FFS and IP ———					
Number of particles per bunch at IP (10% loss assumed)	N^*	10^{10}	0.678	0.678	0.693
Beta function at IP	β_x^*	mm	10.0	11.9	22.8
	β_y^*	μm	100	100	107
Rms beam size at IP	σ_x	nm	260	200	227
	σ_y	nm	3.04	2.20	1.96
Crossing angle	ϕ_{cross}	mrad	5.52	5.00	5.00
Beam diagonal angle	σ_x/σ_z	mrad	3.25	2.78	3.17
Disruption parameter	D_x		0.1019	0.0868	0.0505
	D_y		8.70	7.90	5.84
Effective disruption parameter due to crossing angle	$D_{y,eff}$		6.32	5.25	3.96
Number of beamstrahlung photons	n_γ		1.03	1.22	1.07
Maximum Upsilon	Υ_{max}		0.316	0.802	0.993
Energy loss by beamstrahlung	δ_{BS}	%	3.78	8.00	8.00
Detector solenoid field	B_{sol}	Tesla	2.0	2.0	2.0
Distance from IP to mask tip		m	0.66	0.66	0.66
Required mask angle		radian	0.0848	0.0873	0.0839
Blowup factor of multibunch crossing instability			3.00	1.64	1.30
Geometrical luminosity reduction factor			0.676	0.624	0.633
Pinch enhancement factor	H_D		1.60	1.55	1.48
Luminosity	L	$10^{33}/\mathrm{cm}^2/\mathrm{s}$	5.42	8.66	8.68

Longitudinal wake function $W_L(z) = W_0 + W_1\sqrt{z} + W_2 z$ with $W_0 = 1.90\times10^{15}$, $W_1 = -6.41\times10^{16}$, $W_2 = 7.03\times10^{17}$, (z in m, W in V/C/m).

Transverse wake slope $dW_T/dz = 1.532\times10^{20}$ V/C/m^3.

NLC Parameters

R. Ruth
KEK/SLAC X-Band
Design Miniworkshop
SLAC. December 5-9, 1994

1.) Layout and General Parameters

2.) Sources

3.) Damping Rings

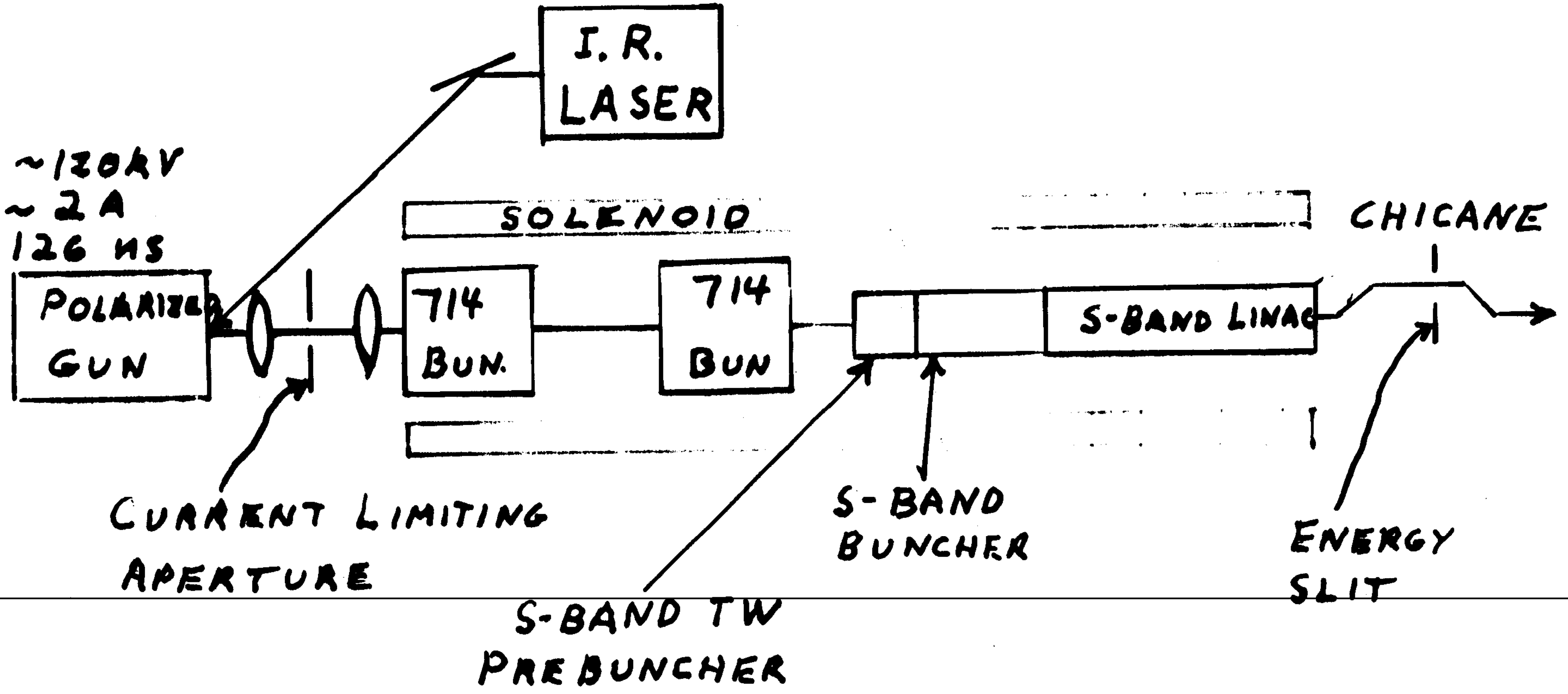
4.) RF System

5.) Final Focus

NLC e- Source

- High Polarization
- “Acceptable” emittance
- Polarized cathode current limit?
- Conventional approach may be O.K.

INJECTOR FOR XLC

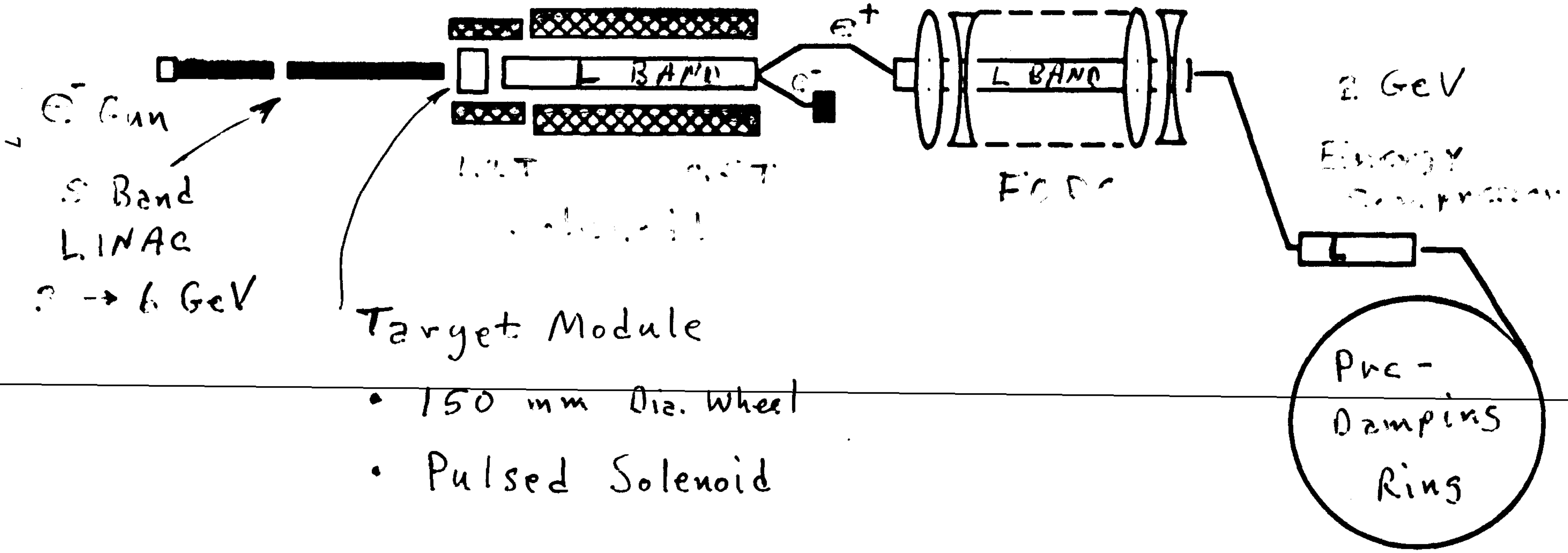


NLC INJECTOR: CRITICA ISSUES

ALL RESULT FROM LONG PULSE TRAIN

- HIGH CURRENT - LONG PULSE PERFORMANCE OF GUN:
  - CURRENT LIMIT
  - DROOP DURING PULSE
- LASER
  - PULSE TO PULSE JITTER
  - PULSE SHAPING TO CORRECT DROOP
- NON-RELATIVISTIC BEAM TRANSPORT
  - CURRENT LIMITED APERTURE TO REDUCE JITTER
- BEAM LOADING COMPENSATION
  - SUBHARMONIC BUNCHERS
  - S-BAND BUNCHER(S)
  - S-BAND ACCELERATOR SECTIONS
- MULTIBUNCH DIPOLE WAKEFIELDS
  - IN BUNCHERS + S-BAND ACC.
- TIME STRUCTURE FLEXIBILITY

Draft
NLC Positron System



Target Module

- 150 mm Dia. Wheel
- Pulsed Solenoid

Positron System Parameters

Parameter	SLC 93	SLC max design	NLC 500 GeV	NLC 1.0 or 1.5 TeV
Scavenger Beam				
Energy Ee- (GeV)	30.00	30.00	3.11	6.22
Intensity Ne- / bunch	3.00E+10	7.00E+10	1.50E+10	1.50E+10
coul / bunch	4.80E-09	1.12E-08	2.40E-09	2.40E-09
bunch length (psec)	3	3	5	5
n bunches / pulse	1	1	90	75
Intensity Ne- / pulse	3.00E+10	7.00E+10	1.35E+12	1.13E+12
coul / pulse	4.80E-09	1.12E-08	2.16E-07	1.80E-07
Beam Pulse Energy (Joules)	144	336	672	1120
rep. rate (Hz)	120	120	180	120
Beam Power (Watts)	1.73E+04	4.03E+04	1.21E+05	1.34E+05
Beam size , sigma (mm)	0.6	0.8	1.6	1.6
Power Density=Ee-*Ne-/pulse/(pi*sigma^2) (GeV/mm^2)	7.96E+11	1.04E+12	5.22E+11	8.70E+11

Positron Collection				
Wall emittance (m)	0.01	0.01	0.06	0.06
Energy Cut at 200 MeV (MeV)	20	20	20	20
Long. Cut at 200 MeV/c (psec)	15	15	60	60
Yield/Ee- (1/GeV)	0.083	0.083	0.300	0.300
Yield	2.50	2.50	0.93	1.87
Intensity Ne+ / bunch	7.5E+10	1.75E+11	1.4E+10	2.8E+10
coul / bunch	1.20E-08	2.80E-08	2.24E-09	4.48E-09
Intensity Ne+ / pulse	7.50E+10	1.75E+11	1.26E+12	2.10E+12
coul / pulse	1.20E-08	2.80E-08	2.02E-07	3.36E-07

Global				
Efficiency	0.4	0.4	0.5	0.5
N e+ / bunch at IP	3.00E+10	7.00E+10	7.00E+09	1.40E+10

Damping Rings

- Postitions --> pre-damping ring
- High Current ~ B-factory
- Single bunch effects important
- KEK ATF Damping Ring:
  Key Prototype

Damping Rings

Parameters for Pre-Damping Ring

Energy	2 GeV
Circ.	114 m
Current[a]	1 Amp
ν_x, ν_y	10.18, 5.18
$\gamma\epsilon_{x,y}$[b]	27 mm-mrad
σ_ϵ	0.1%
σ_z	5.4 mm
$\tau_{x,y}$[b]	3.5 ms
$\mathcal{J}_x$	1.34
α	0.005
V_{RF}	2.5 MV
f_{RF}	714 MHz
$\Delta E/E_{RF}$[c]	2%
Lattice	30 FOOF Cells
Vacuum Aperture[c]	4.0 cm by 3.2 cm
Dynamic Aperture[d]	> 0.1 m-rad at ±2%

---

[a] Assuming two trains of 75 bunches of 1.5×10^{10} — the maximum train length is 90 bunches with a 1.4 ns spacing (126 ns) leaving 60 ns for the kickers.

[b] Assuming the ring is coupled.

[c] Full aperture — this provides room for a hard edge emittance and energy spread of 0.06 m-rad and ±2% with a 3 ± mm clearance.

[d] Aperture defined as $\gamma\hat{x}^2/2\beta$.

Parameters for Main Damping Ring

Energy	2 GeV
Circ.	220 m
Current[a]	1 Amp
ν_x, ν_y	23.81, 8.62
$\gamma\epsilon_x, \gamma\epsilon_y$[b,c]	2.3 mm-mrad, 0.02 mm-mrad
σ_ϵ[c]	0.09%
σ_z[c]	3.5 mm
τ_x, τ_y[c]	4.2 ms, 4.8 ms
$\mathcal{J}_x$	1.15
α	0.0005
V_{RF}	1.5 MV
f_{RF}	714 MHz
$\Delta E/E_{RF}$	3%
Lattice	40 TME Cells
Vacuum Aperture[d]	2 cm?
Vacuum Pressure	1 nTorr?
Dynamic Aperture[e]	> 0.009 m-rad at ±1%
L_{bend}	68.4 cm
$B_{0\,bend}$	15.3 kG
$B_{1\,bend}$	133 kG/m
$L_{wiggler}$	20 m
B_{eff}	15.6 kG
B_{peak}	22 kG

---

[a] Assuming four trains of 75 bunches of 1.5×10^{10} — the maximum train length is 90 bunches with a 1.4 ns spacing (126 ns) leaving 60 ns for the kickers.

[b] Before IBS has been included.

[c] With 20 meters of wiggler.

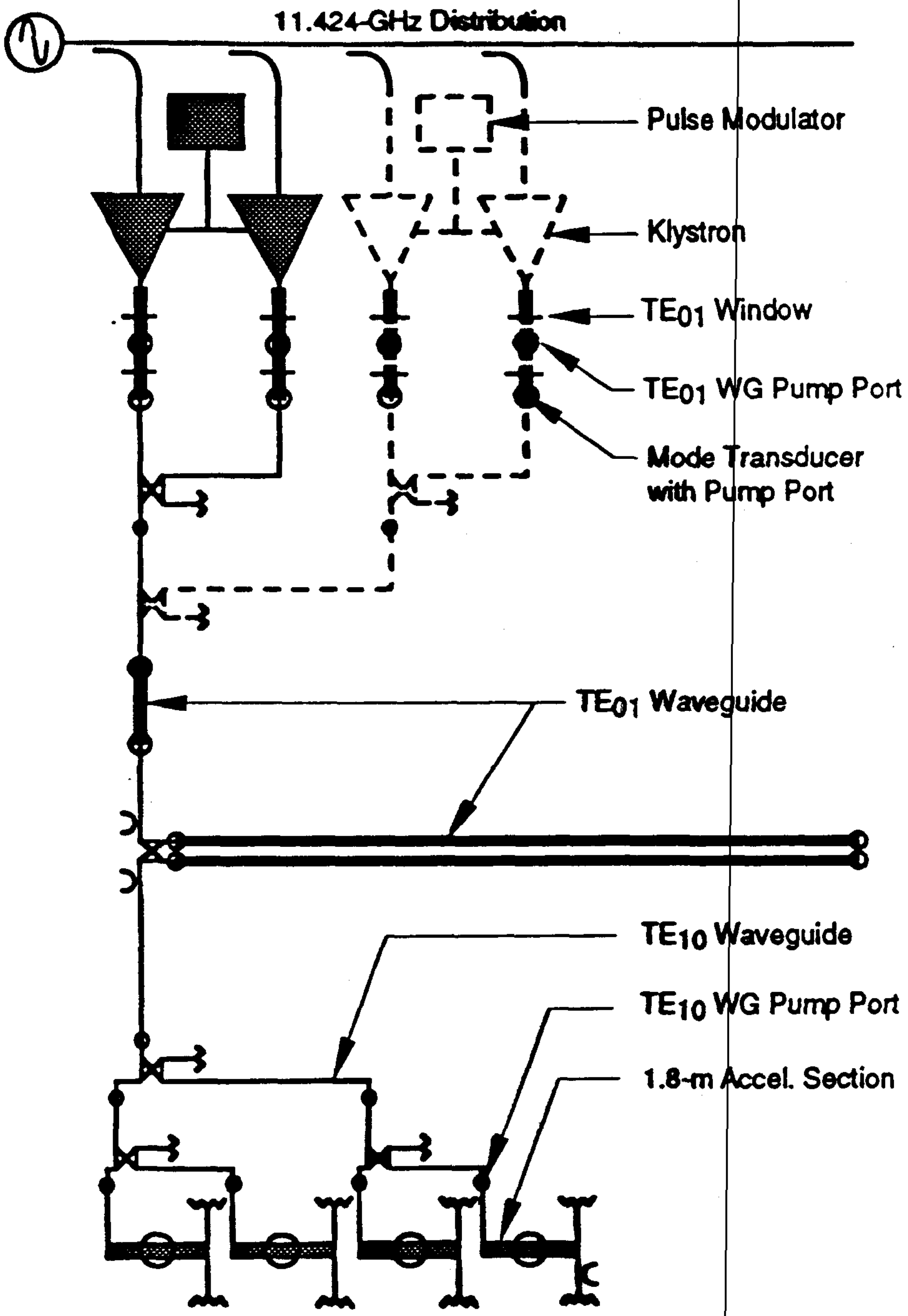
[d] Full aperture — this needs to be determined by the transverse and longitudinal dynamics and the vacuum pressure.

[e] Aperture defined as $\gamma\hat{x}^2/2\beta$ — this is without a proper injection/extraction region.

NLC RF System

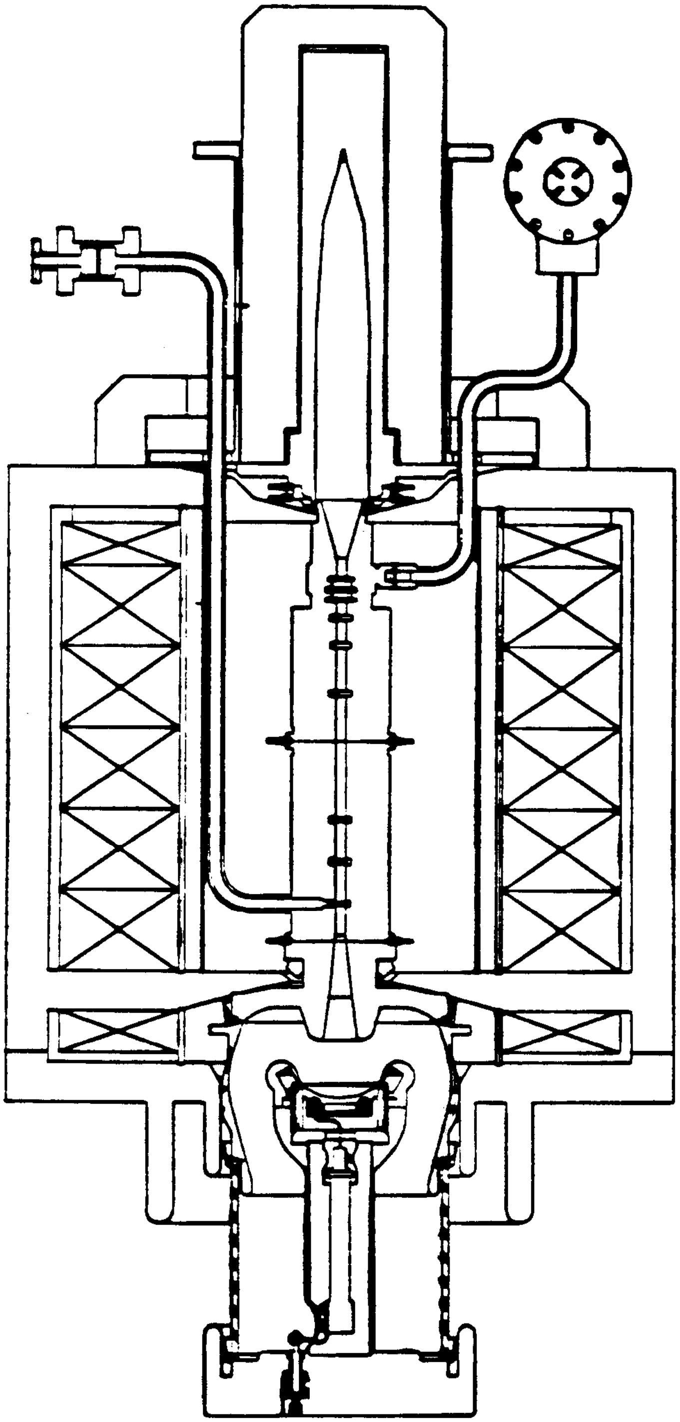
- PPM Focused Klystrons ~ 50-70 MW
- Pulse Compression --> SLED II + ?
- Structure, ⟶ Damped and Detuned
- Moderate Accelerating gradient

RF System Layout



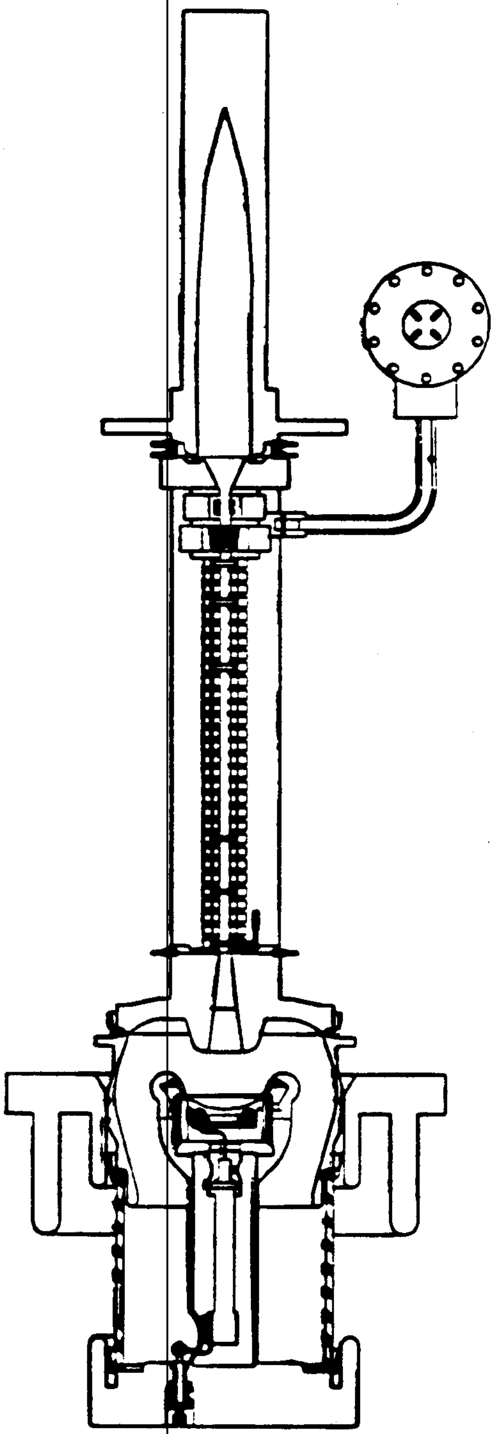
NLC RF Parameters

	500 GeV		1.0 TeV		1.5 TeV
Active Str. Length(1) (km)	13.5	10.7	16.2		24.5
Accelerating Gradient(2) Unloaded/Loaded (MV/m)	50/37.3	60/44.8	85/63.4		85/63.4
Input Power to Str.(2) (MW/m)	50	72	145		145
No. 7.2m RF Stations(3)	1877	1487	2254		3404
Particles per Bunch (10^{10})	0.65	0.78	1.10		1.10
Repetition Rate (Hz)	180		120		120
Bunches per RF Pulse	90		75		75
RF Pulse Length(4)	250		220		220
Pulse Compression System	SLED-II (x5)		SLED-II (x5)	BPC (x8)	BPC (x8)
Power Gain/Comp. Efficiency(5)	3.6 / 72%		3.6 / 72%	7.2 / 90%	7.2 / 90%
Klystron Pulse Length (μs)	1.25		1.10	1.76	1.76
Klystron Efficiency	60%		65%		65%
Peak Pwr. per RF Station (MW)	100	145	289	145	145
No. Kly. per Station @ Peak Pwr. (MW)	2 @ 50	2 @ 72	4 @ 72	2 @ 72	2 @ 72
Total No. Klystrons(6)	3754	2974	9016	4508	6808
Modulator Efficiency(7)	PFN @ 75%		PFN @ 80%		PFN @ 80%
Energy per Pulse per Station(8) (J)	278	401	611	489	489
Net RF System Efficiency	32%		37%	47%	47%
Wall Plug Power(9) (MW)	94	107	165	132	200



XL1

SOLENOID POWER: 24 KW

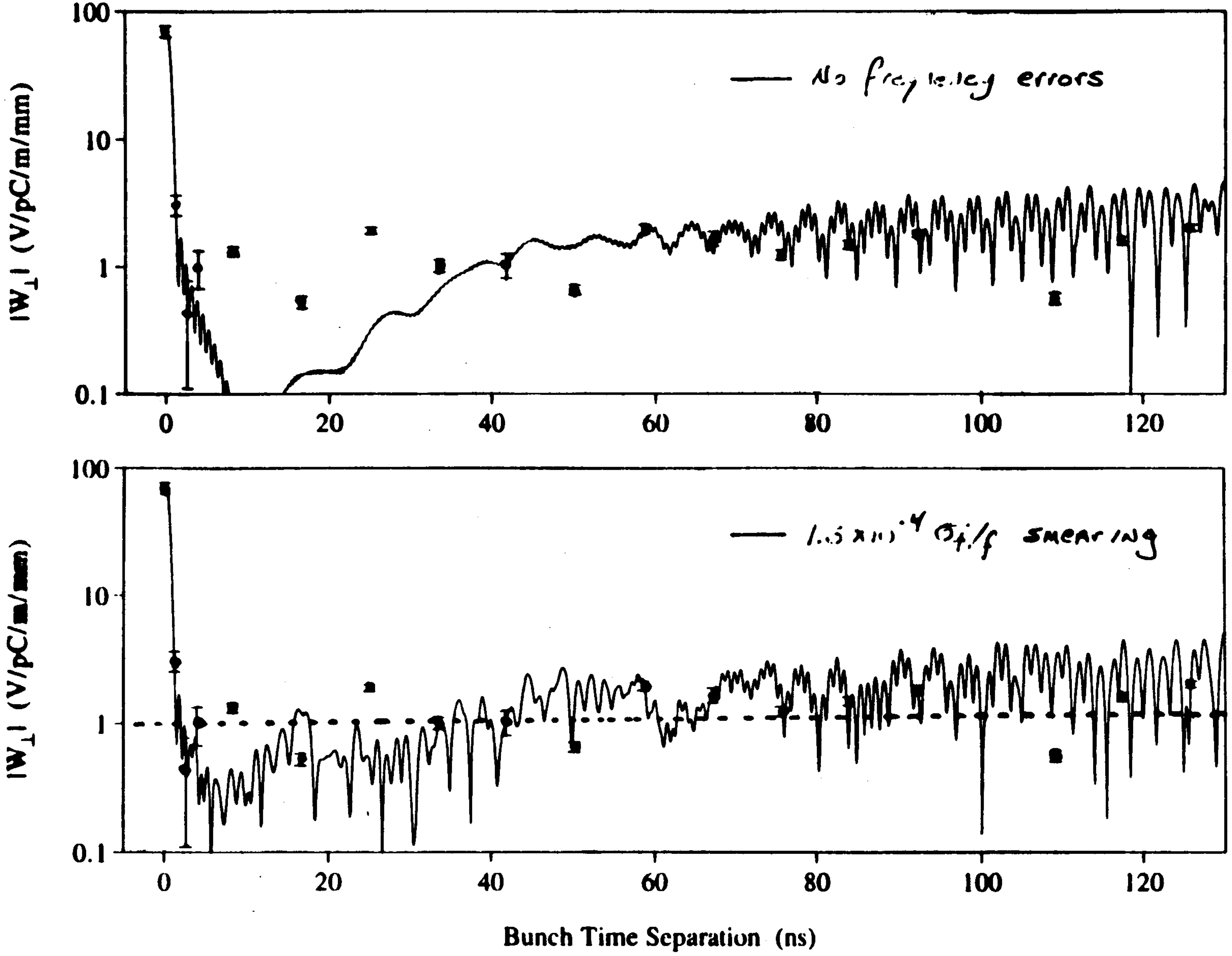


PPM FOCUSED DESCENDANT

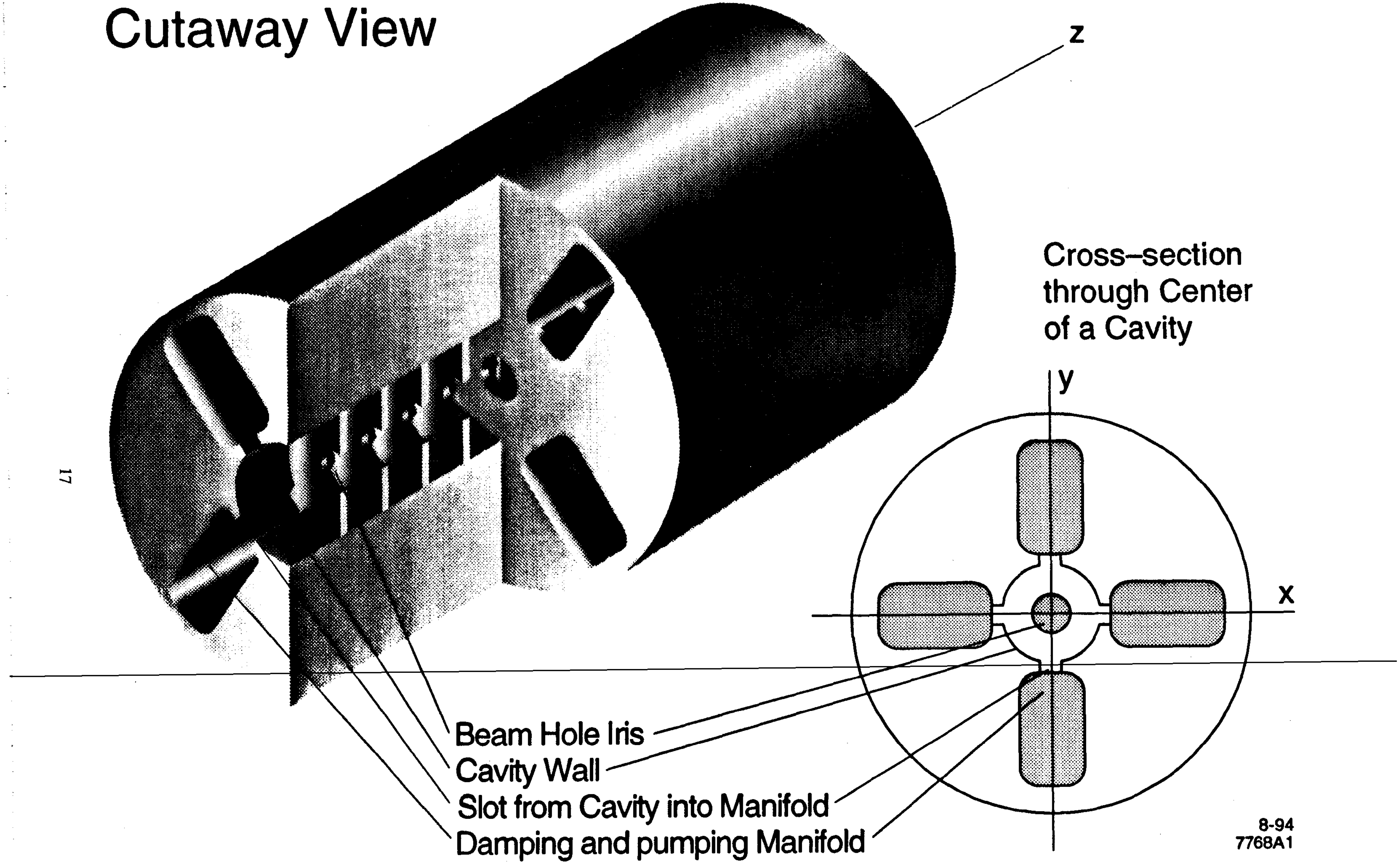
NO FOCUSING POWER

DIPOLE WAKEFIELD AMPLITUDE

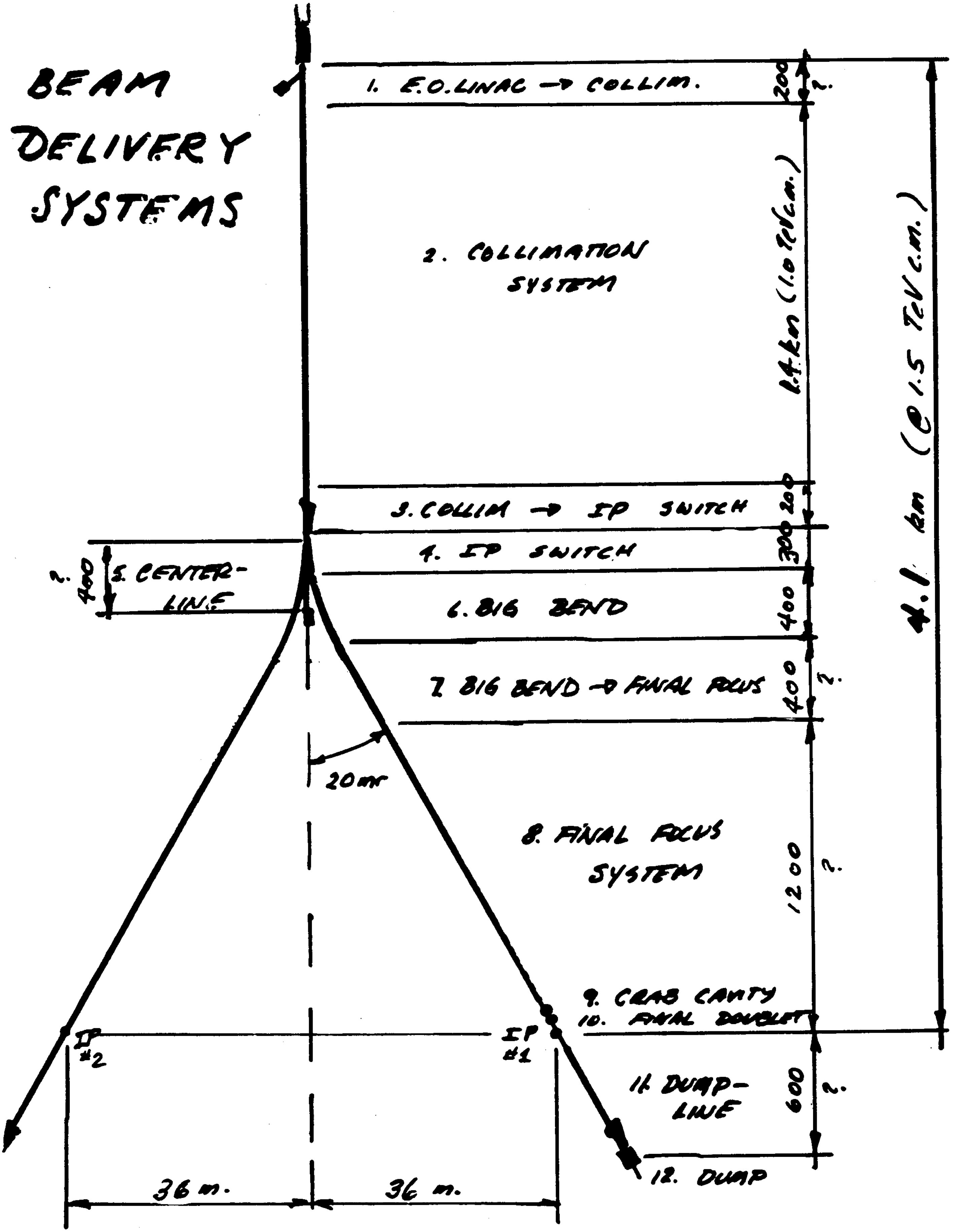
First detuned 1.8m Structure



Cutaway View



BEAM DELIVERY SYSTEMS

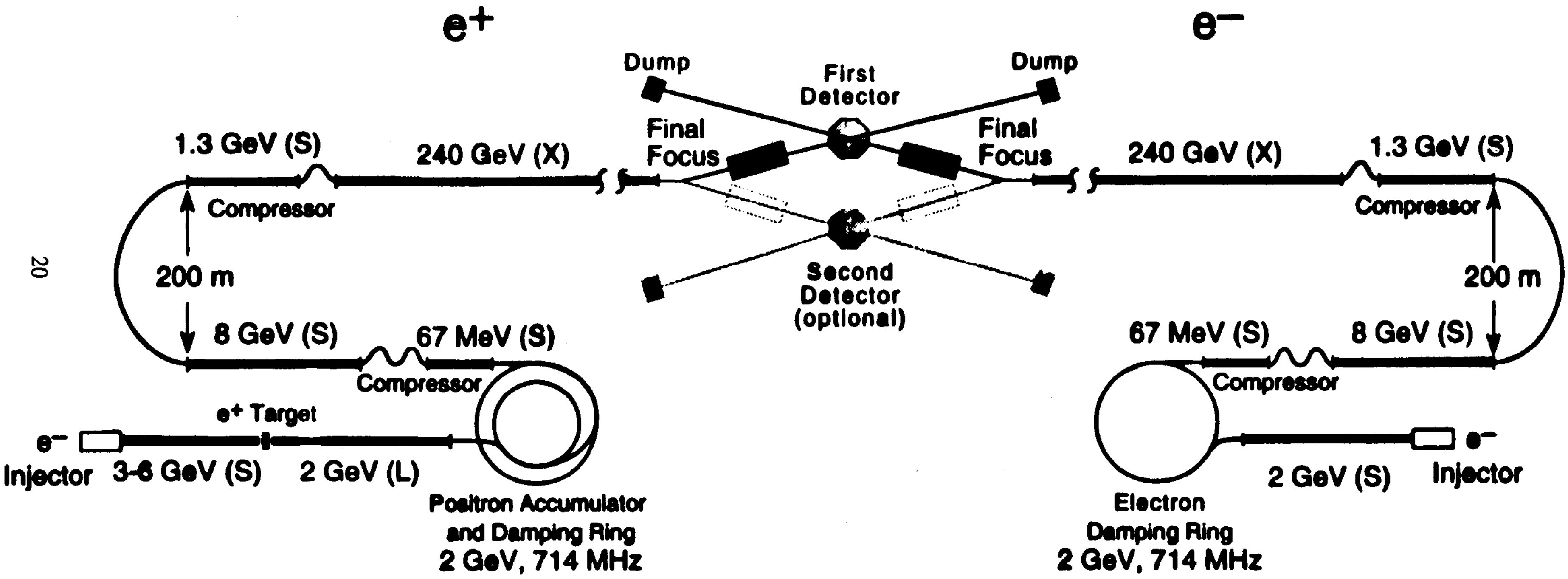


NLC IP Region Working Parameters

Parameter	0.5 TeV	O.5 TeV^2	1.0 TeV	1.5 TeV	Comments
L_0	0.5	0.8	1.06	1.07	
L	0.7	1.0	1.4	1.6	Luminosity w/ Pinch
H_d	1.3		1.4	1.5	Enhancement from Pinch
σ_x	320 nm		360 nm	360 nm	Variable
σ_y	3.2 nm		2.3 nm	2.3 nm	
ε_x	10^{-11}		1/2 10^{-11}	1/3 10^{-11}	$\gamma \varepsilon_x = 5\ 10^{-6}$ m-rad
ε_y	10^{-13}		1/2 10^{-13}	1/3 10^{-13}	$\gamma \varepsilon_y = 5\ 10^{-8}$ m-rad
β_x	10 mm		25 mm	37 mm	
β_y	100 μ		100 μ	150 μ	
$\sigma_{x',y'}$	30, 30 μrad		14, 23 μrad	10, 15 μrad	IP Divergent Angle
σ_z	100 μ		100 μ	100 μ	Bunch Length
θ_d	3.2 mr		3.6 mr	3.6 mr	Bunch Diagonal Angle
$\pm \Delta_{box}$	$< \pm 4\ 10^{-3}$		$< \pm 4\ 10^{-3}$	$< \pm 4\ 10^{-3}$	Square Energy Profile Widt
$D_{x,y}$	.07, 7.3		.04, 8.8	.03, 5.2	Disruption Parameter
Θ_D	.25 mr		.25 mr	.25 mr	Max. Disrupt. Angle @ Beam Energy
Y	.09	.11	.28	.42	Upsilon Parameter
δ_B	.03	.04	.12	.16	Mean Energy Loss to Beamstrahl. γs
n_γ	.8	1.0	1.1	1.1	# of Photons per Electron
N_{Had}	.04	.07	0.3	0.3	# of Hadronic Events / Cross
N_{jet5}	.001		0.03		# of Mini-Jets per Crossing

NLC Diagram

not to Scale



▬ Linac

(L) 1.428 GHz

(S) 2.856 GHz

(X) 11.424 GHz

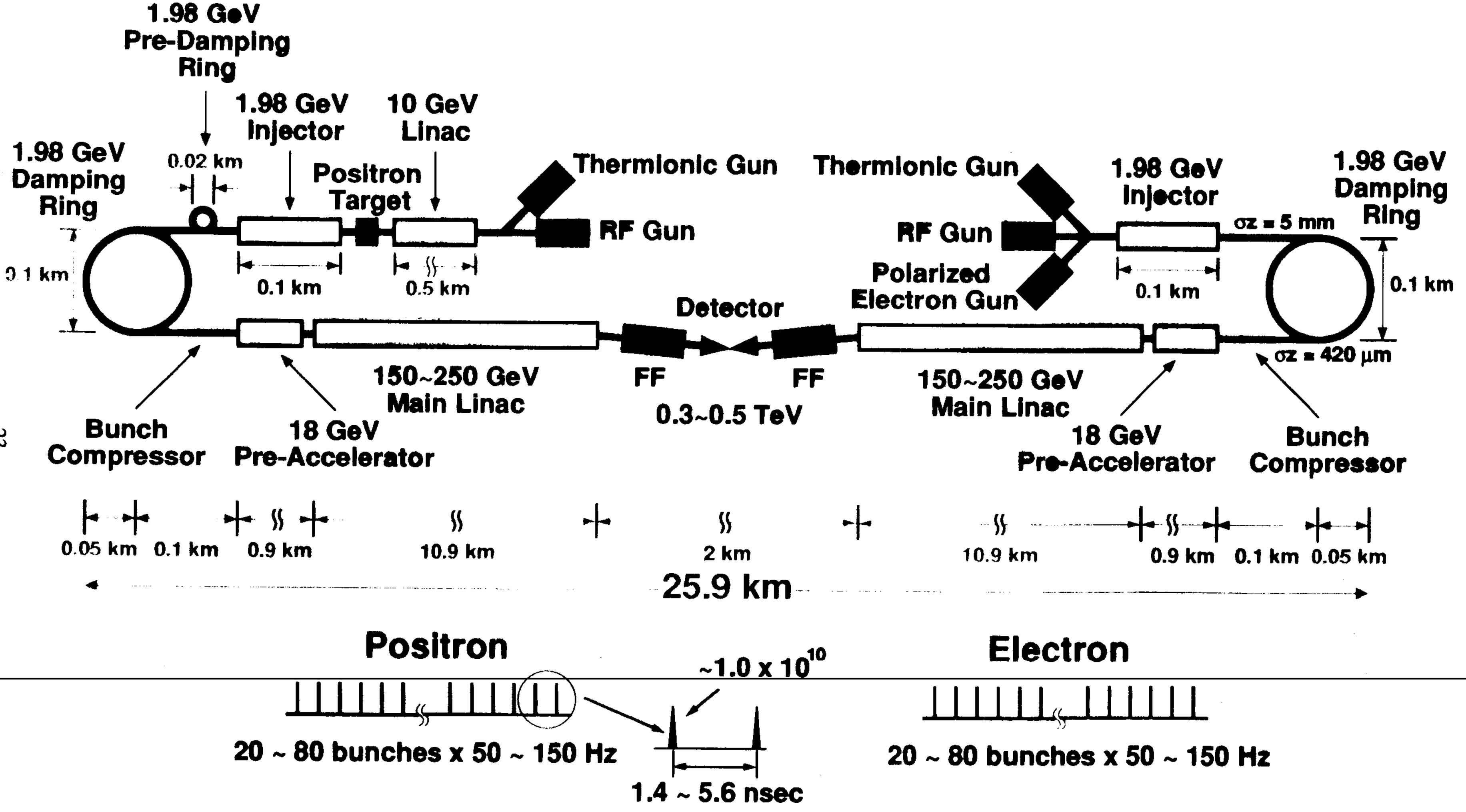
10-94
7636A2

NLC PARAMETERS

Parameter	NLC		
CM Energy (TeV)	0.5	1	1.5
Luminosity (10**33)	8 / 11	14	16
Rep Rate (Hz)	180	120	120
Bunches/RF Pulse	90	75	75
N (10**10)	0.65 /0.78	1.1	1.1
x/y Emittance (10**8m)	500/5	500/5	500/5
x/y Beta at IP(mm)	10/0.1	25/0.1	37/0.15
x/y Sigma at IP(nm)	320/3.2	360/2.3	360/2.3
Bunch Length (microns)	100	100	100
Upsilon	0.09 /0.11	0.28	0.42
Pinch Enhancement	1.4 /1.4	1.4	1.5
Beamstrahlung Delta	0.03 /0.04	0.11	0.16
No. Photons per e-	0.8 /1.0	1.1	1.1
Loaded Grad.(MV/m)	37 /45	63	63
Linac Length (km)	13.5 /10.7	16	24
Number of Klystrons	3750/2970	9000/4500	13.5k/6.8k
Klystron Pk Pwr (MW)	50 /72	72 /72	72 /72
Pulse Compression Gain	3.6	3.6 /7.2	3.6 /7.2
Power/Beam PB (MW)	4.2 /5.0	7.9	11.9
AC Power PAC (MW)	94 /107	165 /132	250 /200
2PB/PAC	0.09 /0.09	0.10 /0.12	0.10 /0.12

12/5/94.

Schematic Diagram of JLC-I


1.98 GeV Pre-Damping Ring

1.98 GeV Injector

10 GeV Linac

1.98 GeV Damping Ring

0.02 km

Positron Target

Thermionic Gun

RF Gun

0.1 km

0.1 km

0.5 km

Detector

Thermionic Gun

RF Gun

Polarized Electron Gun

1.98 GeV Injector

1.98 GeV Damping Ring

σz = 5 mm

0.1 km

0.1 km

σz = 420 μm

150~250 GeV Main Linac

FF

FF

0.3~0.5 TeV

150~250 GeV Main Linac

Bunch Compressor

18 GeV Pre-Accelerator

18 GeV Pre-Accelerator

Bunch Compressor

0.05 km 0.1 km 0.9 km 10.9 km 2 km 10.9 km 0.9 km 0.1 km 0.05 km

25.9 km

Positron

Electron

~1.0 x 10^{10}

20 ~ 80 bunches x 50 ~ 150 Hz

1.4 ~ 5.6 nsec

20 ~ 80 bunches x 50 ~ 150 Hz

S.Takeda & H.Matsumoto / JLCDiag / 910906

Basic Parameters of Electron Bunch

Total number of bunch / shot :	90 bunches
Bunch separation :	1.4 ns
Repetition rate :	150 Hz
Bunch population :	0.63×10^{10}
Total number of electrons / shot :	5.7×10^{11}
Tolerance of bunch population :	$< \pm 1.0$ %

Electron Sources

Thermionic Electron Gun

Laser Driven Photocathode RF Gun

Polarized Electron Gun

Pre-Injector Linac

Thermionic Electron Gun System

Thermionic electron gun : up to 200 kV

714 MHz subharmonic bunchers

Buncher section

Accelerator section : ~ 30 MeV

Beam diagnostics section for individual bunch

Accelerator section : ~ 80 MeV

* Total system similar to the ATF pre-injector

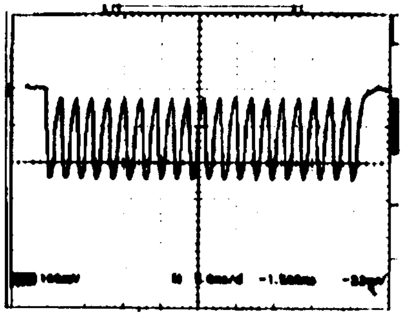
Laser Driven Photocathode Gun System

* Gun is under development

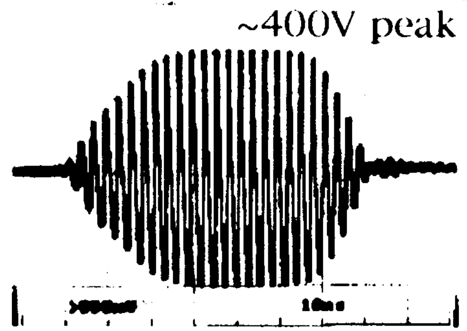
* Total system in near future

80 MeV Pre-Injector Linac & 1.54 GeV ATF Linac

Multi-bunch generation by Thermionic Gun

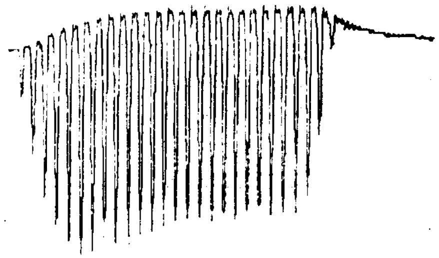


Pulse Train output
at ECL level

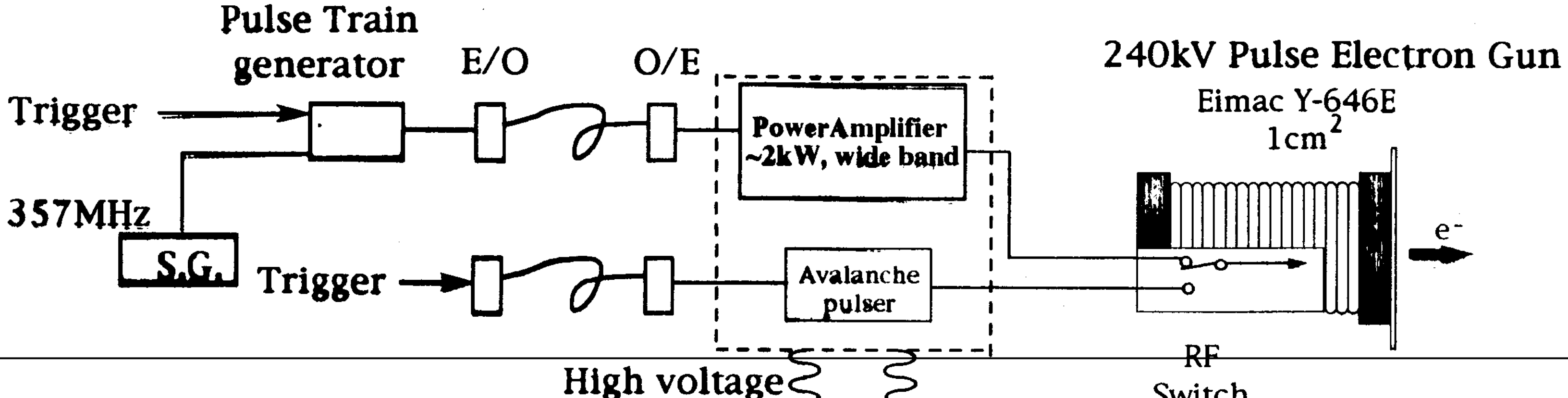


~400V peak

Power Amp Output



Beam $2x10^{10}$electrons
20 bunches



Pulse Train generator

E/O

O/E

240kV Pulse Electron Gun

Eimac Y-646E

$1cm^2$

Trigger

357MHz

S.G.

Trigger

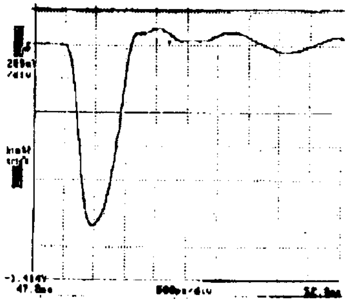
PowerAmplifier
~2kW, wide band

Avalanche pulser

e^-

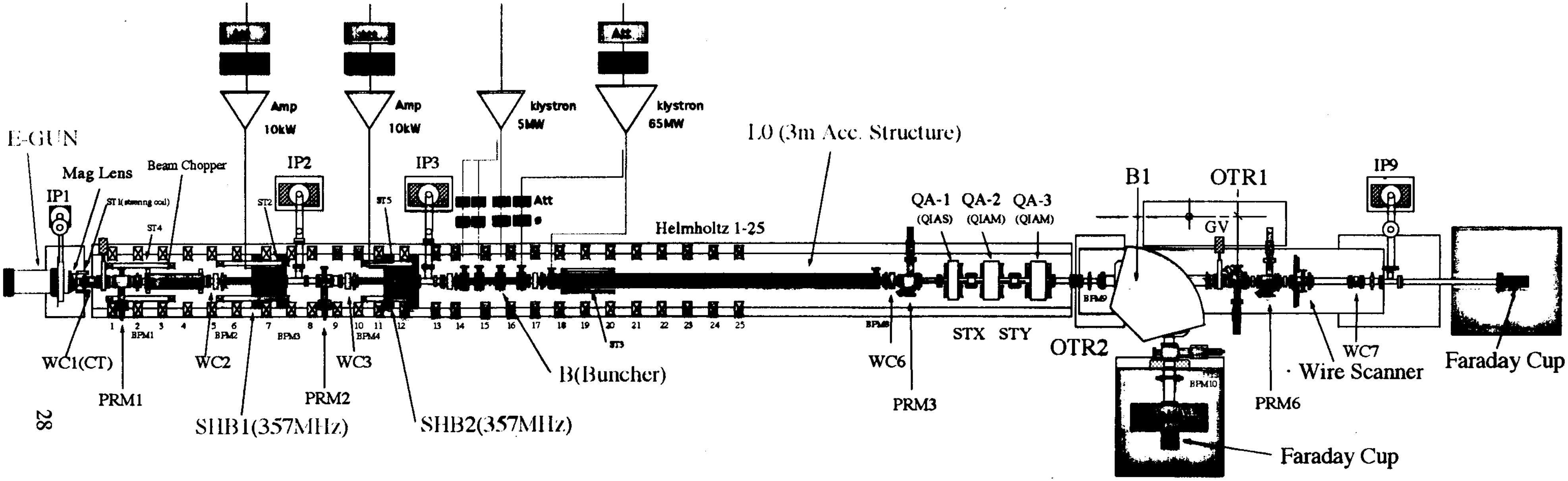
High voltage station

RF Switch

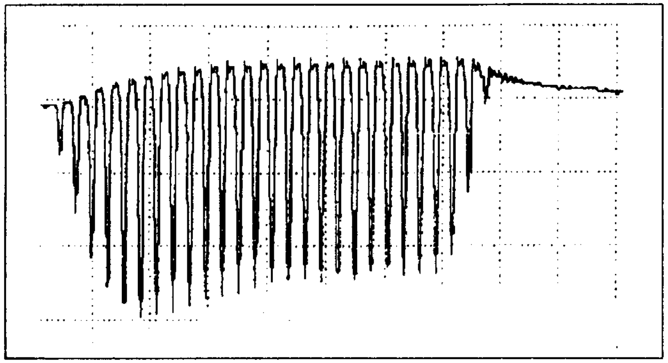


1ns single bunch beam

80 MeV Injector of ATF LINAC ('95 plan)



Multibunch from thermionic Gun



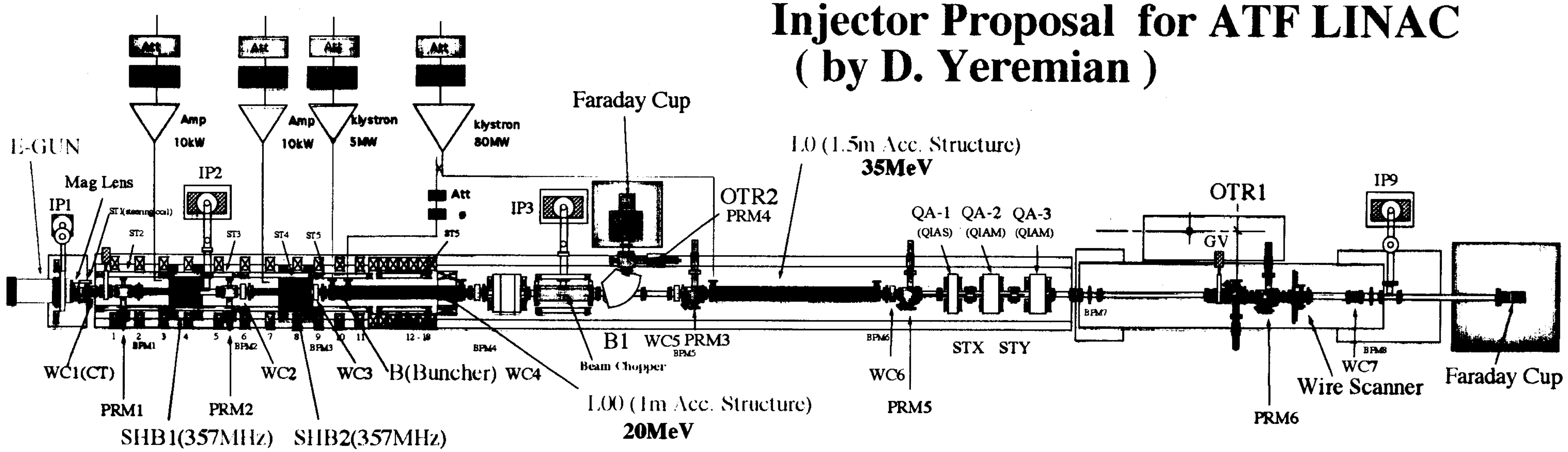
Specifications of Injector

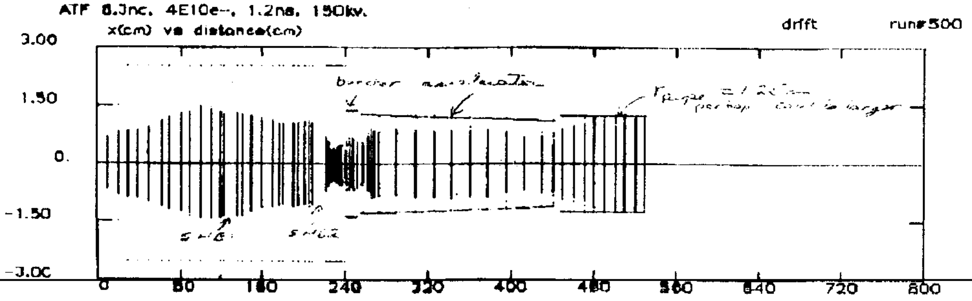
1. 2.8ns spacing / 20 Multi-bunch / 25Hz repetition
2. 2 e10 electrons/bunch
3. energy E=80MeV / ΔE/Erms ≤0.3%
4. bunch length σz ≤5ps
5. normalized rms emittance εx, εy ≤ 3 e-4 rad.m

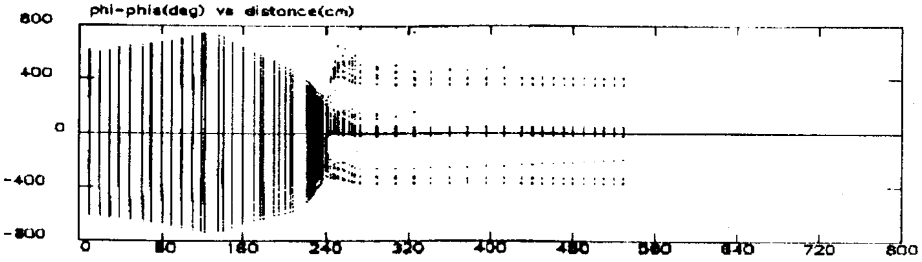
Injector Configuration

200keV Gun + 2 x 357MHz SHB + 4 x 2856MHz Buncher + 3m Acc.

Injector Proposal for ATF LINAC
(by D. Yeremian)







Specifications of Injector

1. 2.8ns spacing / 20 Multi-bunch / 25Hz repetition
2. 3 e10 electrons/bunch
3. energy E=20MeV
4. bunch length FWHM ≤15ps
5. Beam Chopper at 20MeV
6. Small analyzer magnet
7. small R/Q SHB and TW-buncher for multi-bunch beam loading

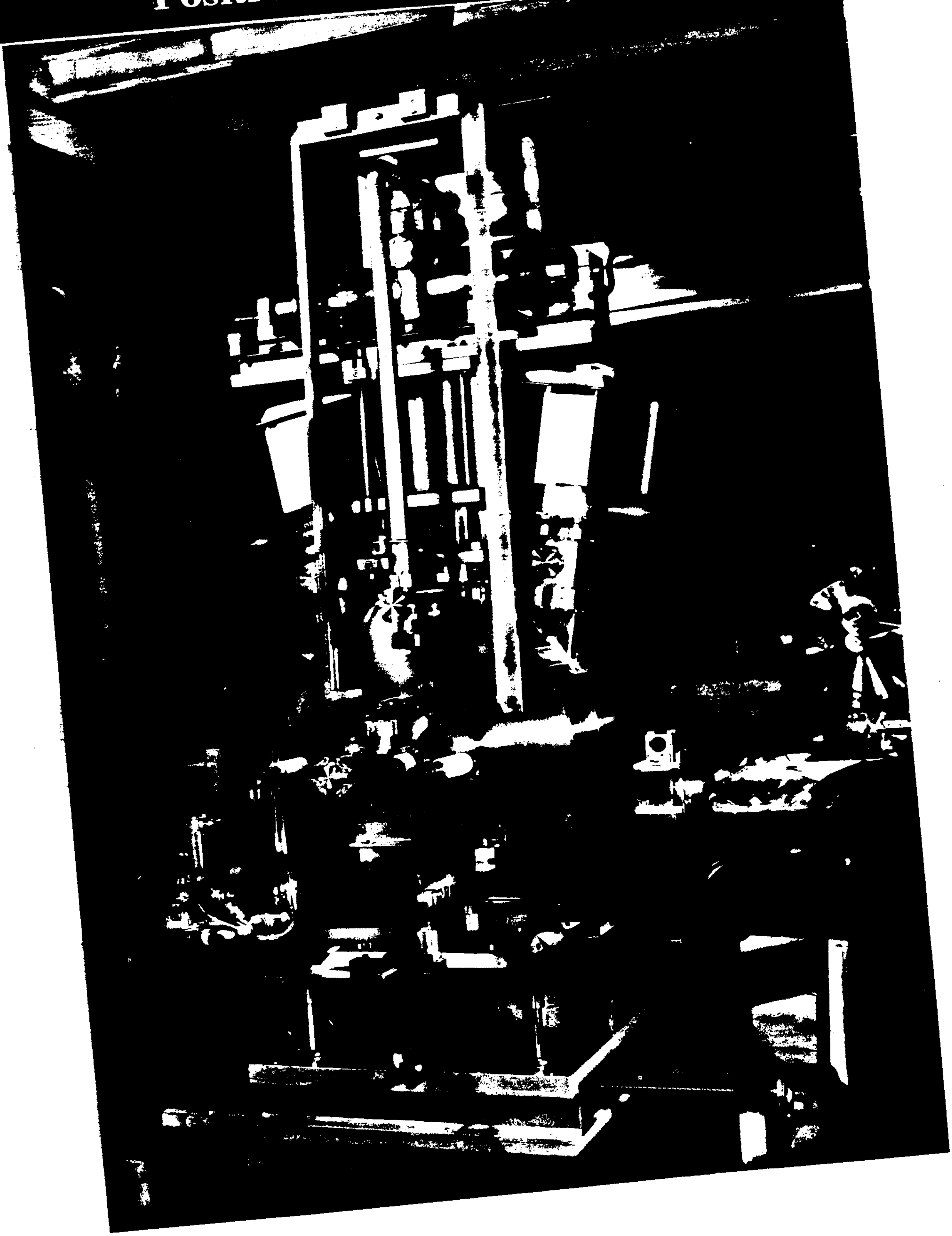
Injector Configuration

200keV Gun + 2 x 357MHz SHB
+ 2856MHz TWBuncher &1m Acc. complex

Basic Parameters of Positron Bunch

	JLC	ATF
Incident Electrons		
Beam energy :	10 GeV	1.54 GeV
rms beam radius :	1.2 mm	0.7 mm
Repetition rate :	150 Hz	1 Hz
Number of electrons / shot :	5.4×10^{11}	6.25×10^{9}
Beam power :	130 kW	0.04 kW
Target		
Material :	W-Re	W
Thickness (radiation length) :	6 (21 mm)	4 (14 mm)
Phase-space Transformer Section		
Length :	180 mm	120 mm
Initial magnetic field :	8.0 T	8.0 T
Accelerating Section		
Accelerating gradient :	30 MV/m	
Length :	1.5 m x 2	
Iris diameter at exit :	26 mm	
Solenoid field :	0.8 T	

Positron Target Test Stand



Positron Sources

Basically scale up present SLC design

Need to increase positron/pulse by ~10

Larger electron beam diameter at target

Increase beam power

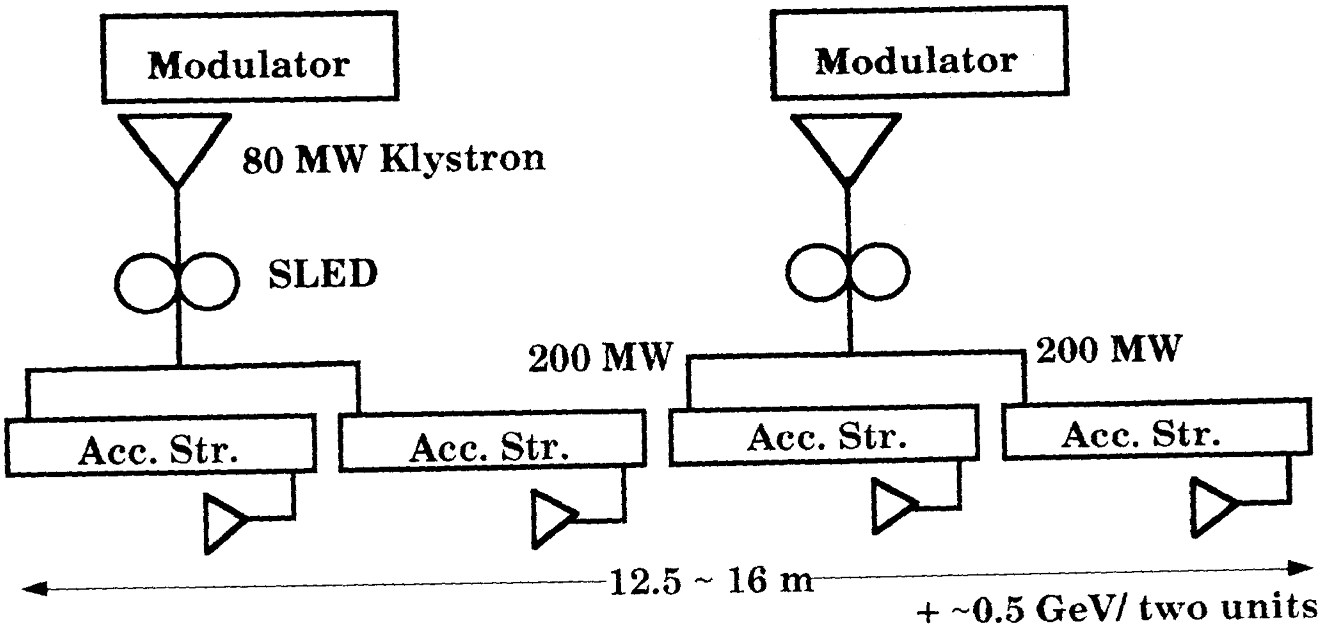
Keep energy density fixed

Larger acceptance for capture and acceleration

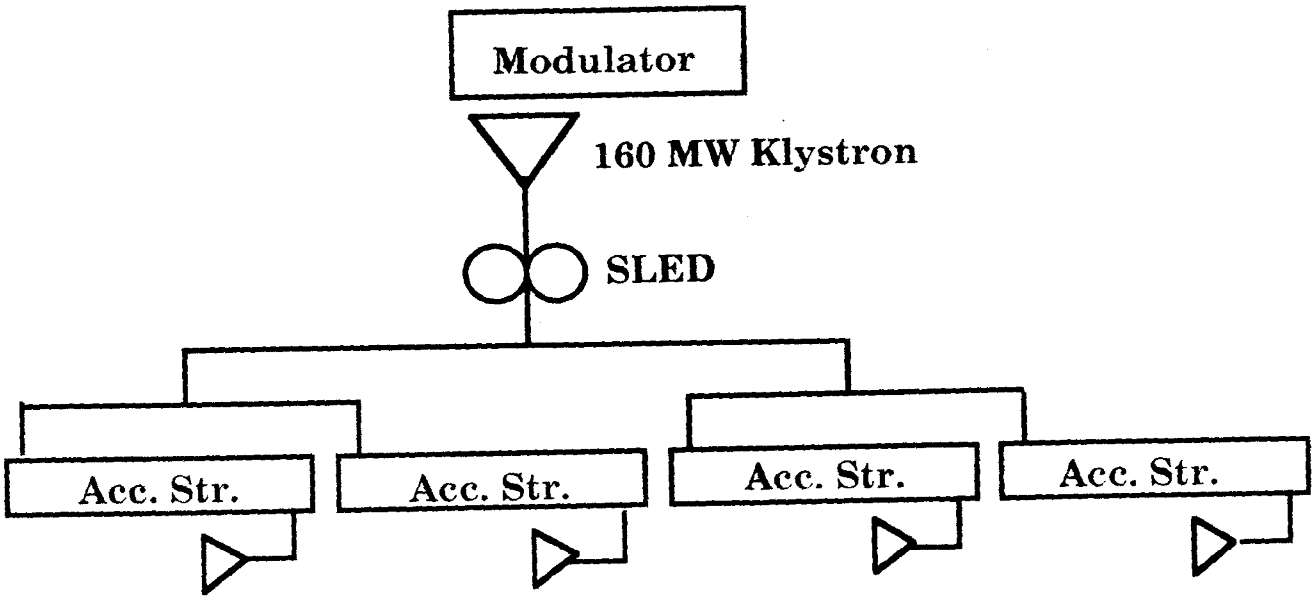
Pre-damping ring

10 GeV S-band Pre-Linear Accelerator

~40 MeV/m with beam loading
Multi-bunch Energy Compensation System
40 (or 20) RF units / Linac, L=~300 m / Linac

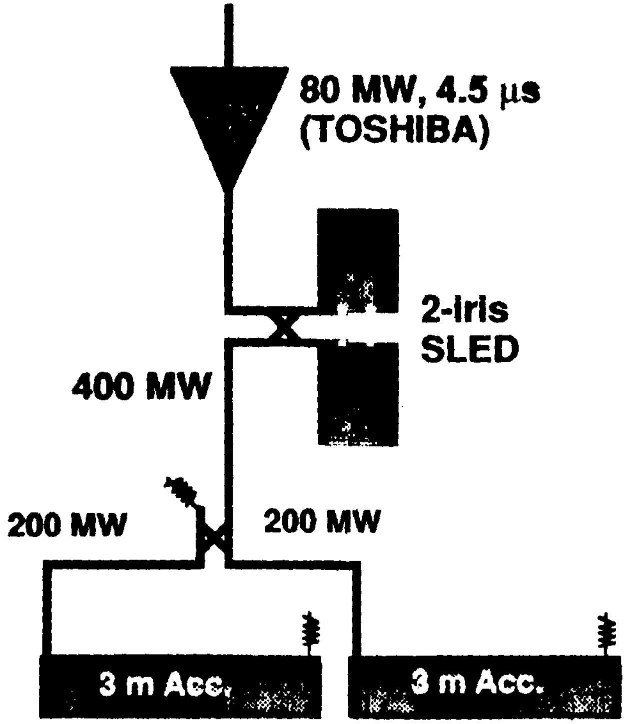

Modulator
80 MW Klystron
SLED
200 MW
Acc. Str.
Acc. Str.
Modulator
200 MW
Acc. Str.
Acc. Str.
12.5 ~ 16 m

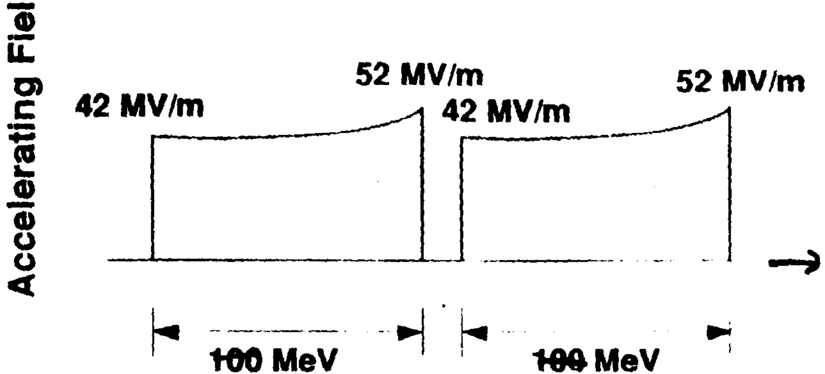
+ ~0.5 GeV/ two units


Modulator
160 MW Klystron
SLED
Acc. Str.
Acc. Str.
Acc. Str.
Acc. Str.
12.5 ~ 16 m

+ ~0.5 GeV/ unit

High Power Operation of the ATF 1.54 GeV Linac Unit

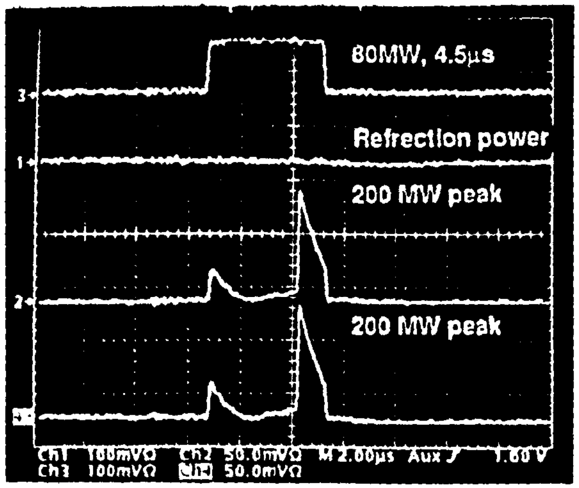




Energy Gain with Beam Loading

→ 240MeV

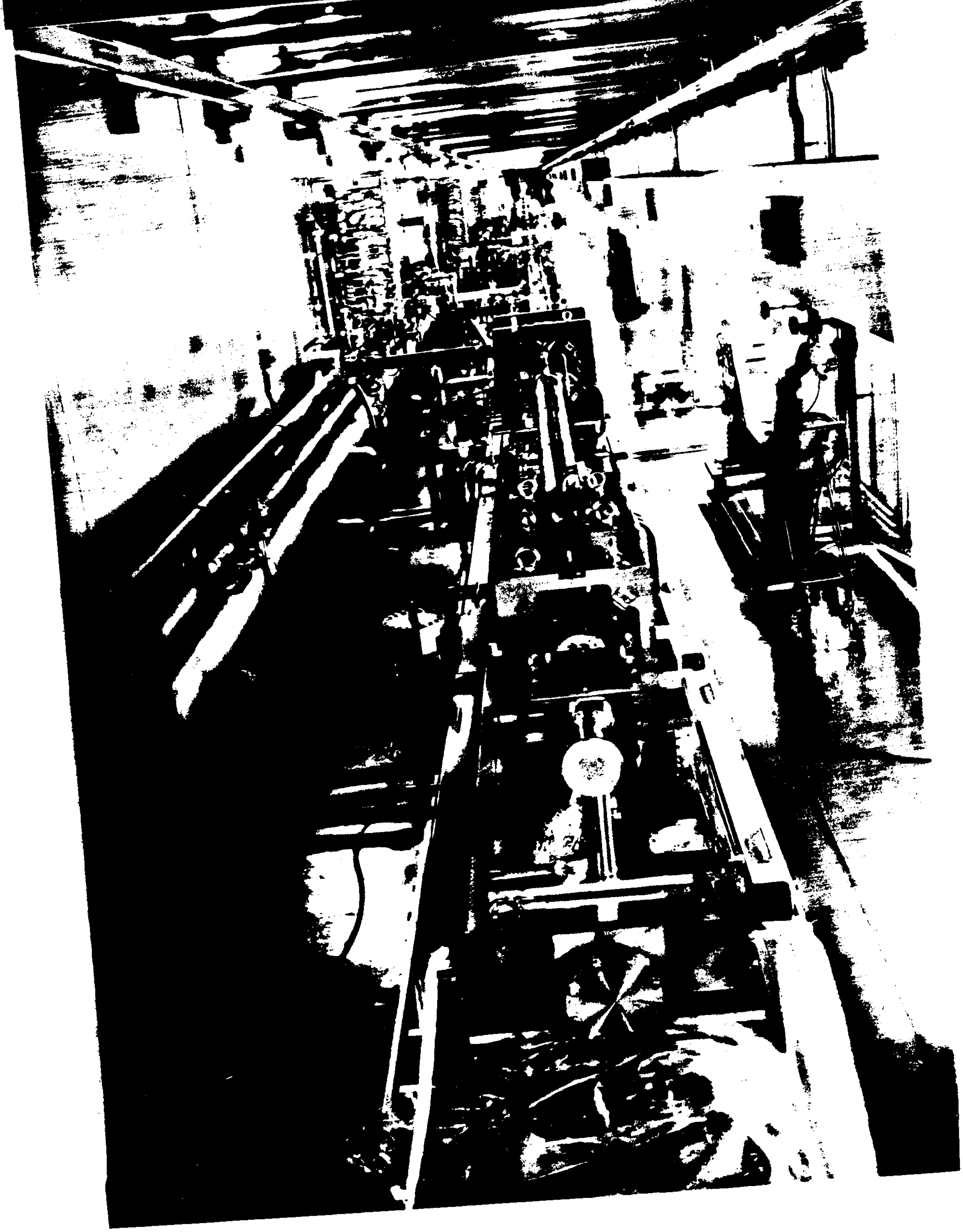
Waveforms of RF Power



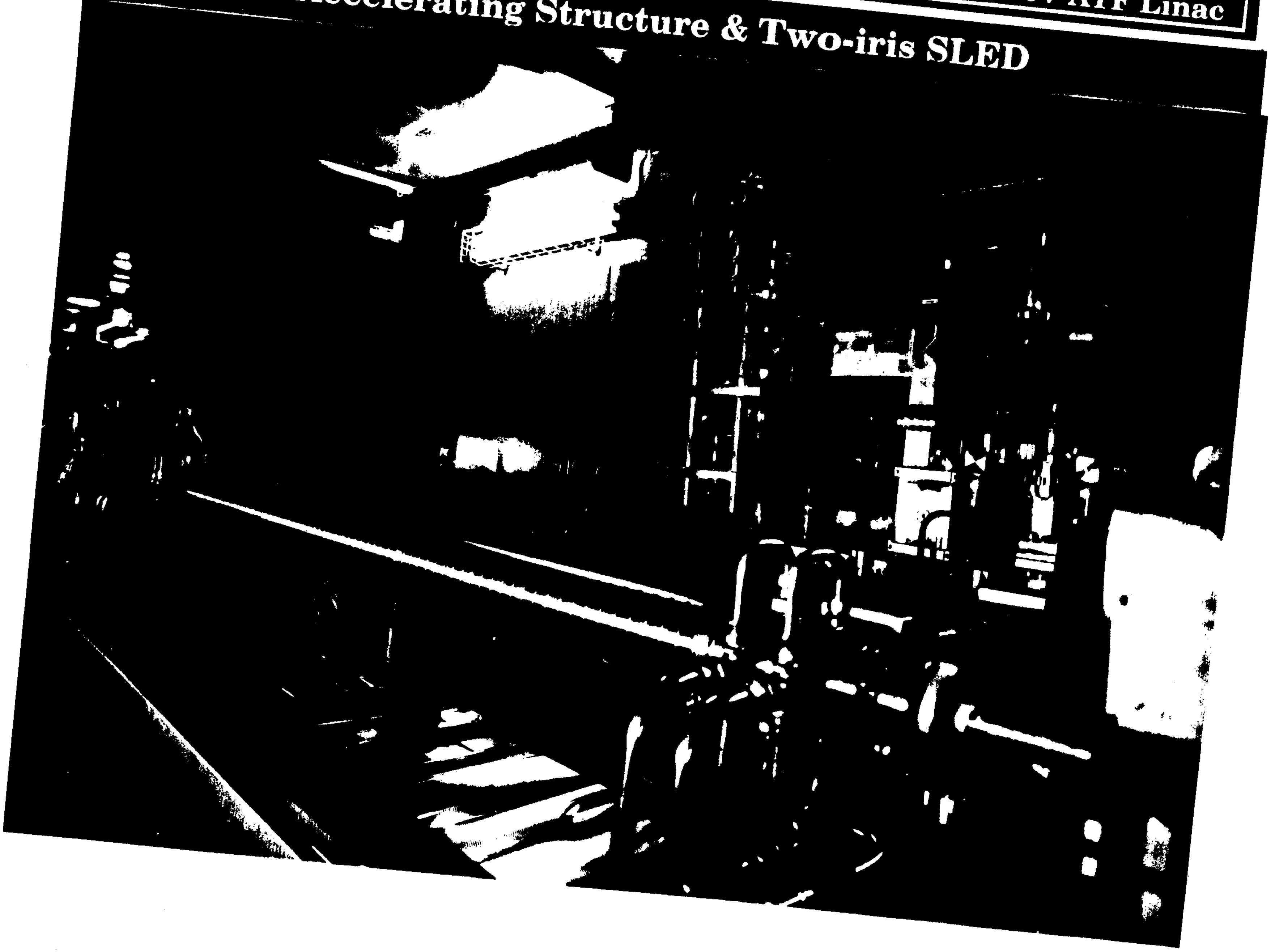
1st : Klystron output power, 80MW, 4.5µs
2nd : Refrection power from SLED+Acc.x2
3rd : Input power for left Acc., 200MW peak, 1µs
4th : Input power for right Acc., 200MW peak, 1µs

KEK ATF group, FEB. 15 '94
(H. Matsumoto)

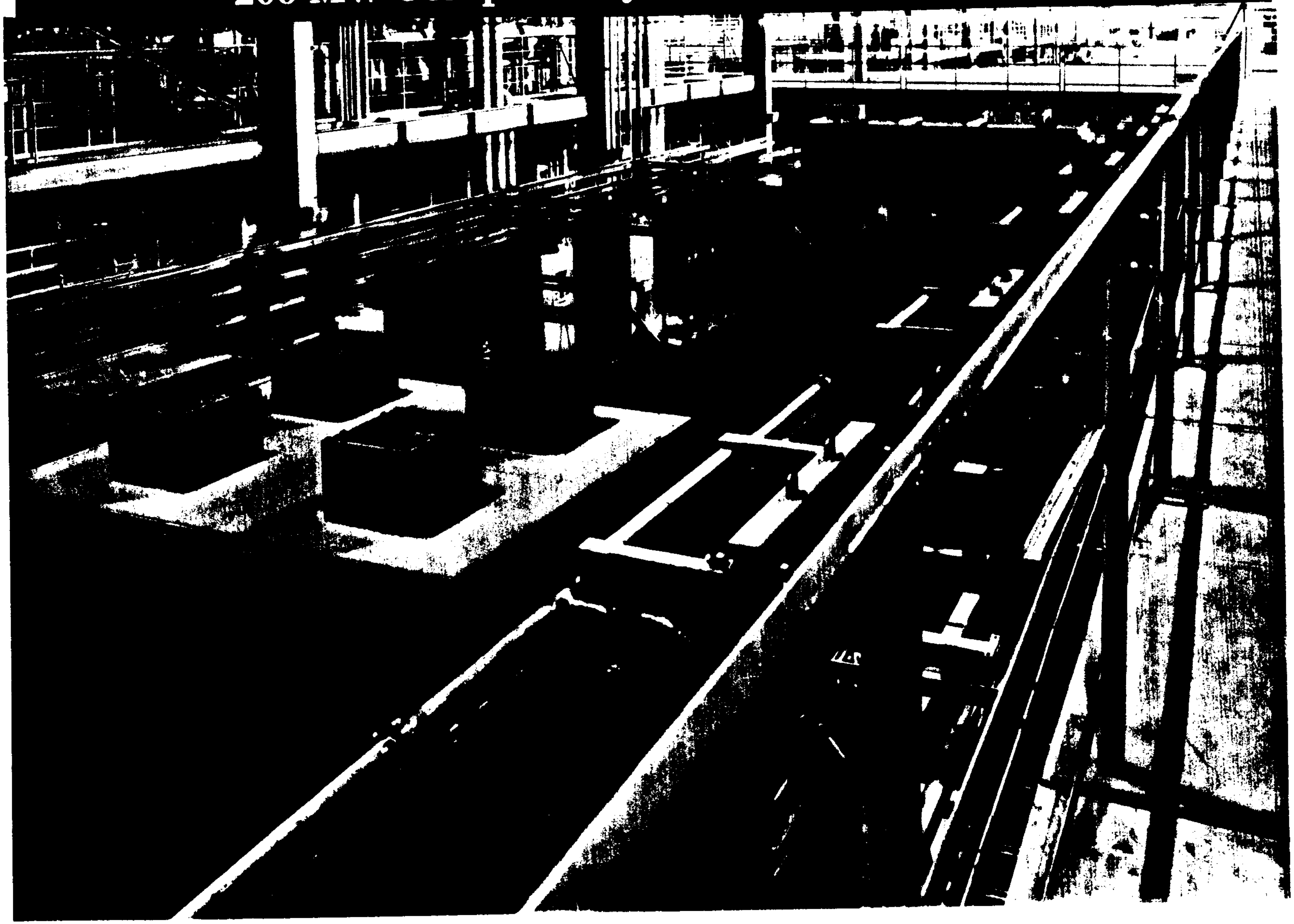
Regular Section of 1.54 GeV ATF Linac



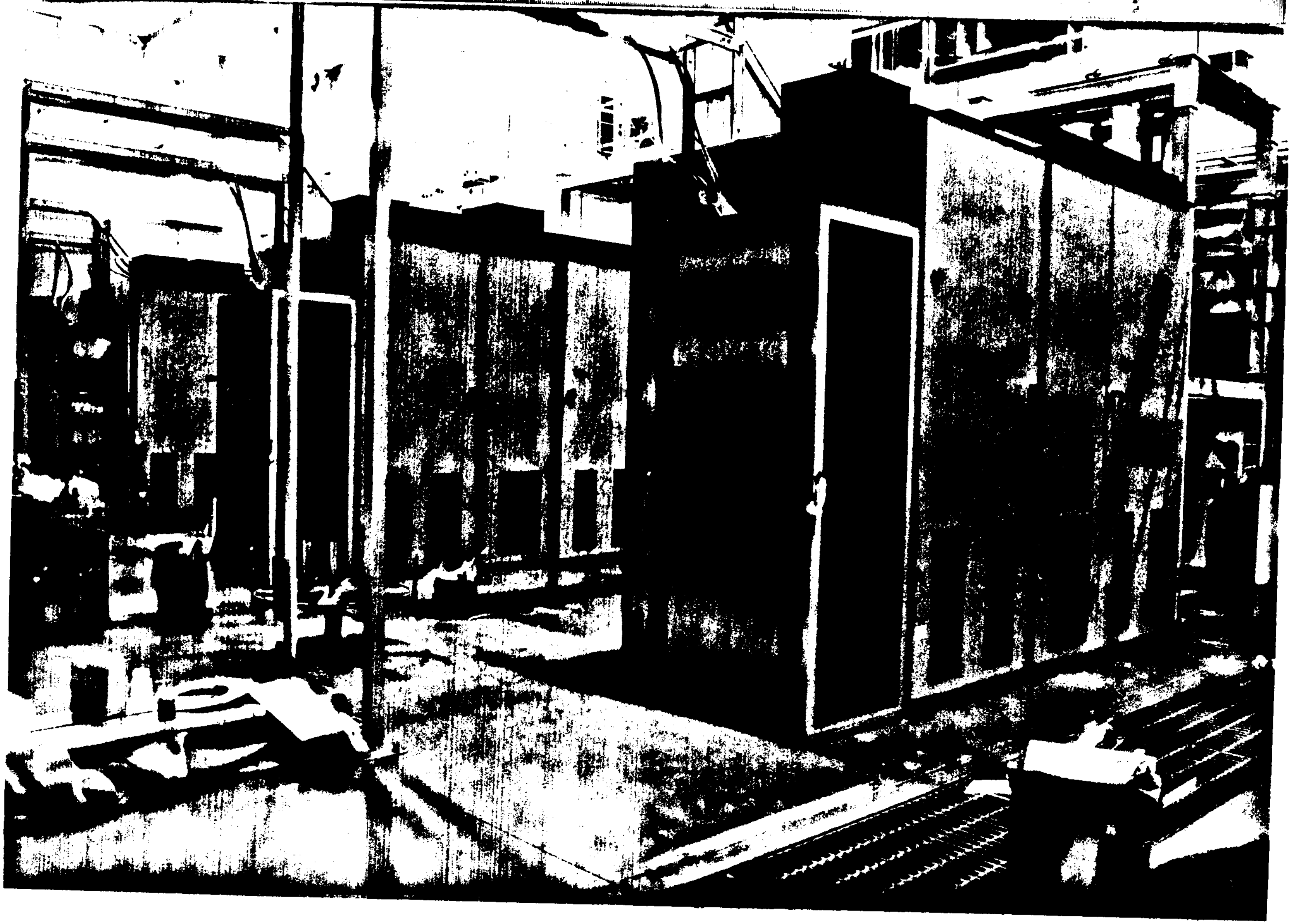
Accelerating Structure & Two-iris SLED



200 MW Compact Klystron Modulators

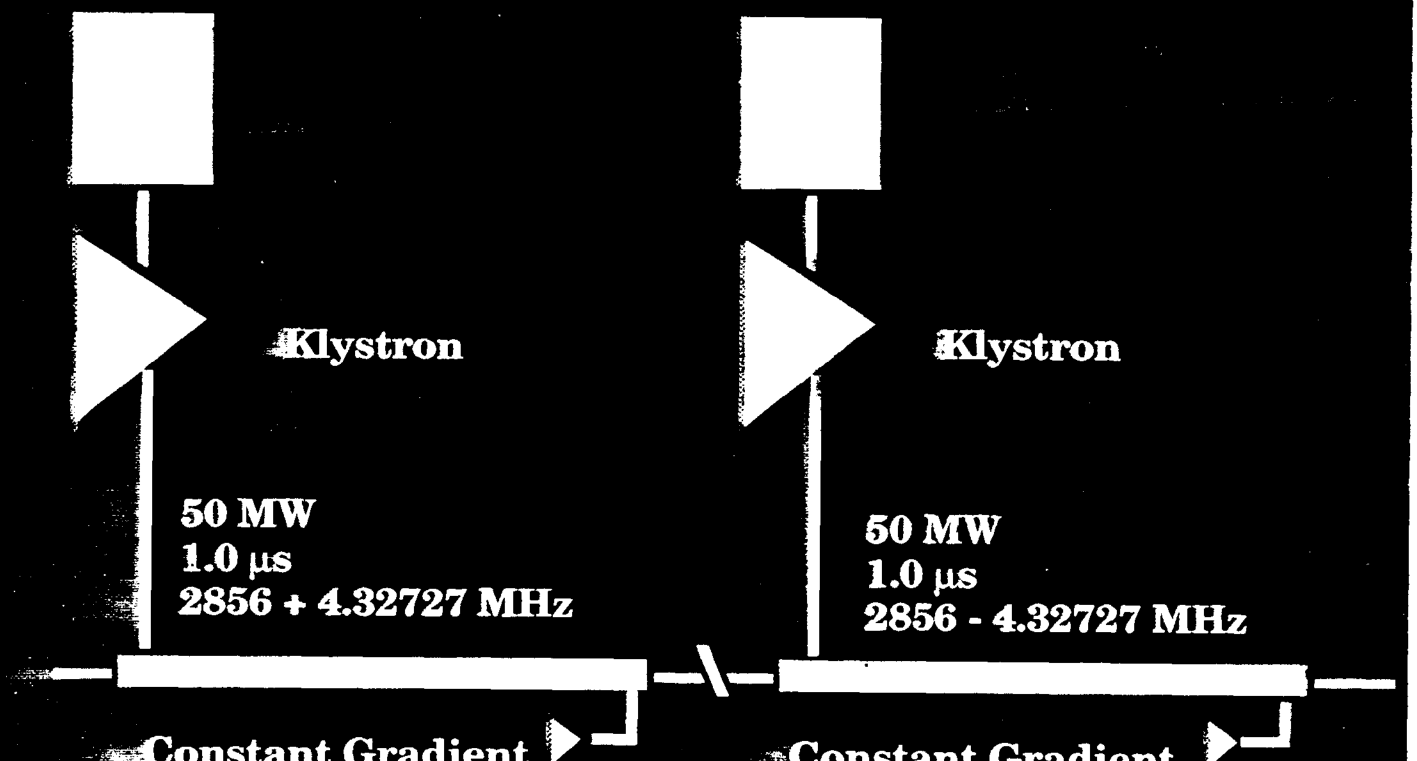


200 MW Compact Klystron Modulators



ATF (KEK) JLC Accelerator Test Facility

Energy Compensation System of 1.54 GeV ATF Linac



Klystron Modurator

Klystron

50 MW
1.0 μs
2856 + 4.32727 MHz

Constant Gradient
Accelerating Structure
designed at
2856 + 4.32727 MHz

Klystron Modurator

Klystron

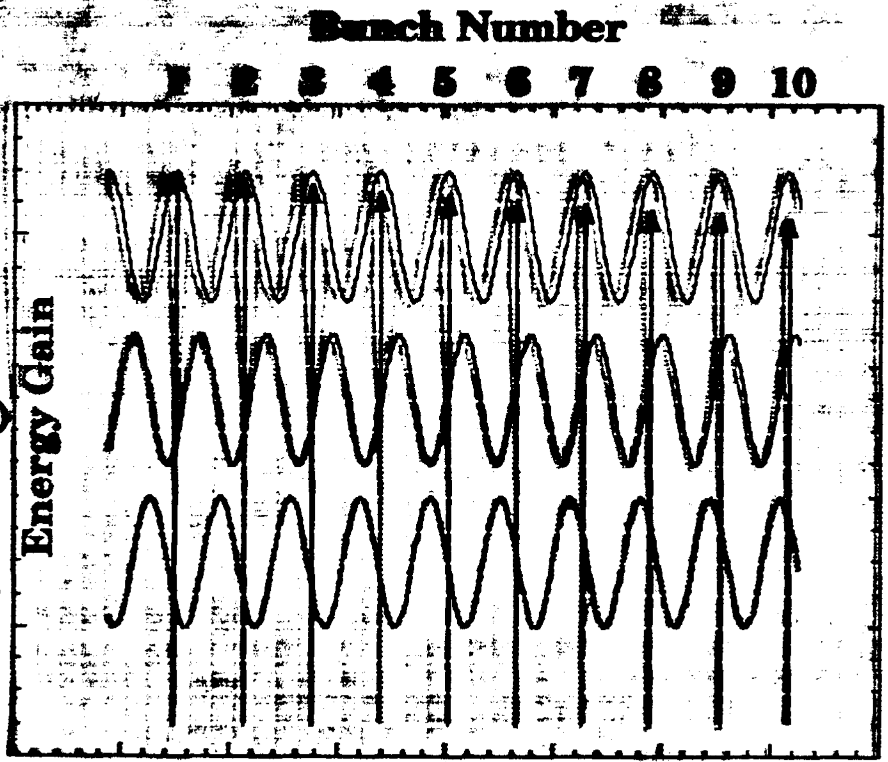
50 MW
1.0 μs
2856 - 4.32727 MHz

Constant Gradient
Accelerating Structure
designed at
2856 - 4.32727 MHz

Constant Gradient Accelerating Structure

Ls = 3 m
Pin-max = 50 MW
Eg-max = 26 MeV / m
Ecomp-max = 80 MeV/unit

Principle of Energy Compensation System



$f = f_0$
(2,856 MHz)

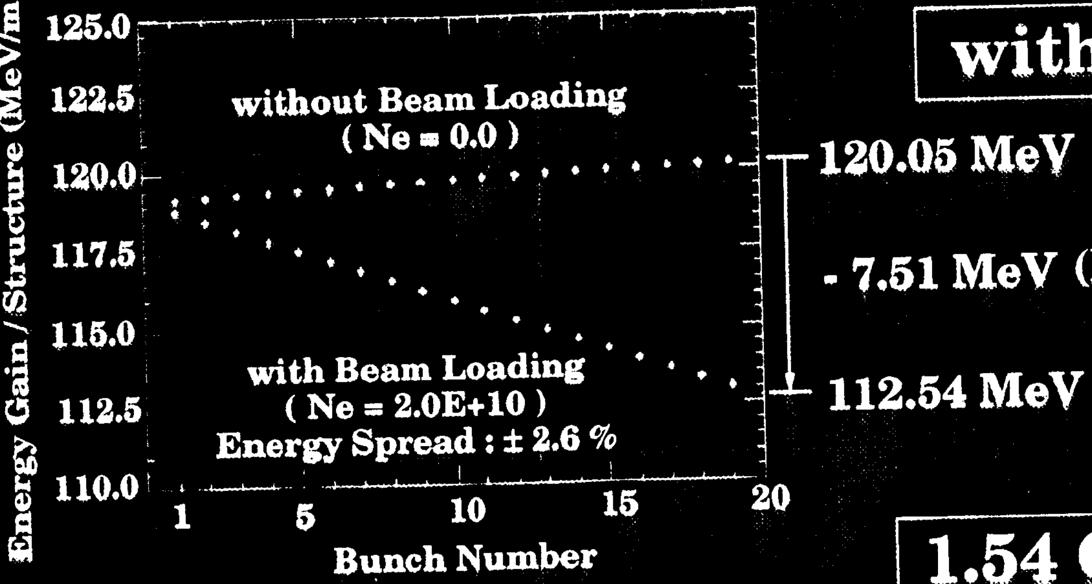
$f = f_0 + \Delta f$
(2,856 + 4.32727 MHz)

$f = f_0 - \Delta f$
(2,856 - 4.32727 MHz)

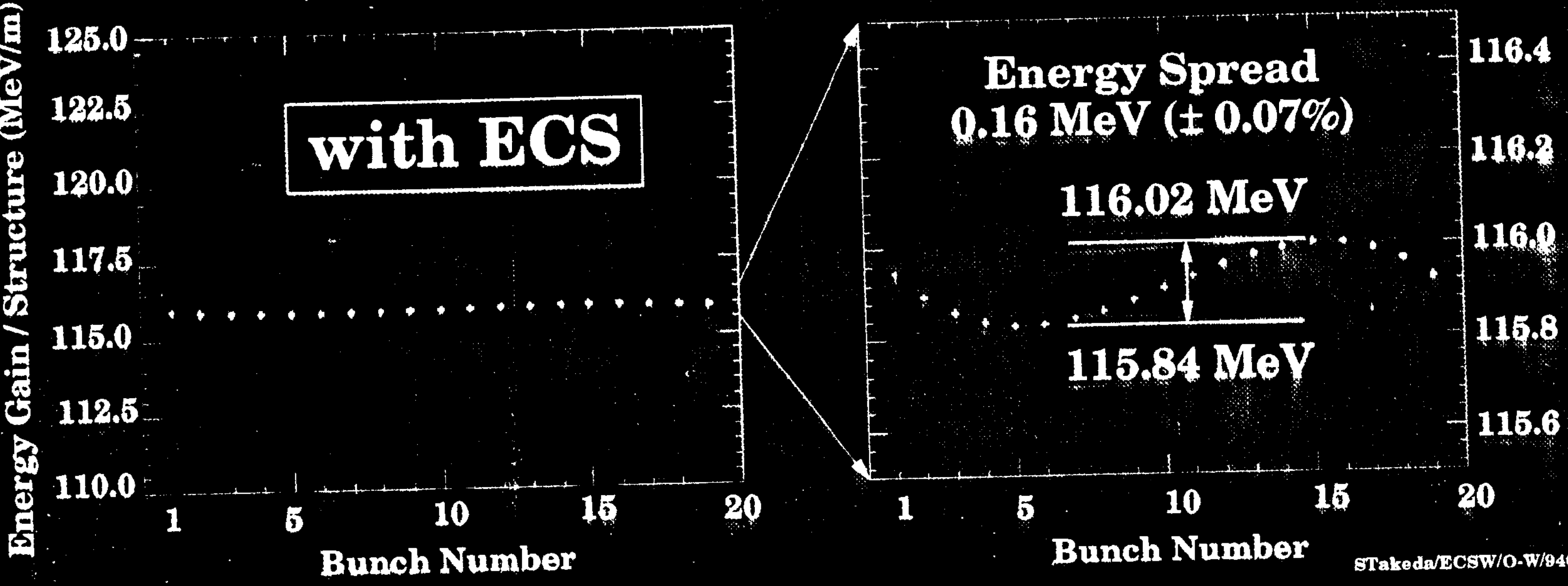
STakeda/EnergyCompSys/940711

Energy Spectrum of Multi-bunch with and without ECS

without ECS



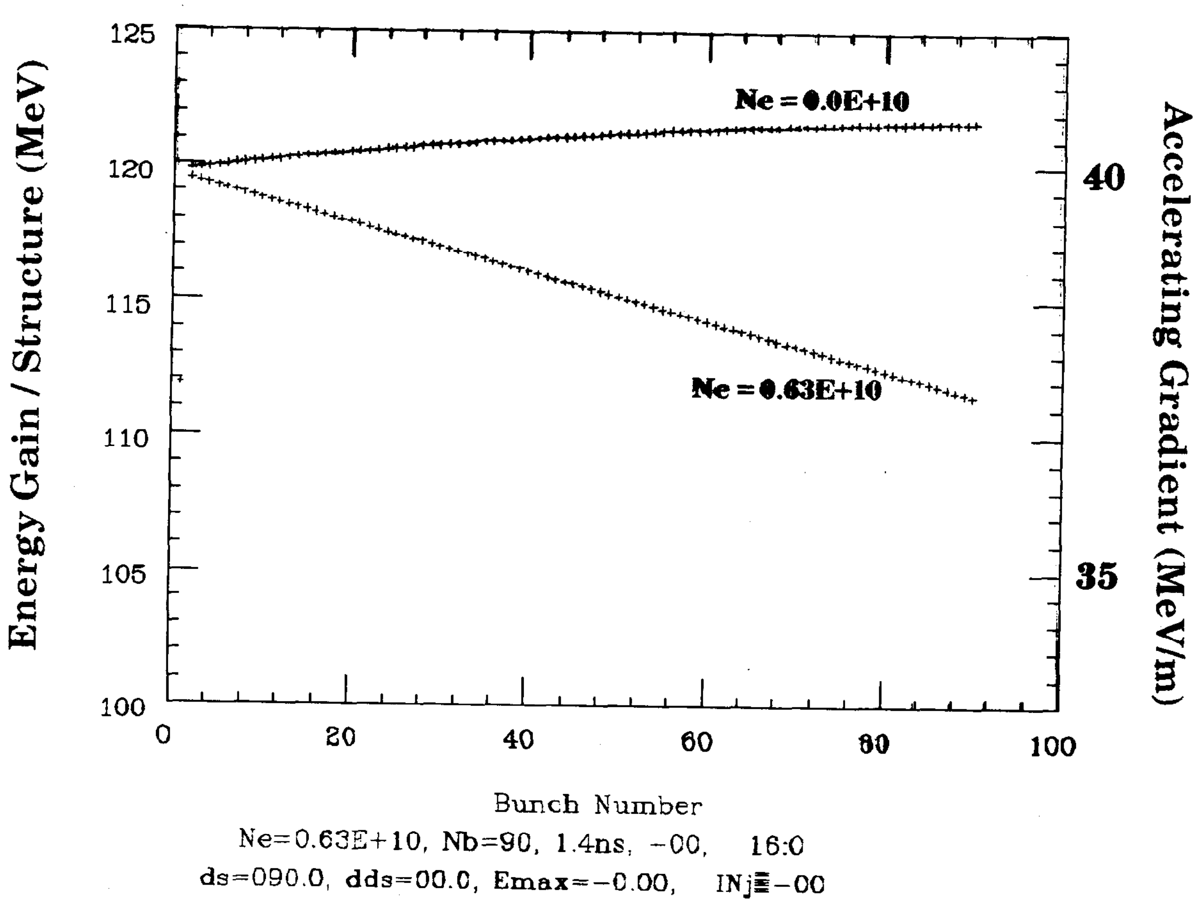
1.54 GeV± 1.1 MeV



STakeda/ECSW/O-W/940715

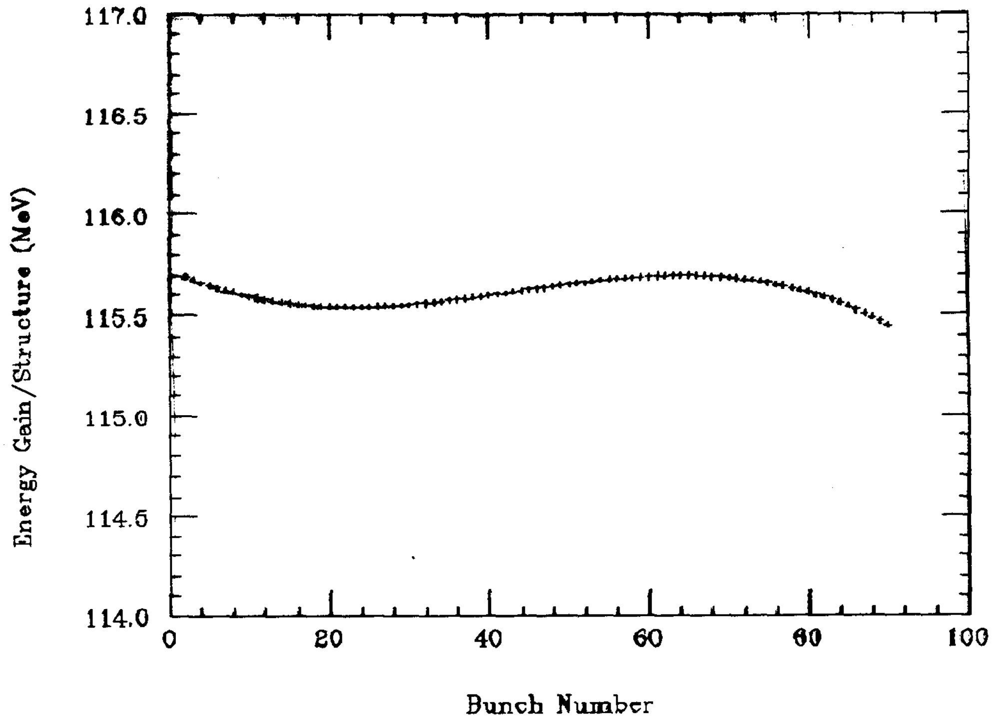
Beam Loading in an S-band Pre-Linac Structure

without Energy Compensation System

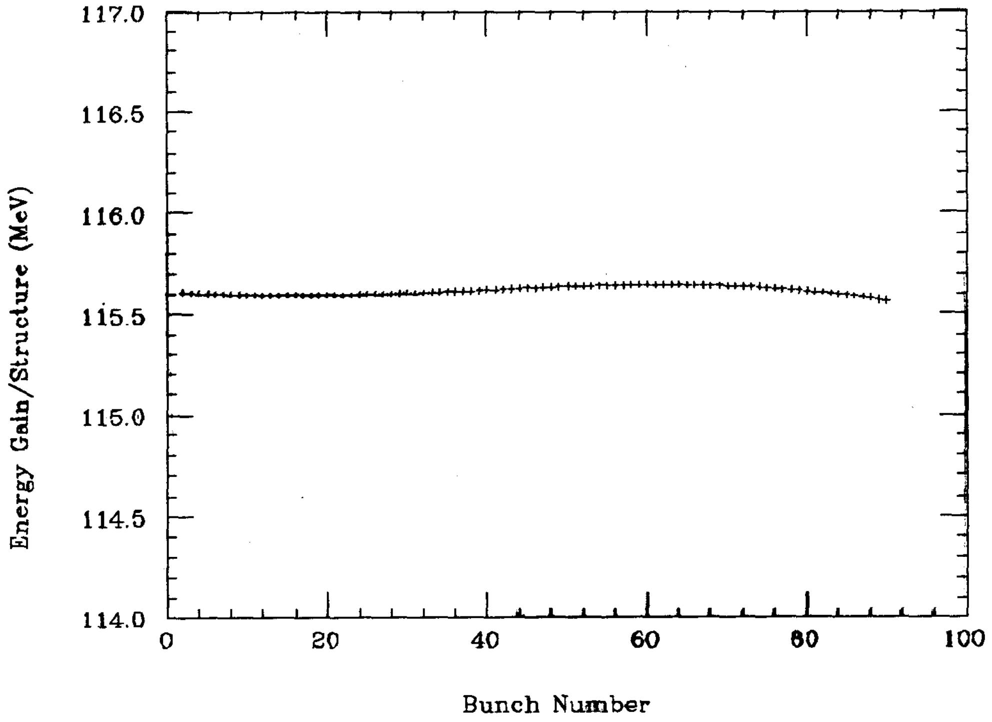


STakeda/Beam941202

Energy Distribution of 90 Multi-bunch After ECS



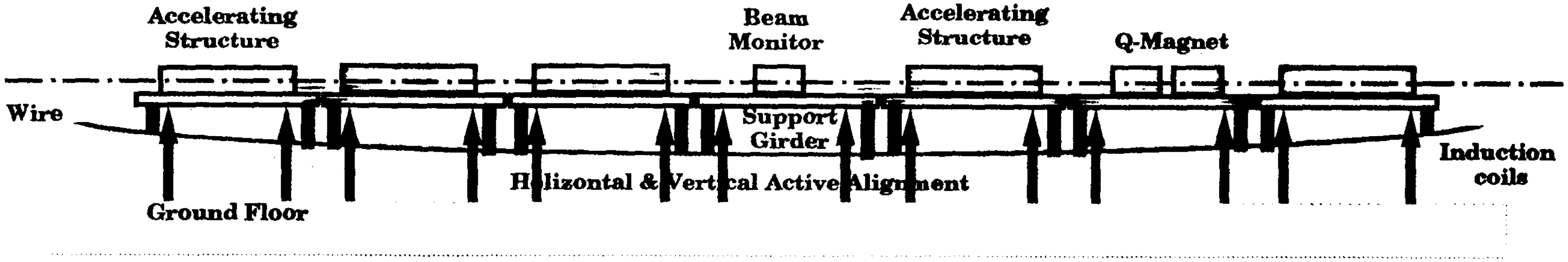
Ne=0.63E+10, Nb=90, 1.4ns, −00, 16:0
ds=090.0, Emax=−5.7 MV, Inj=−120, df=1.923232 MHz



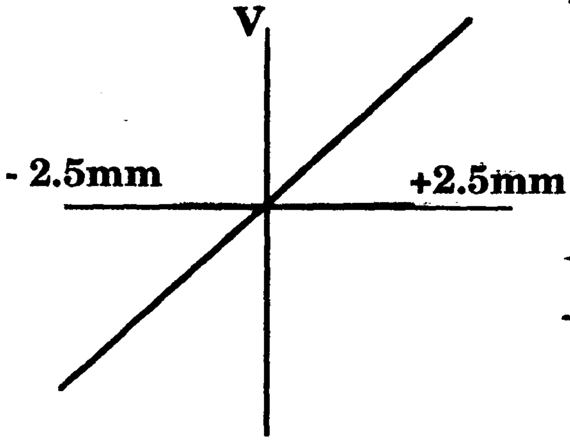
Ne=0.63E+10, Nb=90, 1.4ns, −00, 16:0
ds=090.0, Emax=−10.9 MV, Inj=−120, df=0.961616 MHz

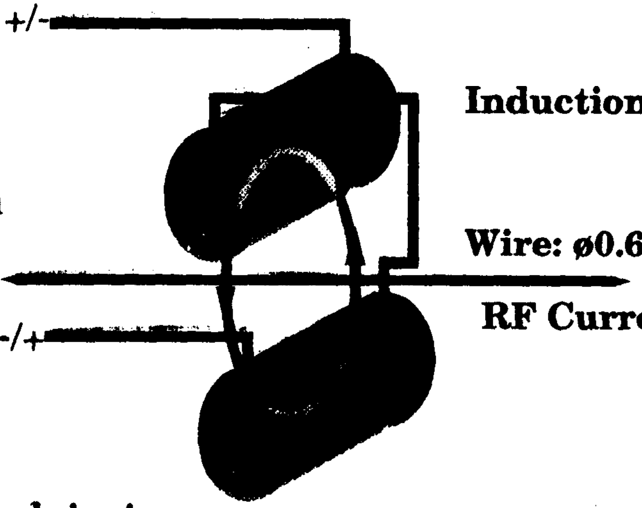
Active Alignment System

Total Length of Wire: 91 m
Total Number of Active Girder
Acc. Structure Girder: 13
Q-Magnet Girder: 13



Active Alignment:
- 4(6) Vertical Slide Jack / Stage
- 2 Horizontal Jack / Stage
- by Pulse Motor Drive





Induction Differential Coils

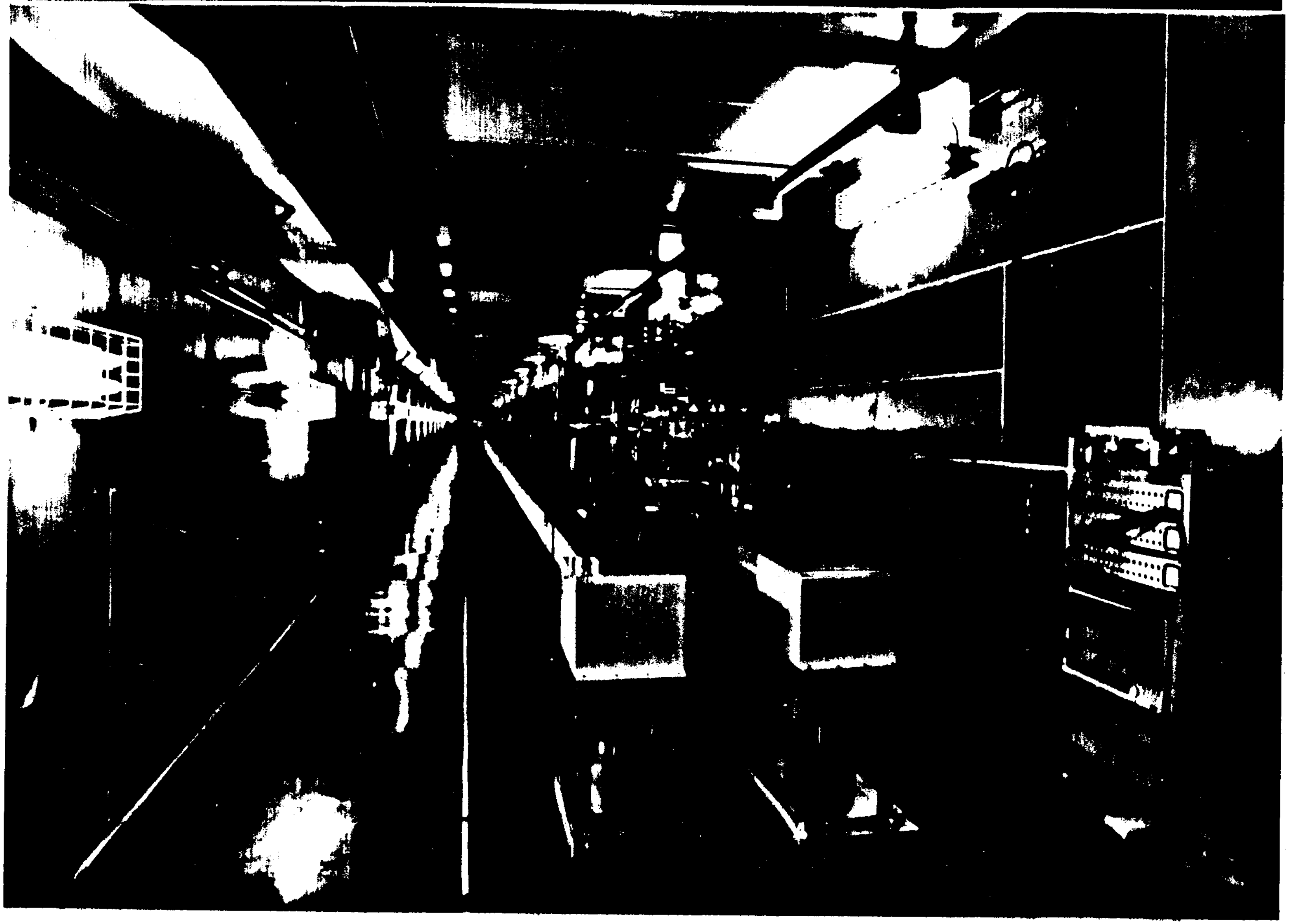
Wire: ø0.6 mm SUS

RF Current : 60 kHz, 100 mA

Synchronous Detection by Lock-in Amp
Sensing Range: ± 2.5 mm
Resolution: < 2.5 μm
Precision: 40 μm

STakeda/ActiveAlignSys/940708

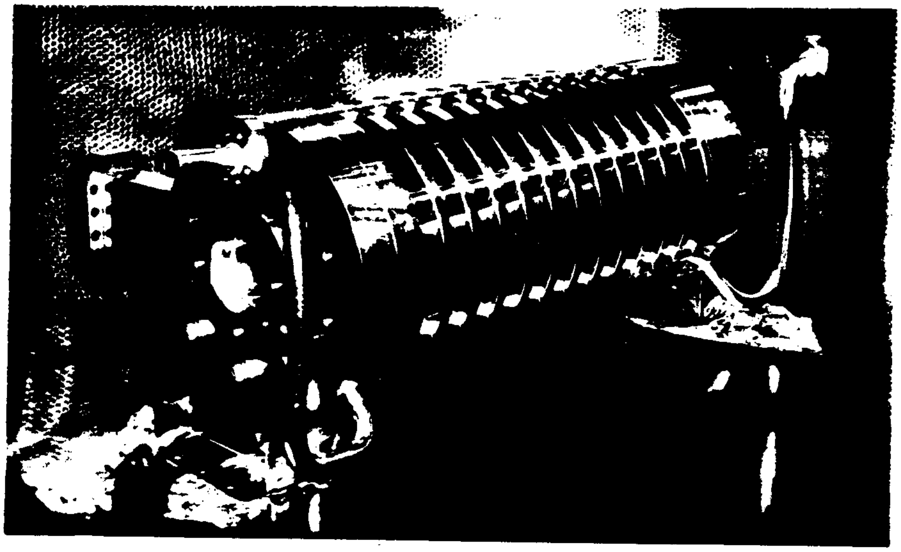
Wire Alignment System for 1.54 GeV ATF Linac



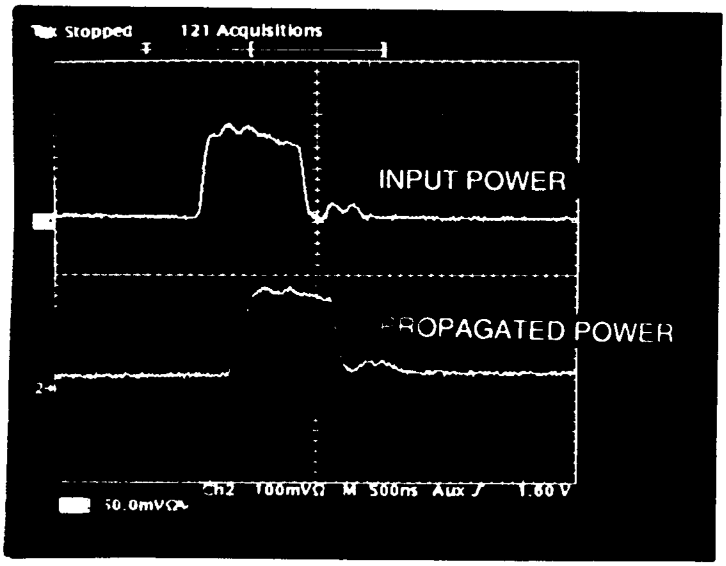
Shintake Choke Mode Cavity is Under Testing at ATF

July 1 '94

The first hot model of the choke mode cavity is under testing at ATF in order to confirm capability of high accelerating gradient for the future linear collider. RF processing has been started since June 25. An average accelerating gradient up to 26MV/m has already been achieved with an integrated rf processing time of 50 hours without any serious problems. Present input rf-power is 33MW and the pulse width 1 micro-sec at S-band. The structure will be processed up to 100MW to generate the gradient of 45MV/m on average. World-wide first trial of the beam acceleration will be started end of this month at ATF.



Shintake Choke Mode Cavity



RF wave form

JLC-ATF (H. Matsumoto and H. Hayano)

XLC SOURCES

GUNS

DC Polarized Gun for Electrons

DC Thermionic Gun for Beam to Drive Positron Converter

TWO S-BAND INJECTORS: (very similar, one with polarized gun, and one with thermionic gun)

714 MHz Subharmonic bunchers

S-band Traveling Wave Prebuncher and Buncher

S-band Capture Section

FOUR S-BAND LINACS

One 2 GeV Linac from Electron Injector to Damping Ring

One 3 GeV Linac to Drive Positron Converter

Two 8 GeV Linacs from each Damping Ring to each Second Compressor

POSITRON SOURCE: A Converter target, Flux Concentrator, a DC Solenoid, an L-band Capture Section, and a Magnetic Chicane for Eliminating Electrons and Collimating the Positrons

ONE 2 GeV L-BAND (1428 MHz) ACCELERATOR: Positron Source to Damping Ring. Focussed with Close-spaced Quadrupoles. mounted around the accelerator sections.

DESIGN ISSUES

- All the Major Design Problems for the Sources are Related to the Long Bunch Train.

- SLC Has Demonstrated all the Technologies for the XLC Injectors for Single Bunch (or a few bunches).

POLARIZED ELECTRON GUN: the Average Current Limit during the 126 ns Pulse and Pulse to Pulse Intensity Jitter are the Dominant Problems. Because of Beam Loading Intensity Jitter Produces Energy Jitter at the end of the Collider.

THE 2 XLC INJECTORS: Beam Loading in the Subharmonic Bunchers and the S-band Prebuncher and Buncher is the Dominant Problem.

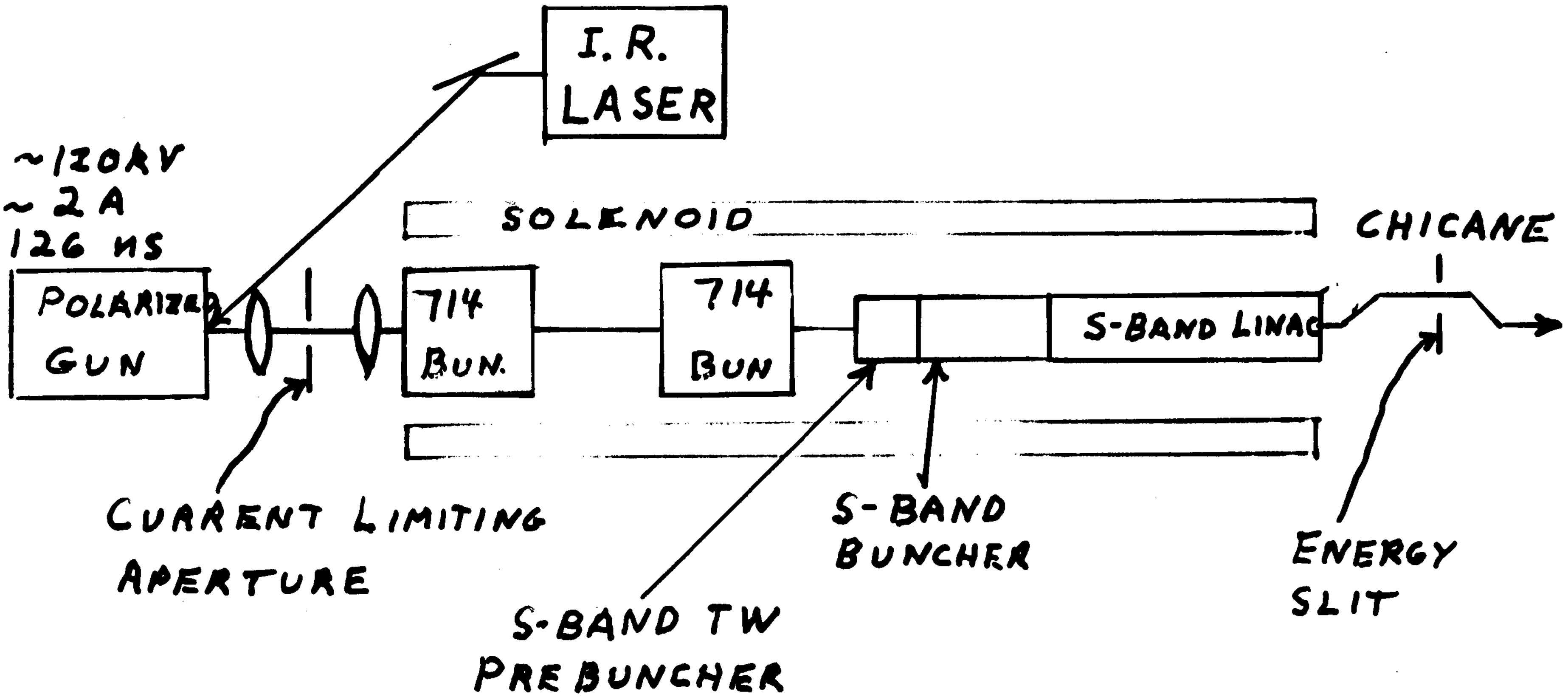
POSITRON SOURCE: Average power and energy per pulse hitting the target are very significant (but solvable) problems.

ELECTRON SOURCE PARAMETERS

NORMALIZED EMITTANCE (RMS)	100 mm-mr
BUNCH LENGTH (FWHM)	15 ps
BUNCH FREQUENCY	714 MHz
BUNCHES PER PULSE	90
MACRO-PULSE INTENSITY JITTER (RMS,)	0.3% *
BUNCH TO BUNCH INTENSITY JITTER	1%
PULSE REPETITION RATE	180 Hz

* PRODUCES 0.07 % ENERGY JITTER
DUE TO BEAM LOADING $= \frac{1}{3} \times 0.2$ %
↑
SPEC. FOR $\sigma_{\Delta E}$

INJECTOR FOR XLC



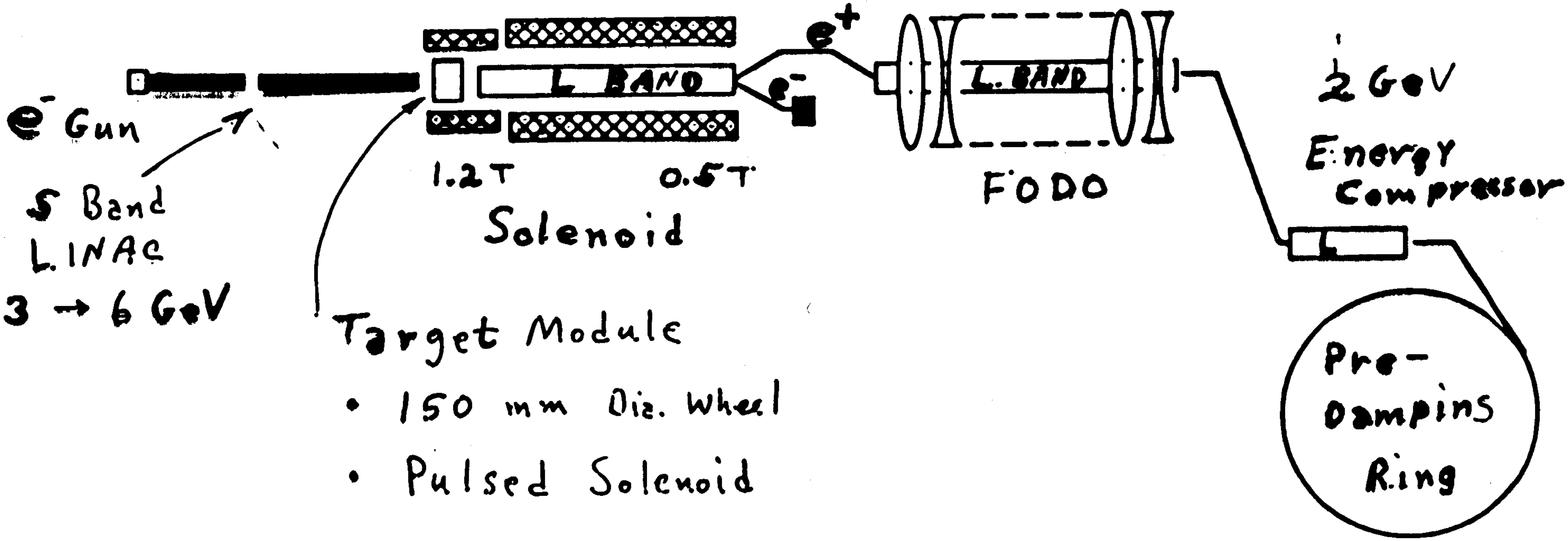
POLARIZED GUN SPECIFICATIONS

TYPE	PIERCE DIODE
VOLTAGE	120 kV
CURRENT	2 A
PULSE LENGTH	1 to 120 ns
CATHODE	STRAINED GaAs or SUPER LATTICE
POLARIZATION	> 80%
MACRO-PULSE JITTER (RMS)	1%

POSITRON SOURCE PARAMETERS

NORMALIZED EDGE EMITTANCE	.06 r-m
BUNCH LENGTH FULL WIDTH	60 ps
ENERGY SPREAD FULL WIDTH	10%
NLC/SLC; NUMBER e+/MACRO-PULSE	12
NLC/SLC; NUMBER e+/sec	18

Draft
NLC Positron System



POSITRON CAPTURE SECTION

L-BAND BECAUSE:

- INCREASES VOLUME IN 6-D PHASE SPACE × 32

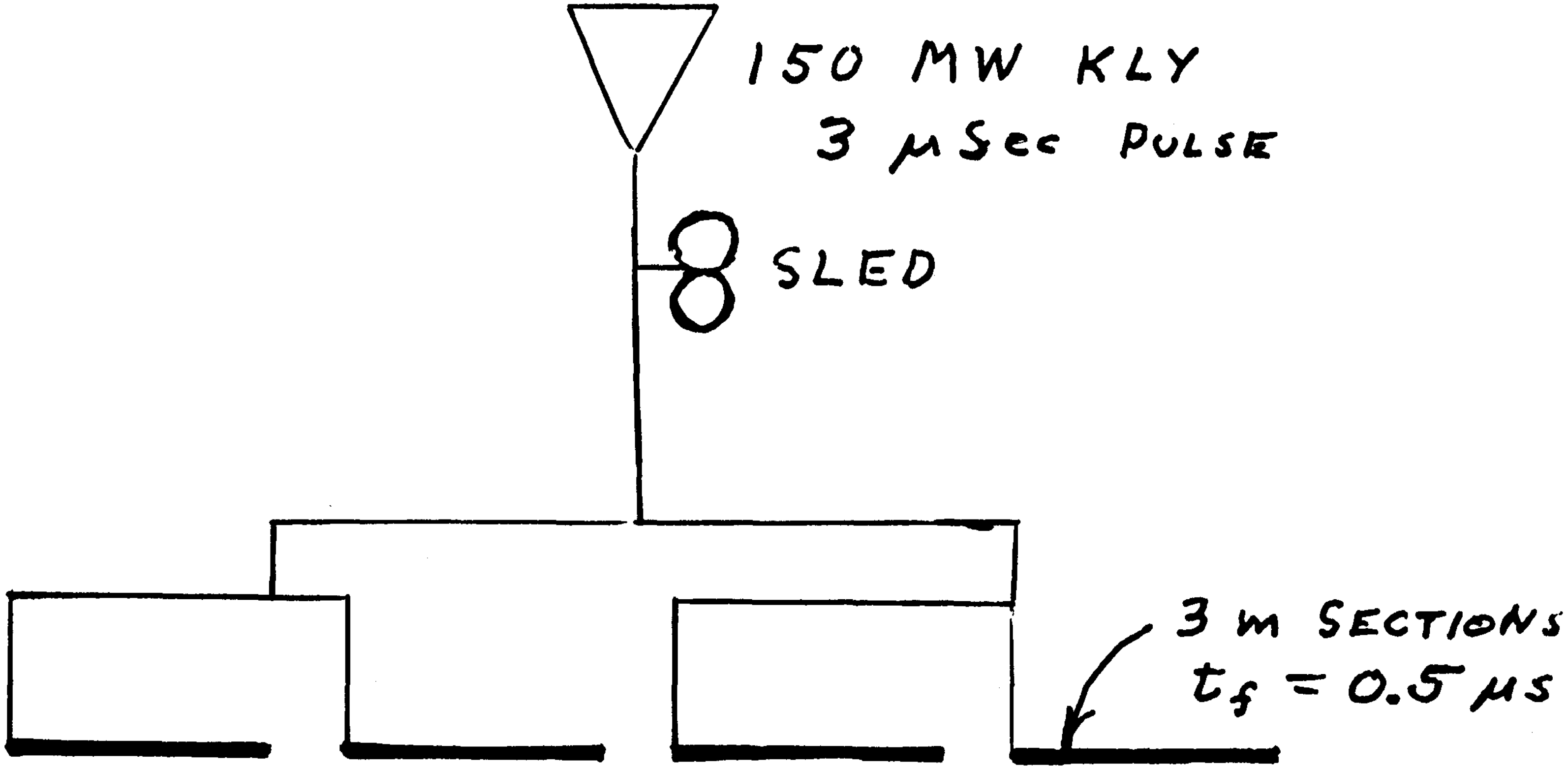
  ε_x : × 4

  ε_y : × 4

  Δz : × 2

USE ONE FACTOR OF ~4 FOR POWER: $\sigma_r = 1.6$ mm = 2 × SLC

S-BAND LINAC MODULE



ACCELERATES 1 AMP × 126 ns BEAM BY 260 MeV

(4 KLYSTRONS + ~50 m PER GeV)

Damping Rings / Compressors

Junji Urakawa (KEK), 1994.12.5 at SLAC

1. Damping Rings (DR) and Bunch Compressors (BC) Scheme for JLC

* Requirements to the Beam Sources

* DR Scheme

Long Wiggler Sections in a Zero-dispersion Region

Racetrack Shape to minimize the Space for the Dispersion Suppression and Matching

Combined Function FOBO Cell for the Arc

DR are designed, using the same components as those developed for the Accelerator Test Facility (ATF) at KEK.

* BC Scheme

Two-stage Scheme

Single-stage Scheme

Bunch-Compressor Test Facility

2. Technical R&D Status at ATF

* Alignment

Initial Alignment

On-line Monitoring

Reconfiguration

* Magnet

Machining and Constructing Accuracy for Magnetic Poles is less than 20μm.

* RF

The Cold Model of Damped Cavity showed enough results. A Hot Model of Damped Cavity was ordered.

* Vacuum Chamber

18 Vacuum Chambers with Two BPM for Arc Section were completed.

The resolution of the BPM is less than 5μm.

3. Summary

SLAC/KEK Collaboration
1994. December 5
Junji Urakawa, KEK

Requirements to the Beam Source for the JLC-1 at the damping ring

e^-/e^+	S-band	C-band	X-band	ATF
Bunch spacing [nsec]	5.6	2.8	1.4	2.8
Particles per bunch [10^{10}]	1.75	1.11	0.65	2.0
Bunches per train	55	72	90	20
Repetition rate [Hz]	50	150	150	25

Normalized emittance of

injected beam / with Pre-DR $1.0\times10^{-4}/2.7\times10^{-2}$ 3.0×10^{-4}

[radm] (r.m.s.-value)

Energy spread $\Delta P/P$ (Full Width 90%) <1%

Bunch Length ~~(Full Width 90%)~~ σ_z <10psec

Polarization 90%/non

Requirements for Energy Compensation in Linac

Intensity Jitter

Pulse to Pulse	±0.5%	for Precise Physics Experiment
Bunch to Bunch	±1.0%	

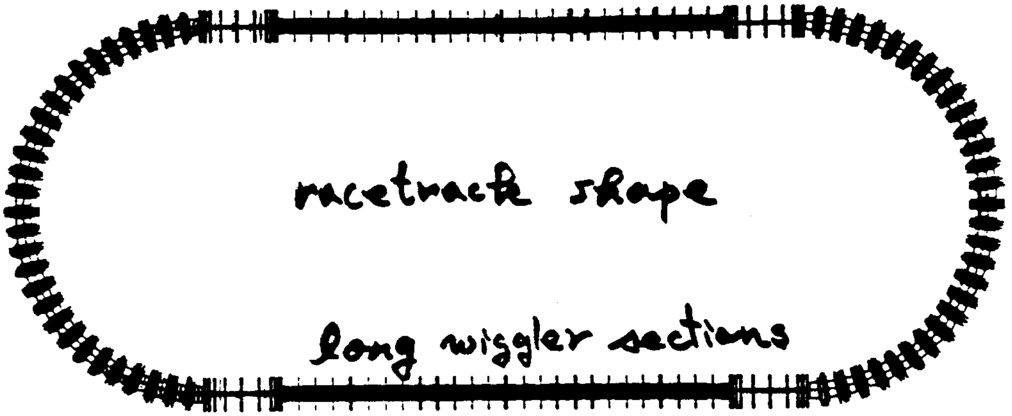
Requirements to the Damping Ring for the JLC-1

Emittance

$\gamma\varepsilon_x < 3\times10^{-6}$
$\gamma\varepsilon_y < 3\times10^{-8}$
$\sigma_z < 5\text{mm}$ ---------->$80\mu\text{m}$ (after BC)
$\Delta P/P < 0.1\%$

*Energy Compensation in Linac
*Momentum Acceptance in BC, Linac and F.F.
*Requirement of energy spread at IP

by "beat method" and precise active alignment technique


racetrack shape

long wiggler sections

in zero-dispersion region

Figure 4.20: Schematic layout of the JLC damping ring.

reduction of the dampin
time

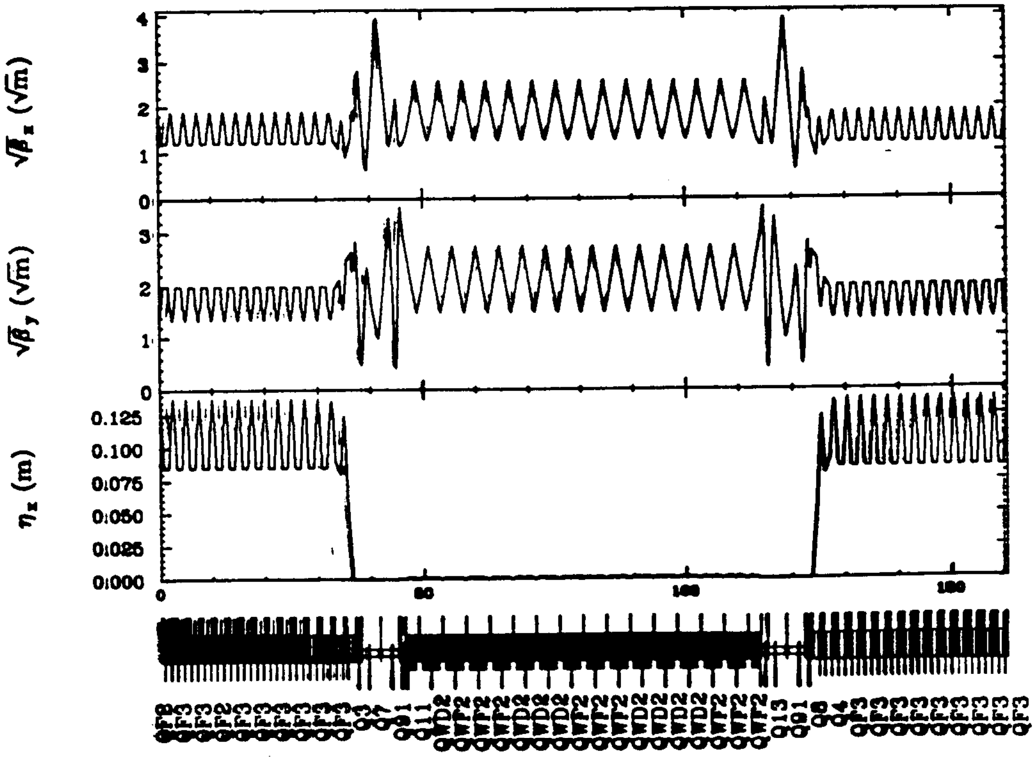


Figure 4.21: Lattice parameters of half of the damping ring.

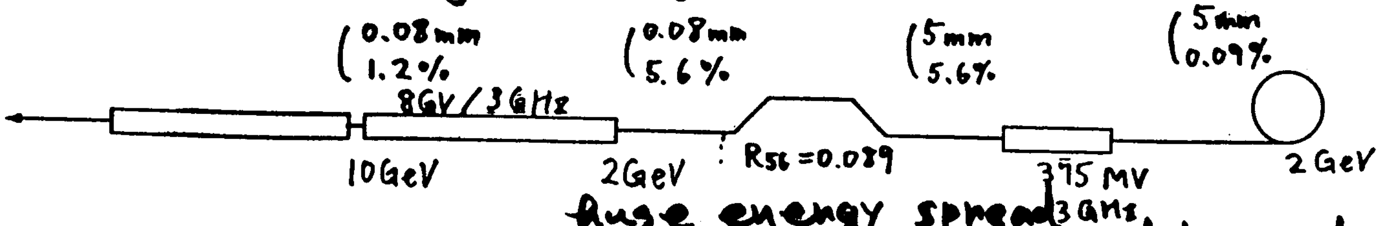
Parameters of damping rings on three options

Items	S-band	C-band	X-band
Synchrotron Radiation per turn	0.367MeV	0.986MeV	0.71MeV
Harmonic Number	530	764	660
Total Current	410mA	478mA	405mA
Circumference	222.5m	320.8m	277.1m
Number of Trains	2	4	4
Number of Bunches per Train	55	72	90
Number of Particles per Bunch	1.73E10	1.11E10	0.65E10
Longitudinal Impedance Threshold	0.145Ω	0.316Ω	0.594Ω
Repetition Rate	50Hz	150Hz	150Hz
Momentum Compaction	0.00098	0.00126	0.00140
Natural Emittance	0.512nradm	0.569nradm	0.618nradm
Horizontal Damping Time	6.13msec	3.54msec	4.04msec
Vertical Damping Time	8.01msec	4.30msec	5.20msec
Bunch Length	4.51mm (4.80mm)	4.90mm (4.98mm)	4.93mm (4.99mm)
RF Voltage (0.714GHz)	1.1MV	2.1MV	1.9MV
Energy Spread	0.086%(0.0909%)	0.091%(0.0929%)	0.0914%(0.0924%)
Touschek Lifetime	41sec	70sec	130sec
Emittance with Intra-beam	6.73E-10	6.41E-10	6.18E-10
Horizontal Phase Advance per Cell	120degree	90degree	92degree
K2 values of SF and SD	33.4,-45.9	25.9,-33.4	26.3,-33.6
Necessary Total Power	5MVA	9MVA	7MVA

Normalized emittance of injected beam 1.0x10^{-4} radm

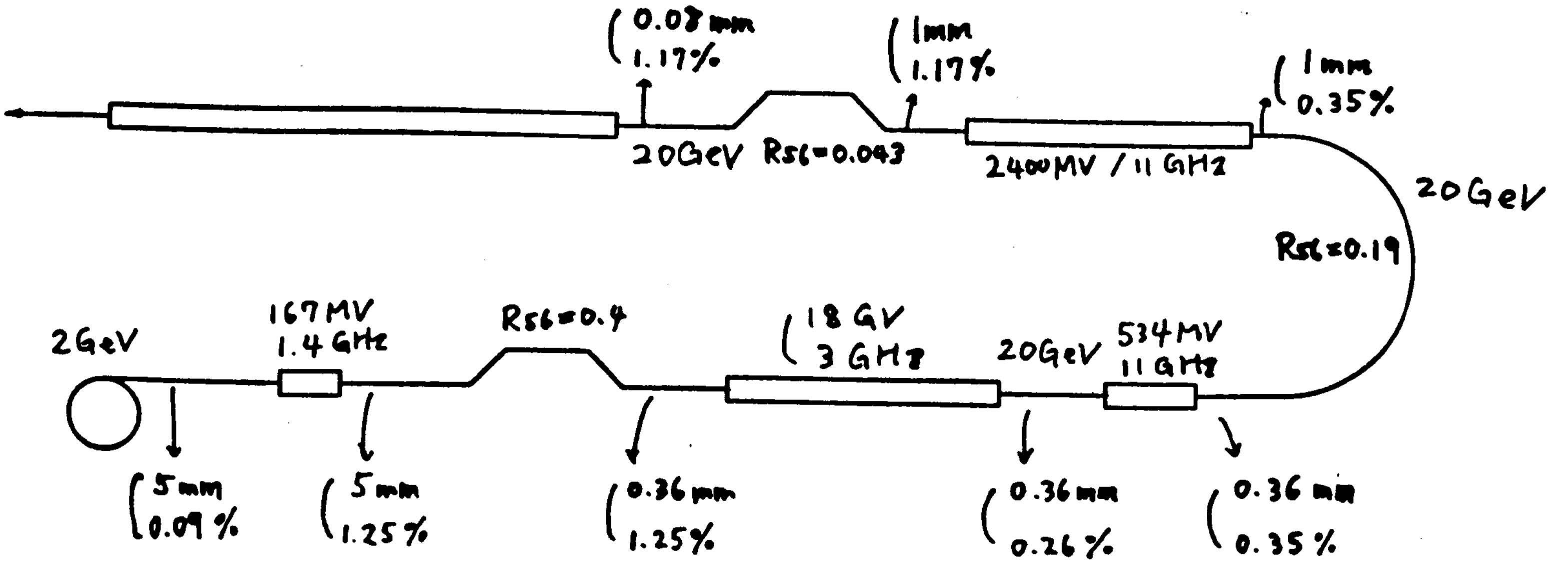
Challenging scheme is better for Linear Collider. Kikuchi proposed at Emittance'93

Single-stage Scheme



huge energy spread and beam density

Two-stage Scheme



Schematic View of BC system

at LC73

Estimated tolerances

item		tolerance
Linac Cavity	Δy	100 μm
Quads	Δy	10 μm
	$\Delta\varphi$	0.2 mrad
Chicane Bends	$\Delta\varphi$	1 μrad
	K_2L_B	110 m^{-2}
	Δy	10 μm
	$\Delta\theta/\theta$	1×10^{-5}
	$\Delta L/L$	1×10^{-4}
Compressor RF	$\Delta\varphi$	0.8°

Problems to be considered

1. Supression of position shifts in DR
2. Detailed correction technique:
   - alignment of quads in linac
   - dispersion correction
   - beta match
3. Design of diagnosis section.

Simple is not easy

to compress the beam from ATF DR until 80μm.

by M. Kikuchi

Table 1: Parameters of Bunch-Compressor

Chicane Bends	$\ell_B = 1.27$ m, $\theta_B = 9.8°$, $\eta_{max} = 0.3$ m
Compressor Cavities	$V_{main} = 473$ MV, $f_{RF} = 2.856$ GHz, $\phi = 22.7°$ $V_{aux} = 76.2$ MV, $f_{RF} = 5.712$ GHz, $\phi = 0°$
Compensation Cavities for Beam-loading	$V = 2 \times 50.4$ MV, $f_{RF} = 2.856$ GHz $\Delta f_{RF} = \pm 10$ MHz

Table 2: Tolerances of Bunch-Compressor

Beam line quads	$\Delta y = 10$ μm, $\Delta\phi_{rot} = 0.2$ mrad
Chicane Bends	$\Delta y = 10$ μm, $\Delta\phi_{rot} = 1$ μrad, $\Delta\theta_B/\theta_B = 1 \cdot 10^{-5}$ $\Delta\ell_B/\ell_B = 1 \cdot 10^{-4}$, $\Delta K_2\ell_B = 100$ m^{-2}
Compressor rf	$\Delta\phi_{RF} = 0.8°$

diagnosis section. The beta functions at the diagnosis section were made as large as possible, otherwise the wire monitors cannot stand the tremendous heating power of beams.

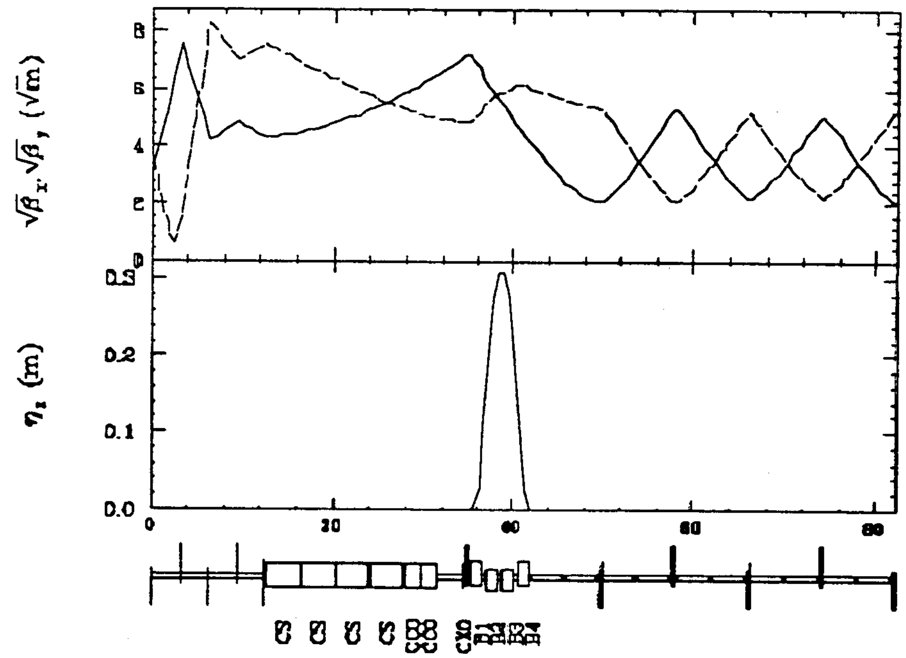


Figure 1: Layout of the Bunch-Compressor beam line

Bunch-Compressor Test Facility

ATF Damping Ring

Target

1. Multi-bunch and Multi-train Operation

20 bunches/train, 5 train----------------> Total Current 600mA

2. Very Flat Beam

Horizontal Normalized Emittance=5x10^{-6}radm

Vertical Normalized Emittance=3x10^{-8} radm

3. Very Stable Operation ------------>Extraction Stability=10^{-4}

R&D Status

High Intensity, Low Emittace, Multi-bunch and very Flat Beam

Low Emittace and very Flat Beam----------------> Damping Ring

Low Emittance Ring------------------> Combined-Function FODO

Fast Damping----------------------> Conventional Electric Wiggler

Extraction Stability-------------------->Double Kicker System

Design is almost completed. and many components are already ordered.

Now we need many low cost reliable accelerator components.

Low Impedance Vacuum Chamber < 0.2Ω------------>No Bunch Lengthening

Alignment Error < 30μm(r.m.s.)-------------------->Very Flat Beam

Field Error<0.1% and No Instatbility------------>Stable Beam Operation

Alignment Control

Good Magnets System

Damped Cavity

Precise Monitor System

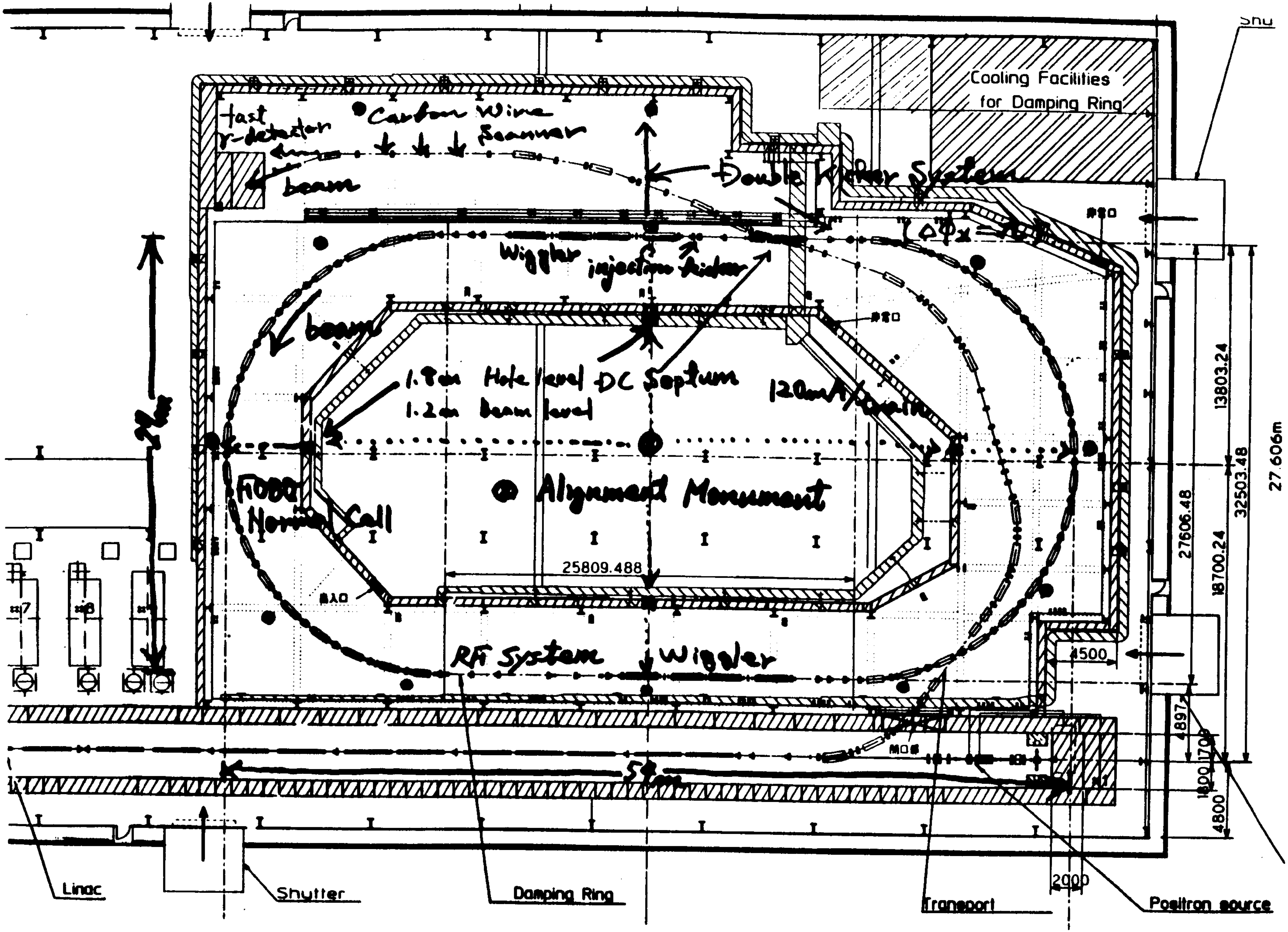
by Junji Urakawa and ATF DR Group

Schedule of ATF Construction

Date	Milestone
1993.8	We succeeded the beam acceleration up to 80MeV in the ATF Injector Linac by using one 3m S-band structure.
1993.12	Generation of High Accelerating Gradient with SLED (51MeV/m maximum; 33MeV/m average)
1993.12	Completion of the Shielding Hall for the Damping Ring.
1994.7	We accelerated the multi-bunch beam up to 80MeV including 0.5-meter S-band Test Structure for Choke-Mode Damped-Cavity.
1994.8	We succeeded the bunch by bunch measurements of beam emittance, energy and energy spread.
1994.12	The Control System for the 1.54GeV S-band Linac will be completed.
1995.2	Test of Hot Model of Damped Cavity will be started.
1995.3	1.54GeV S-band Linac will be completed.
1995.6	Beam Transport Line will be completed.
1995.7	Beam Tuning of 1.54GeV S-band Linac will be started.
1995.11	Alignment System including the supporting tables with active movers will be completed.
1995.12	Vacuum System for the Damping Ring will be completed.
1996.2	Control System for the ATF will be completed.
1996.1	Magnet System for the Damping Ring will be completed.
1996.9	RF System for the Damping Ring will be completed.
1996.10	Extraction Line, Emittance and Bunch Length Measurement System will be completed.
1996.11	ATF Damping Ring will be completed.
1996.12	Beam Operation of ATF Damping Ring will be started.

by Junji Urakawa 1994.5.7

Delayed one year because of lack of budget from the table at LC'93.


Cooling Facilities
for Damping Ring
fast γ-detector array
Carbon Wire Scanner
beam
Double Kicker System
(Δφx =
#20
Wiggler
injection kicker
beam
1.8m Hole level
1.2m Beam level
DC Septum
120mA/train
FODO Normal Cell
Alignment Monument
25809.488
RF System
Wiggler
4500
13803.24
32503.48
27.606m
27606.48
18700.24
4897
1700
1800
4800
2000
58m
#7
#8
Linac
Shutter
Damping Ring
Transport
Positron source

Initial Alignment

- Theodolites
- Laser Tracker
- Water Hydrostatic Level
- etc.

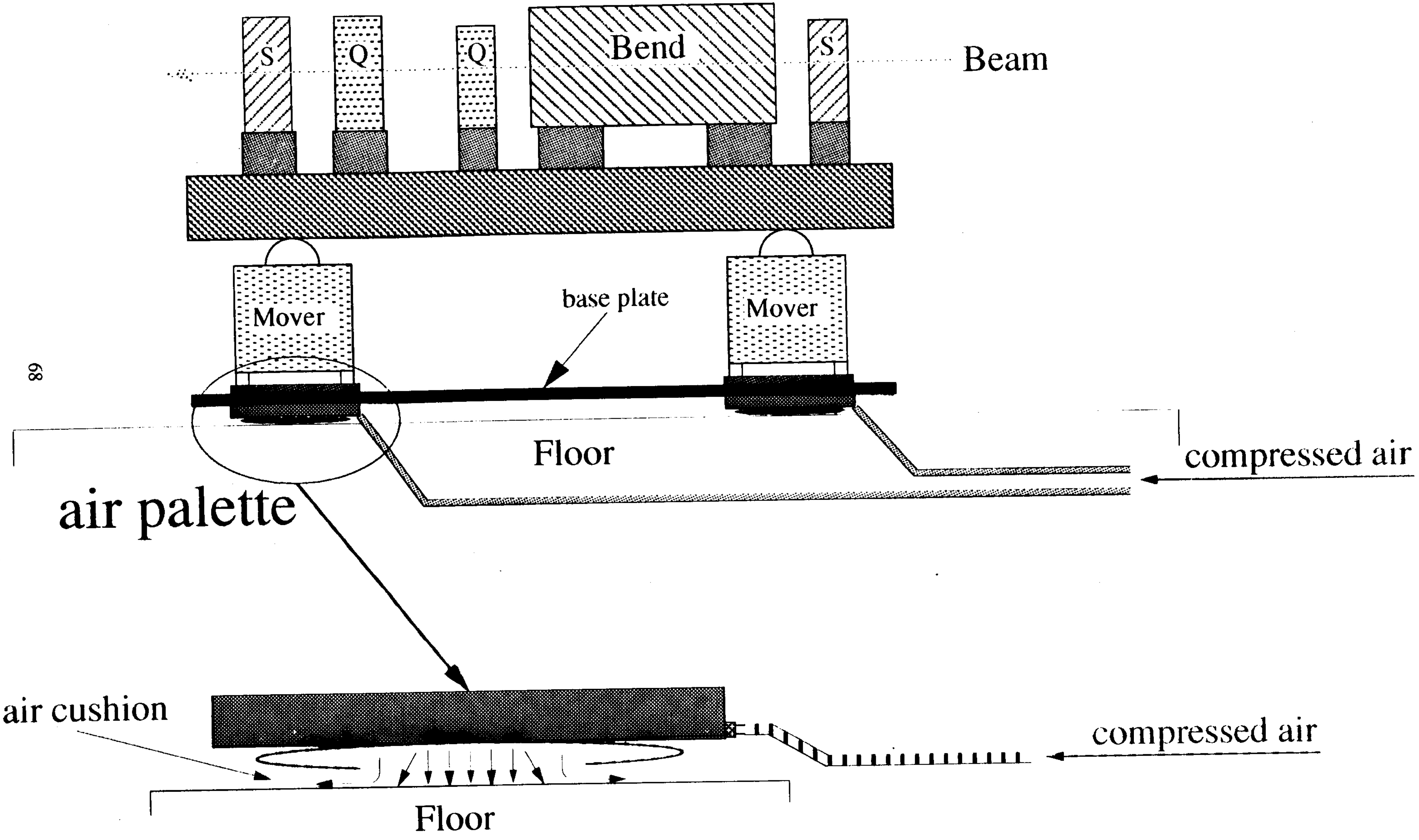
Tolerance : 60μm (H), 50μm (V)

Magnets of Arc Sections

Target accuracy = 30μm

- 5 magnets on one support table
- Alignment of these magnets on the table
  → in an alignment hut

- Movement from the hut to the installation place
  → by "Air Pallet"


S
Q
Q
Bend
S
Beam
Mover
base plate
Mover
Floor
compressed air
air palette
air cushion
compressed air
Floor

On-line Monitoring

- Resolution (desired)

  ≤ 1 μm

★ Vertical position

- Level

Water Hydrostatic Level

{ filled (HLS)
  half-filled (LSHF)

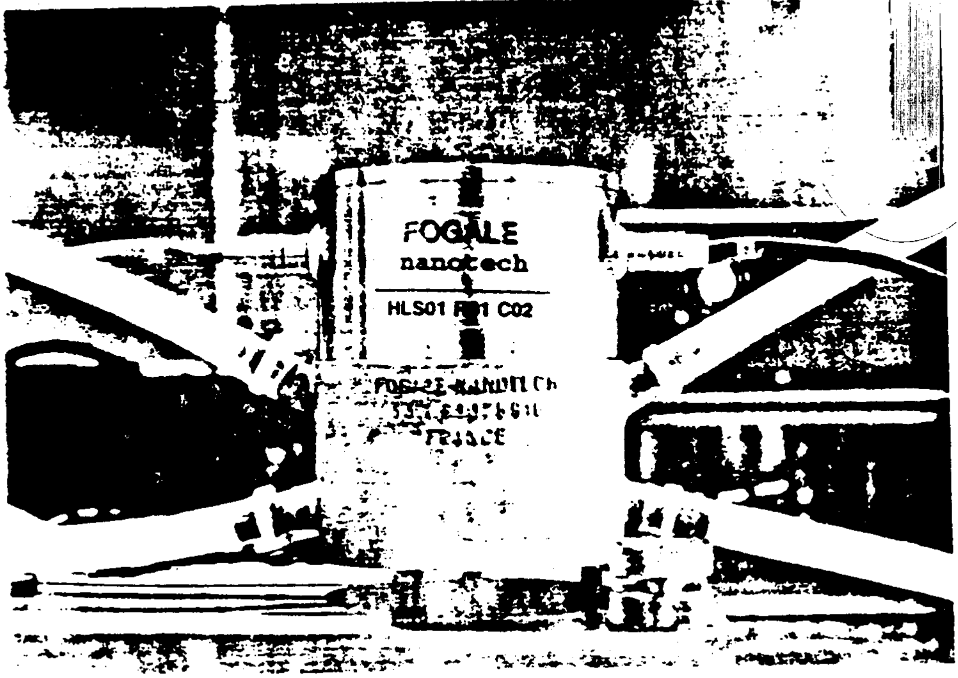
★ Horizontal position

- Relative Position (arc sections)

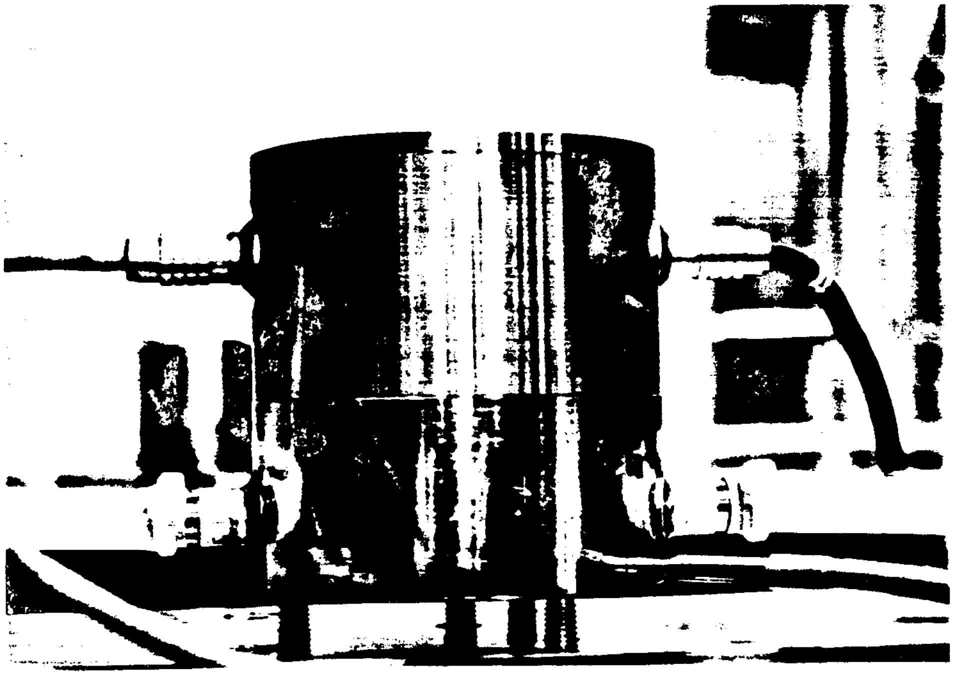
Laser Diode +

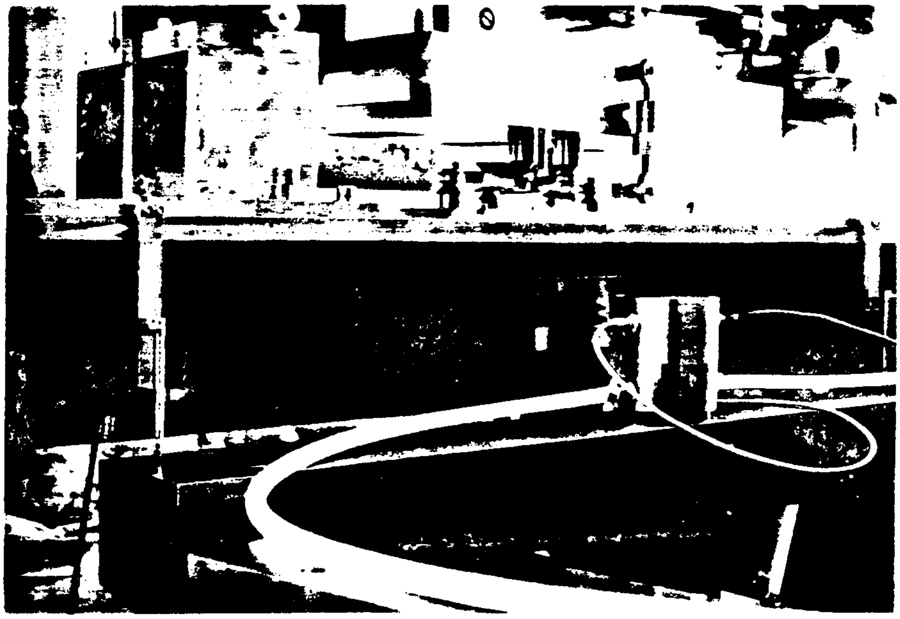
{ PSD (Position Sensitive Detector)
  QPD (Quadrant Photo Diode)

- Wire Alignment system ?
  (straight sections)



FOGALE
nanotech
HLS01 R01 C02
FOGALE NANOTECH
FRANCE



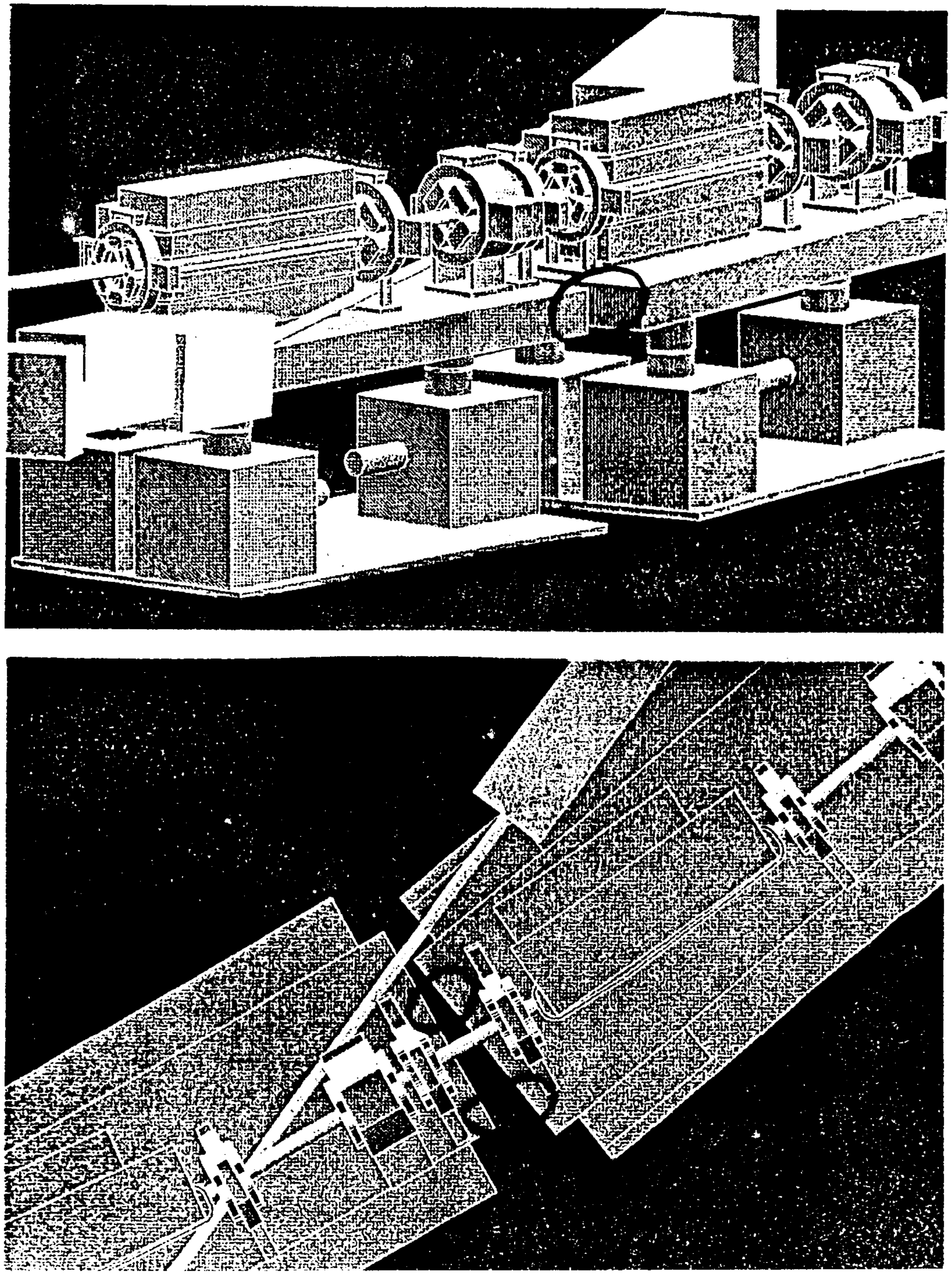


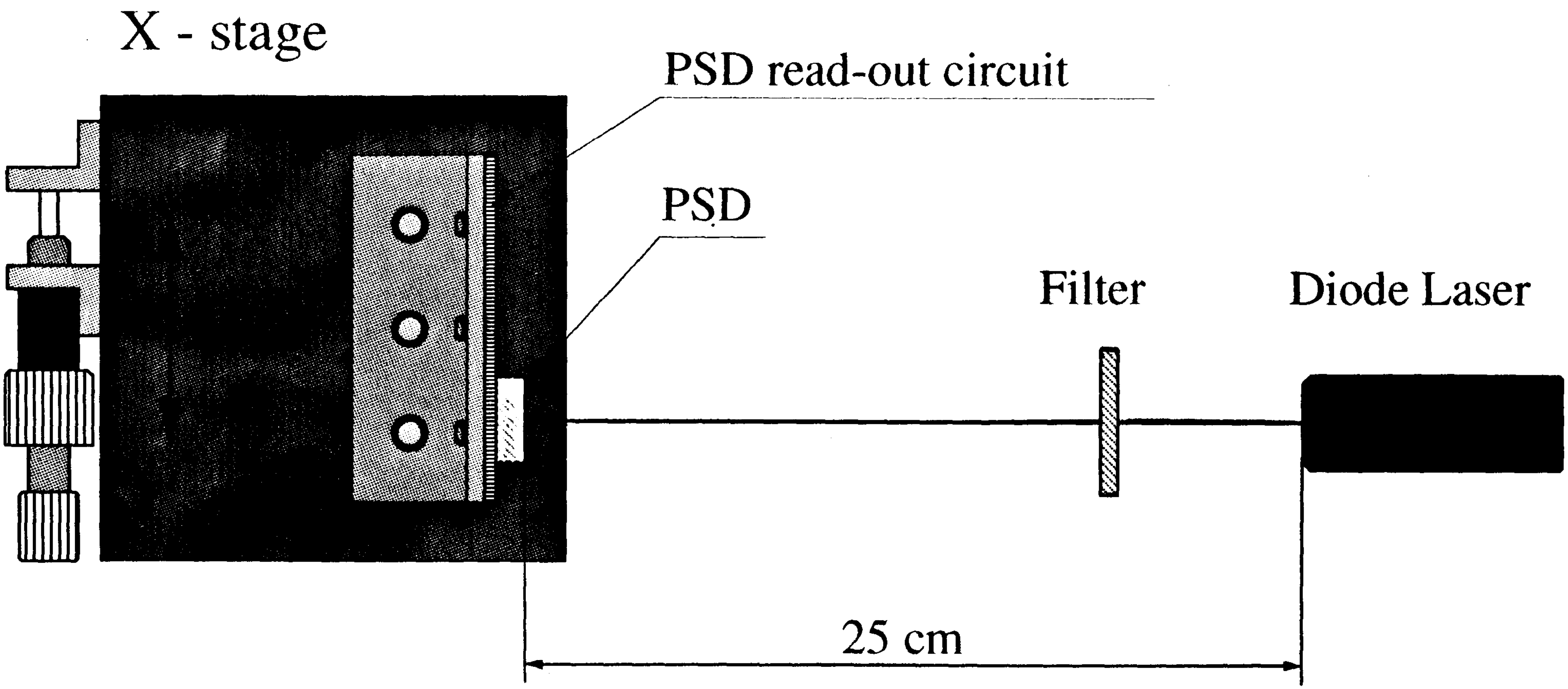
Relative movement between tables

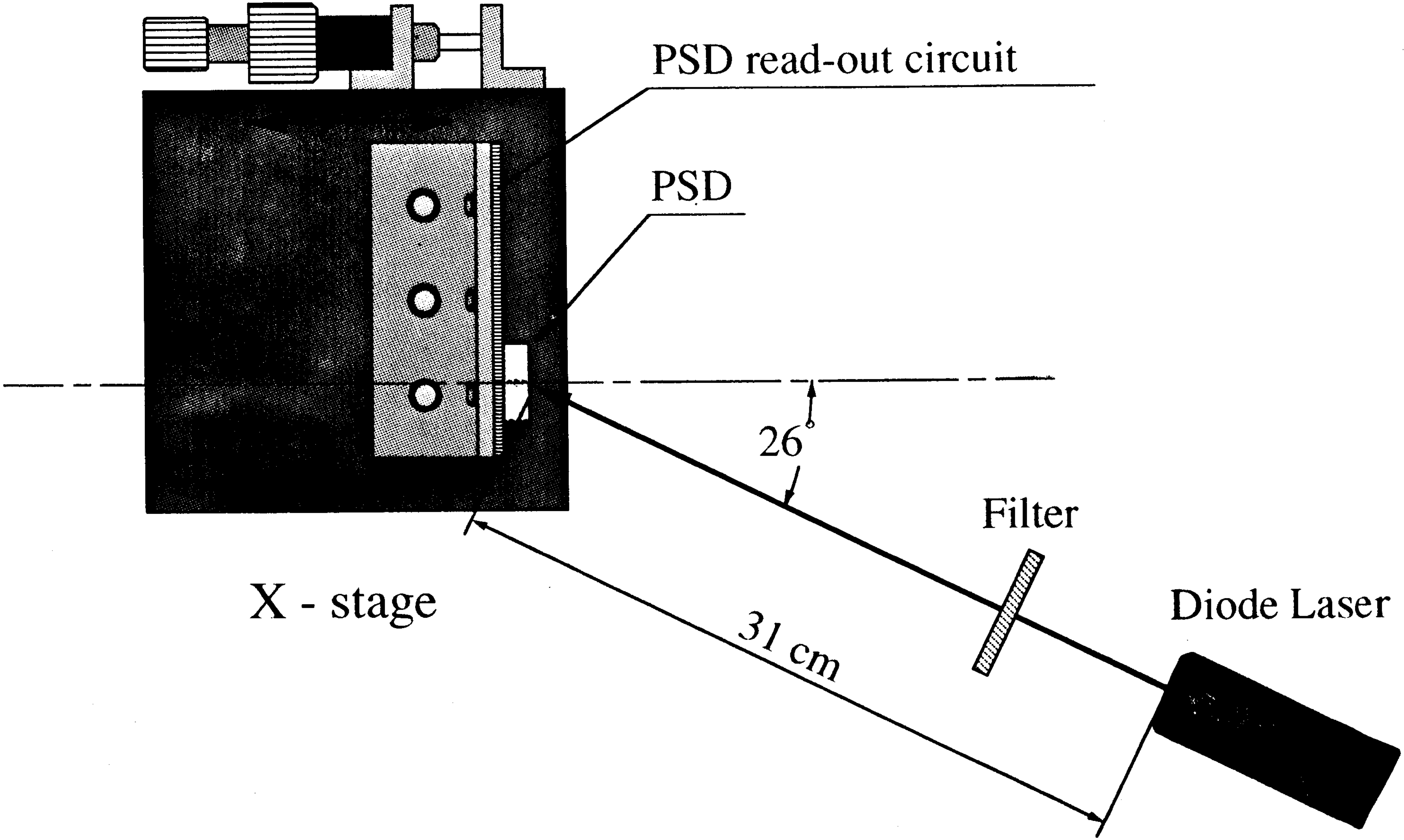
Diode laser +
PSD or QPD

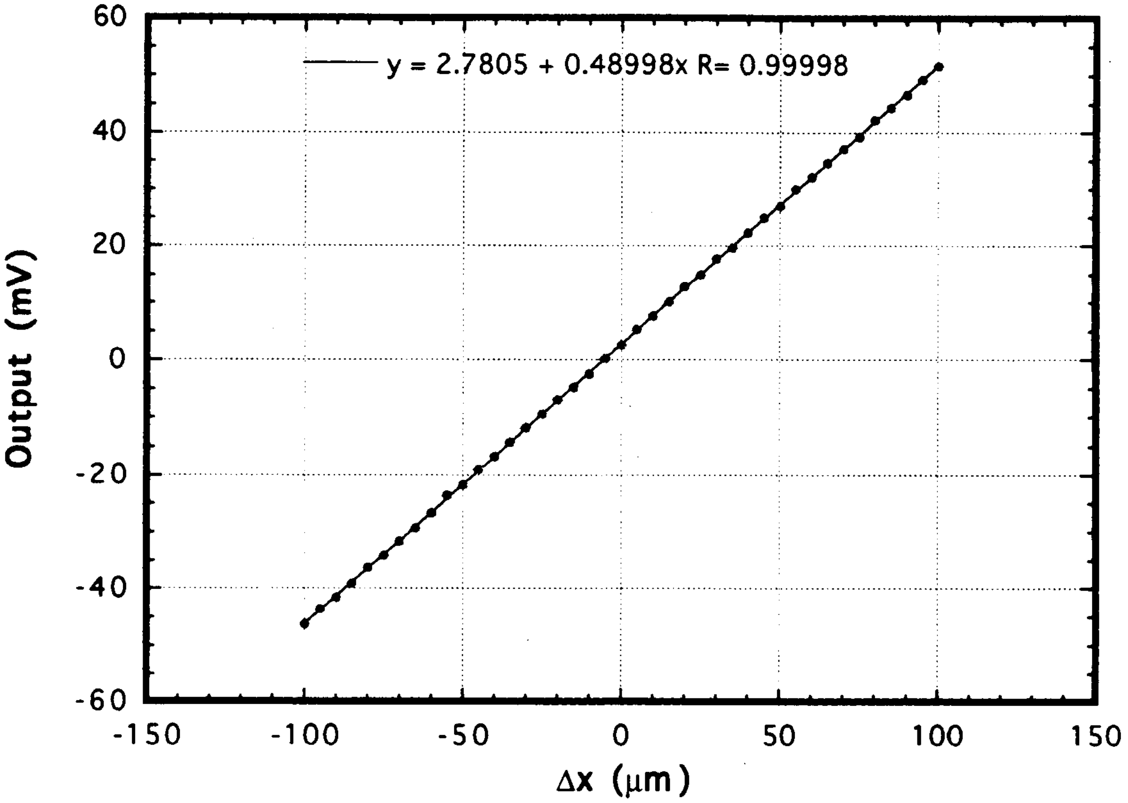
2 sensors for each gap

Δx, Δy
Δz, and roll

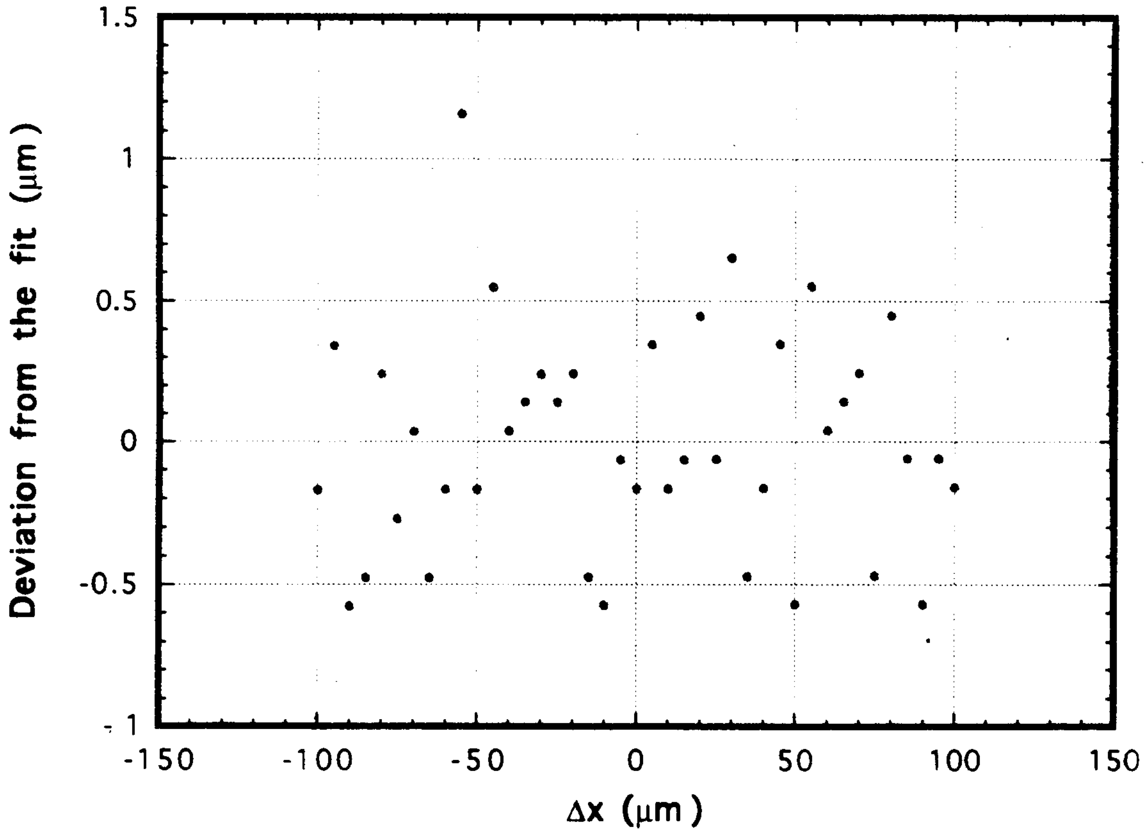



X - stage
PSD read-out circuit
PSD
Filter
Diode Laser
25 cm


PSD read-out circuit
PSD
26°
Filter
X - stage
Diode Laser
31 cm



1μm resolution

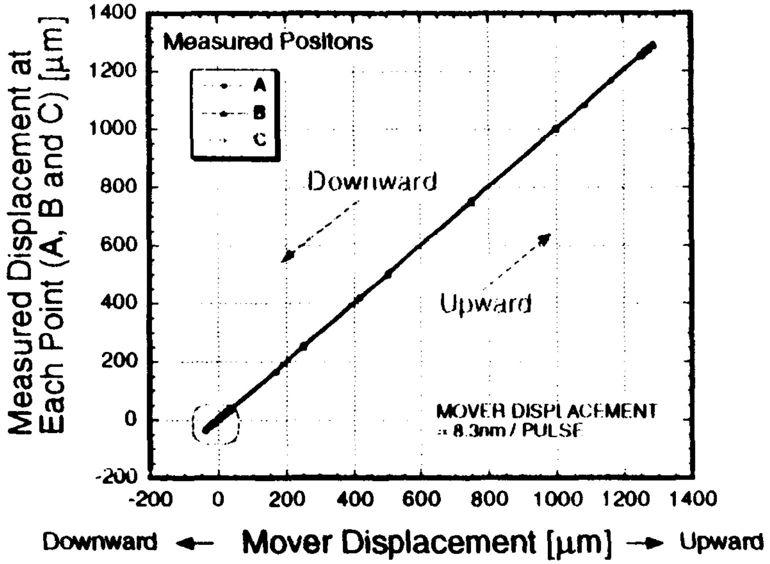


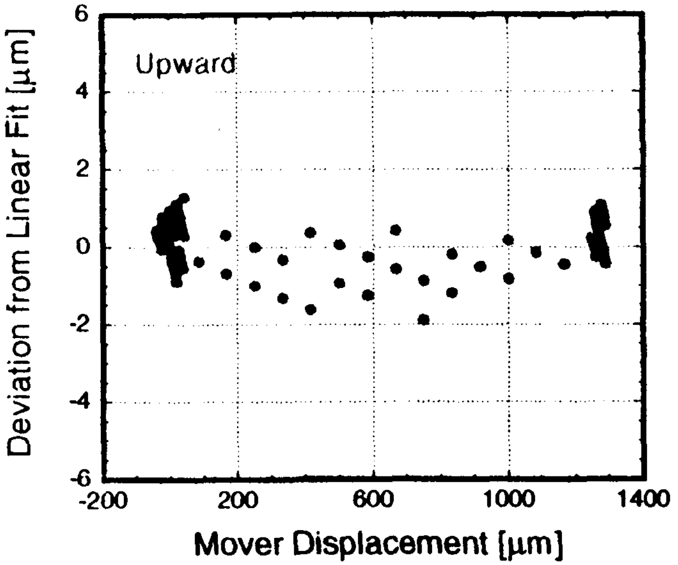

AKAHOSHI.

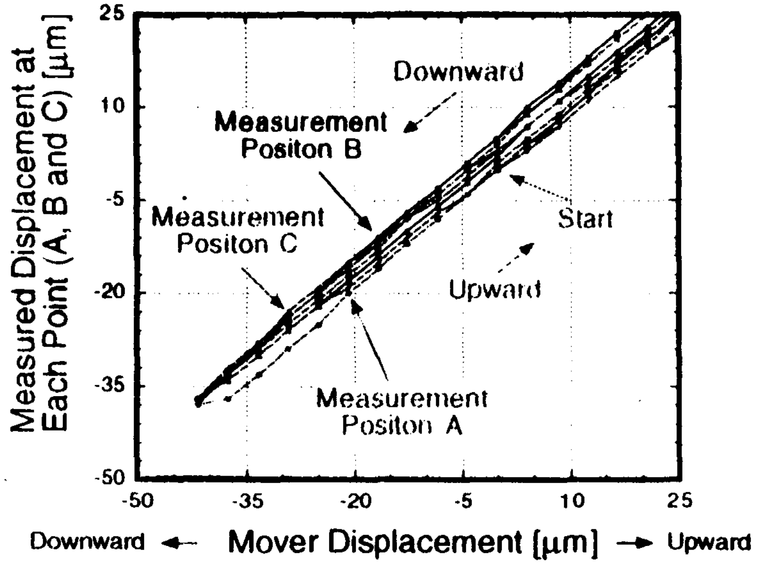
Reconfiguration

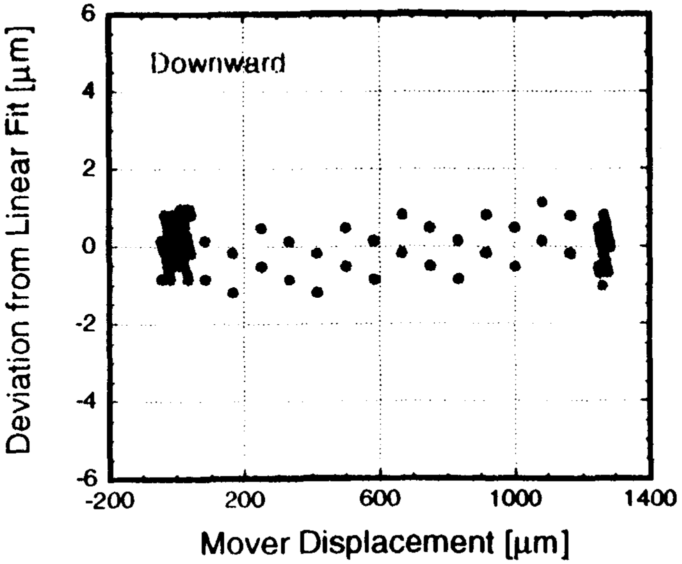
Active Support Table (Funahashi et al.)

Position control accuracy less than 2μm

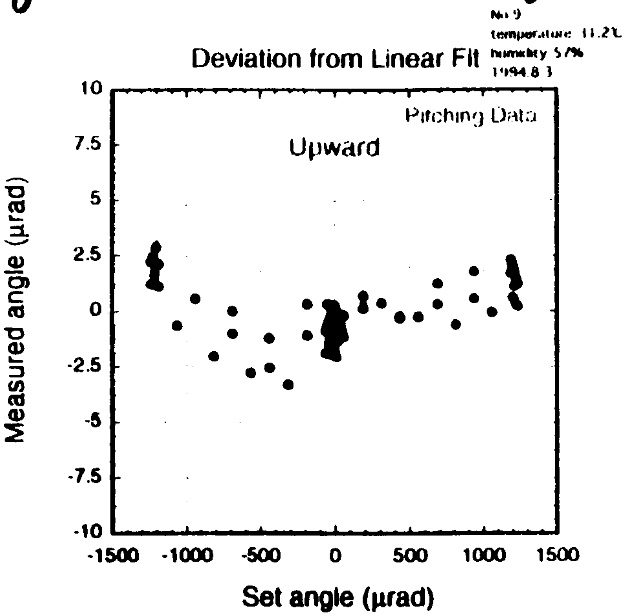

Performance of Active Table for Damping-Ring

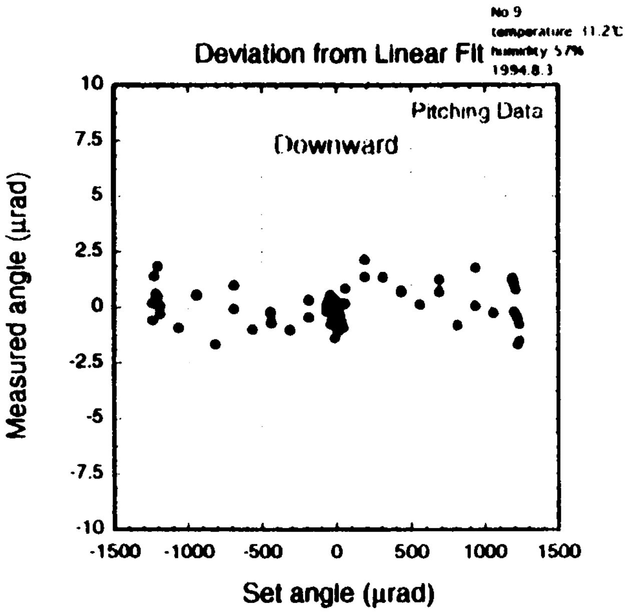

Deviation from Linear Fit at Point [A]


Performance of Active Table for Damping-Ring


Deviation from Linear Fit at Point [A]

Pitching control less than 2.5μrad

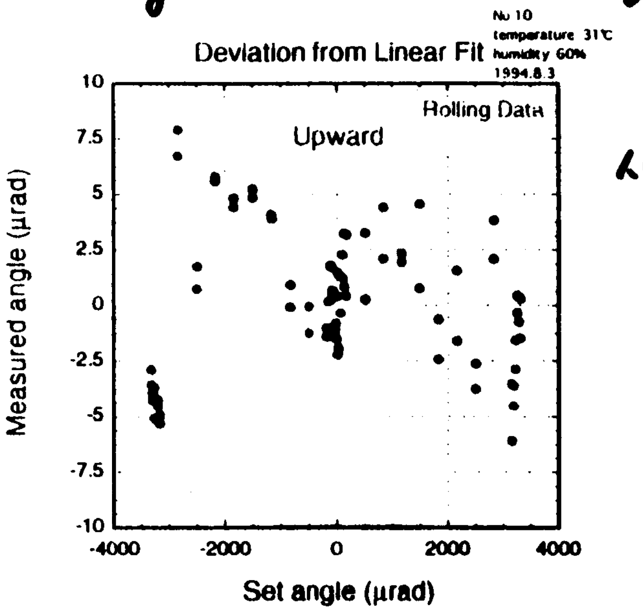


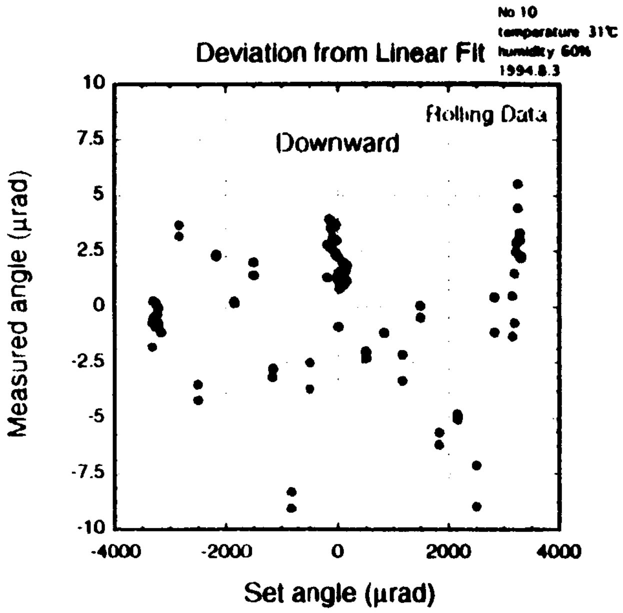


Rolling control less than 7.5μrad

↓ improve

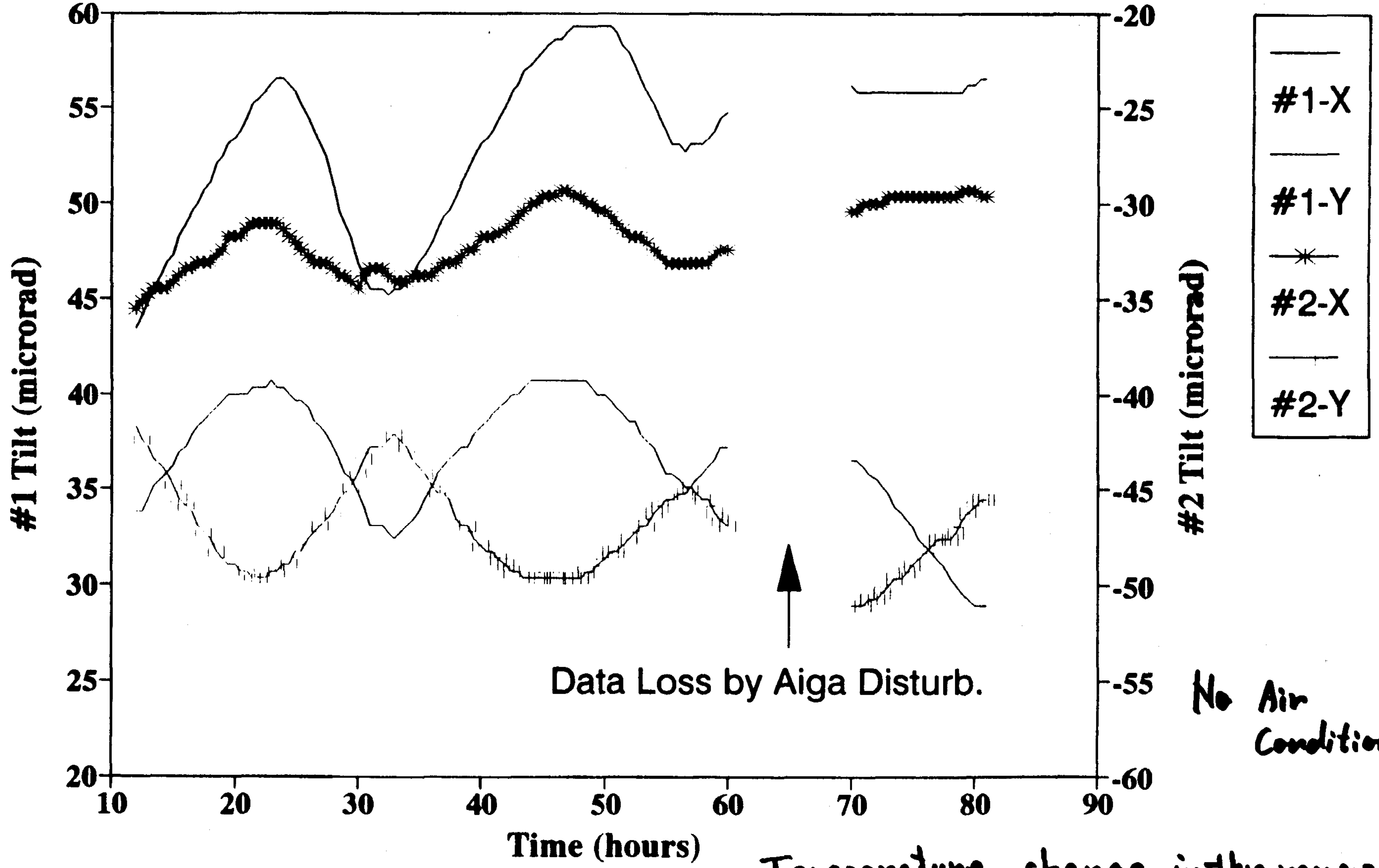
<0μrad





Thermal Distortion of the Table

1994/08/23 - 08/26

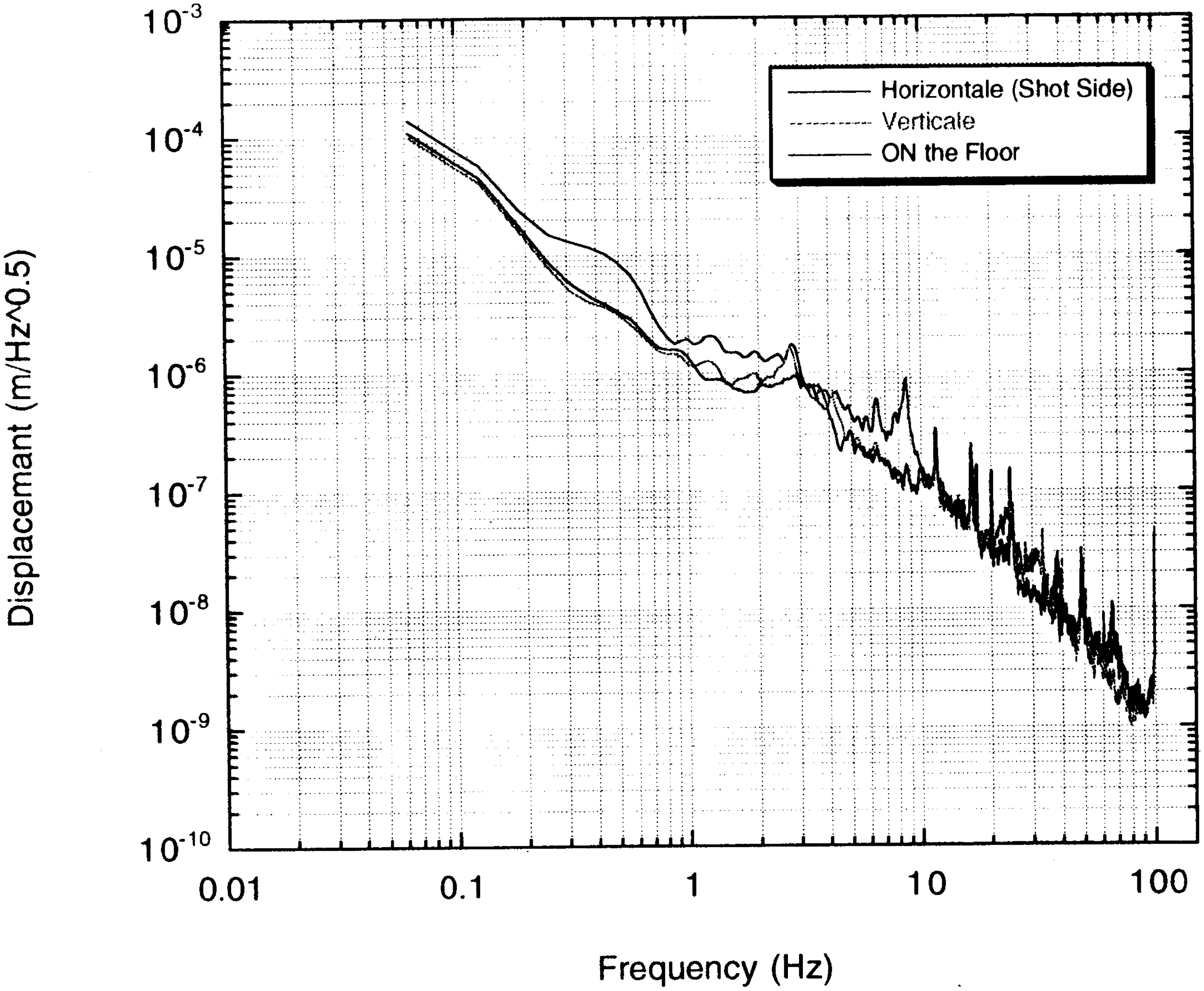


No Air Conditioner

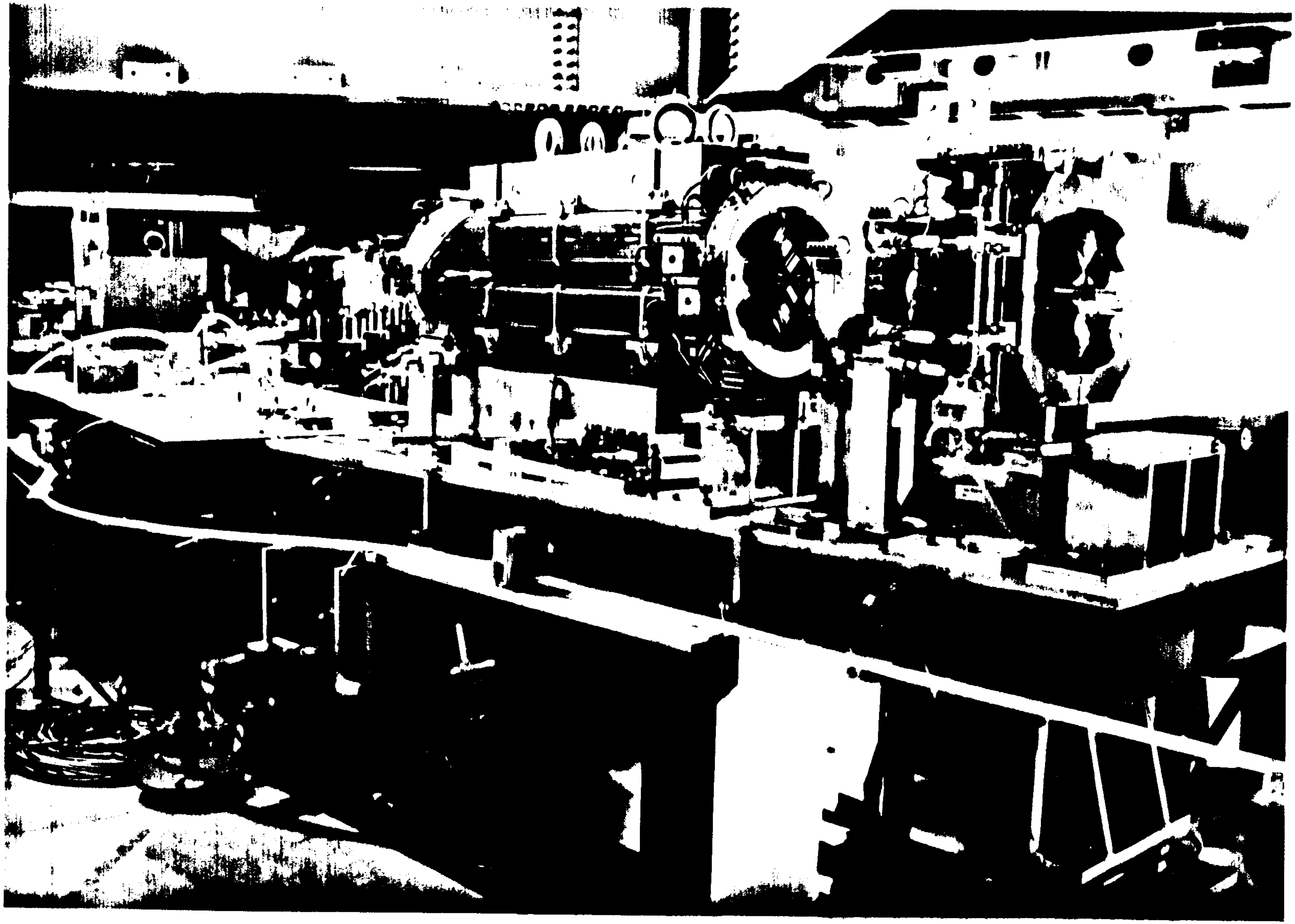
Temperature change in the range of 28 to 36°C.

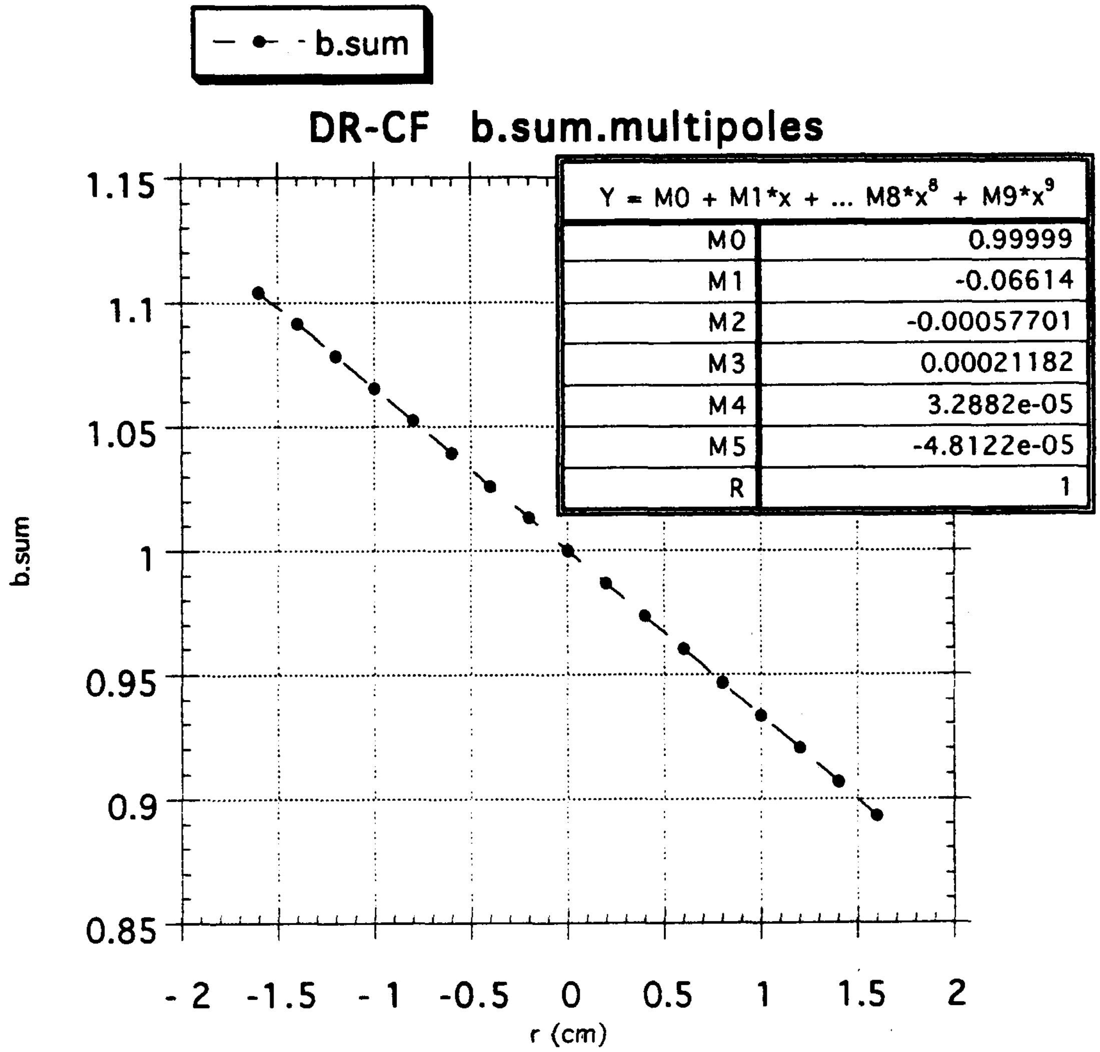
Spectrum of Ground Motion
at the KEK ATF floor

Ka,9
Resolution 1600
1994.11.29 (night)



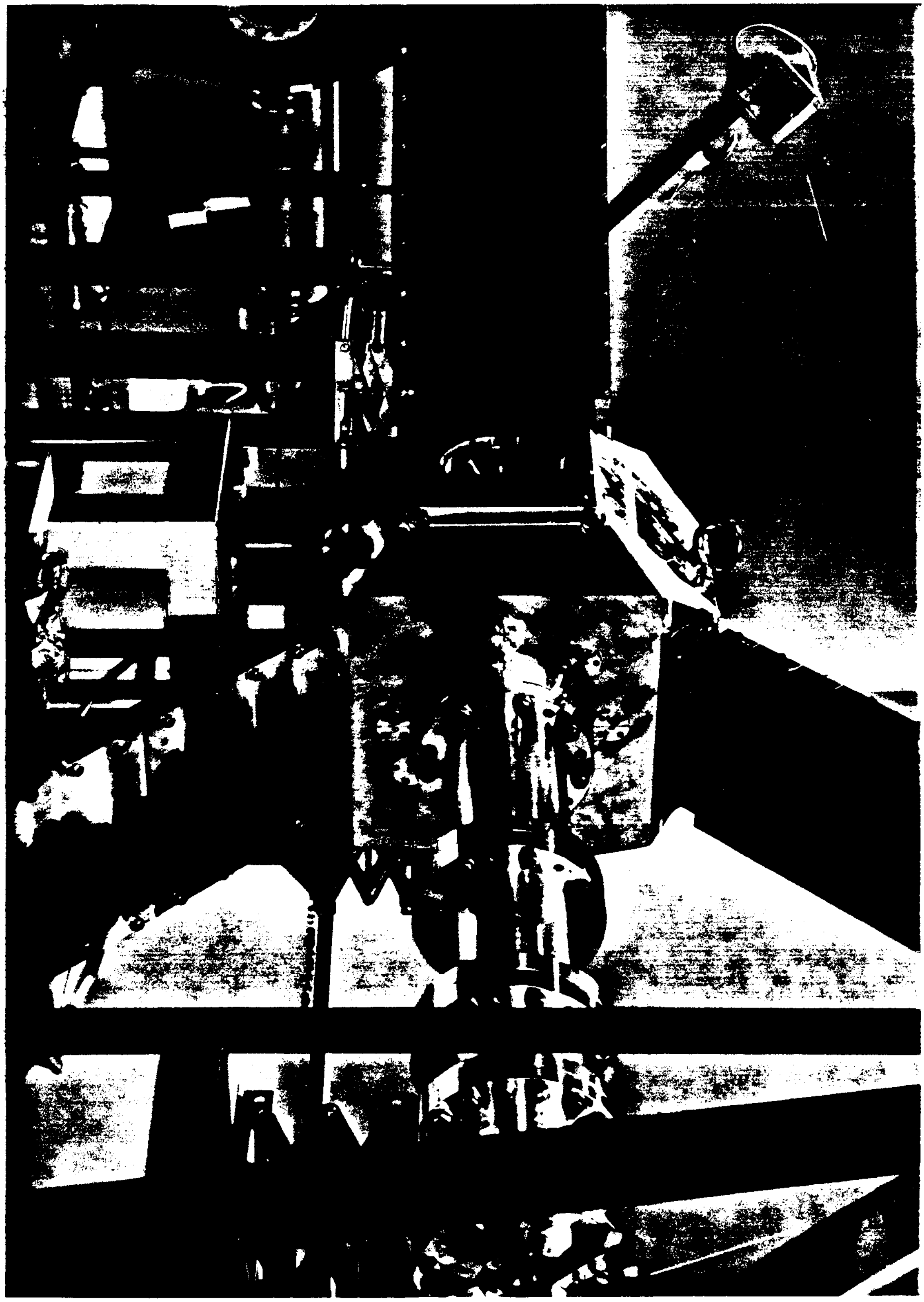
Need Automatic Alignment for the tables in the range less than 1Hz.

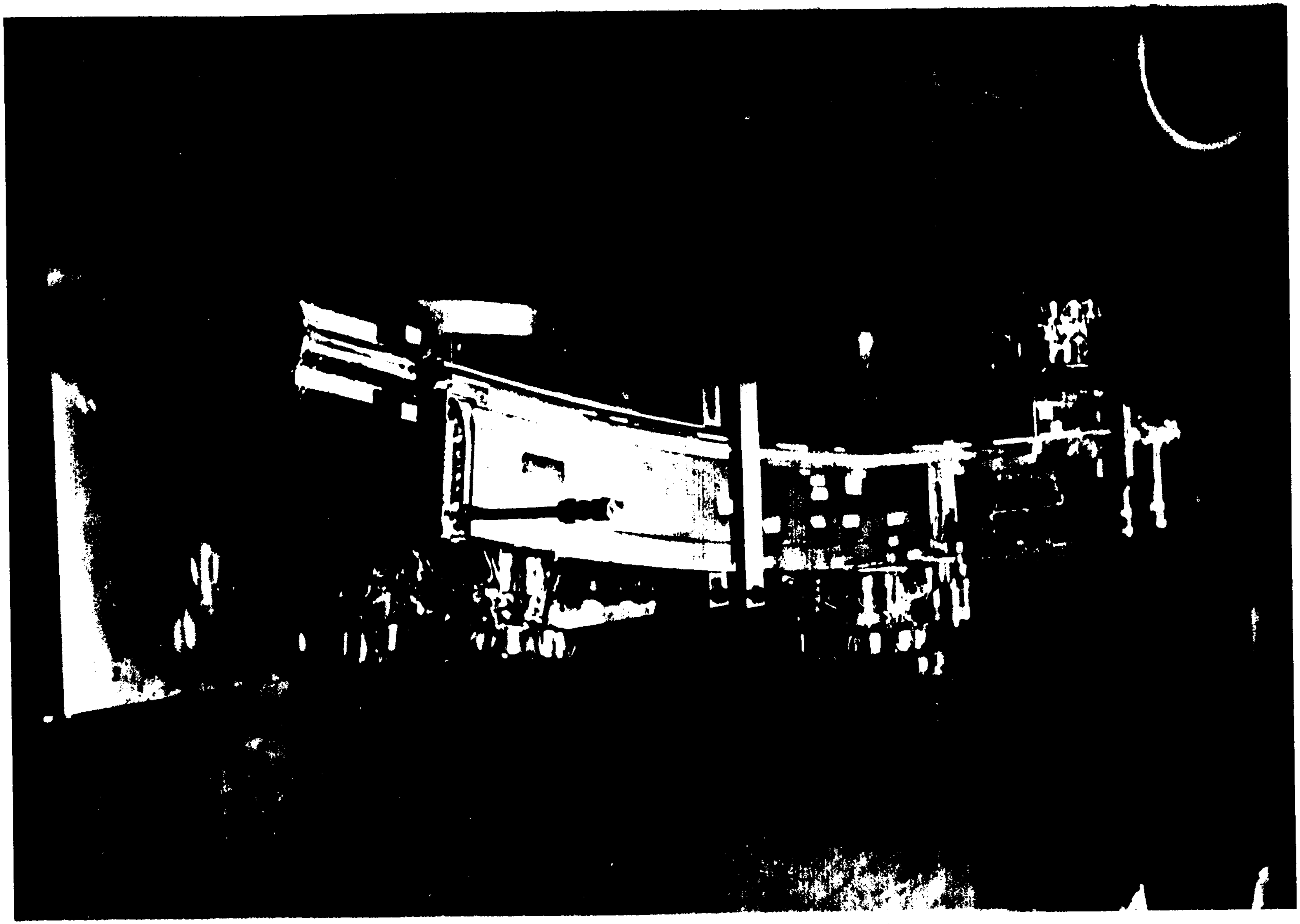




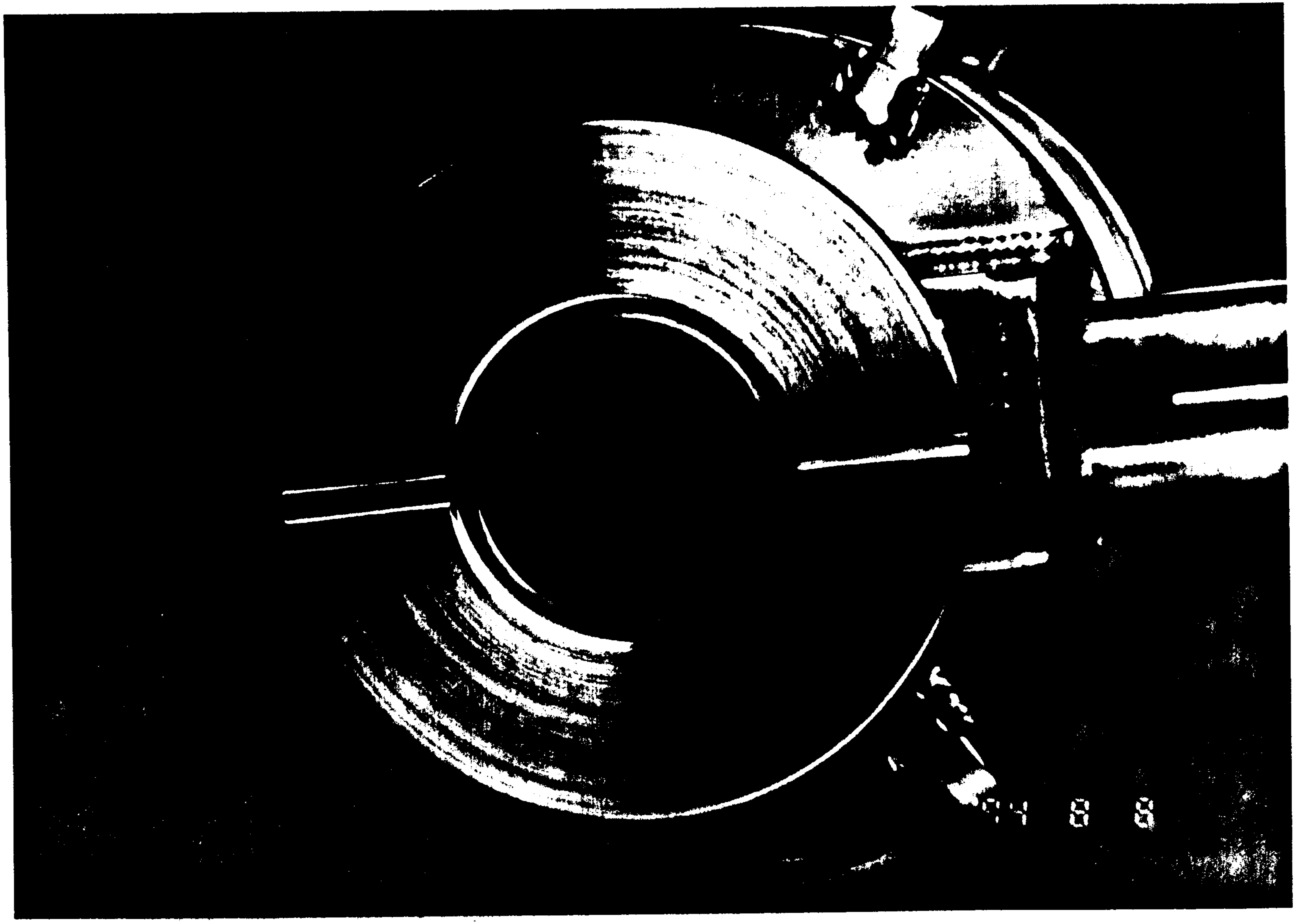
Maching and Constructing Accuracy of Magnetic Poles are less-than $20\mu m$. Base plain on the top of magnet has also the maching accuracy of $20\mu m$ for alignment.

Field Quality is so good.

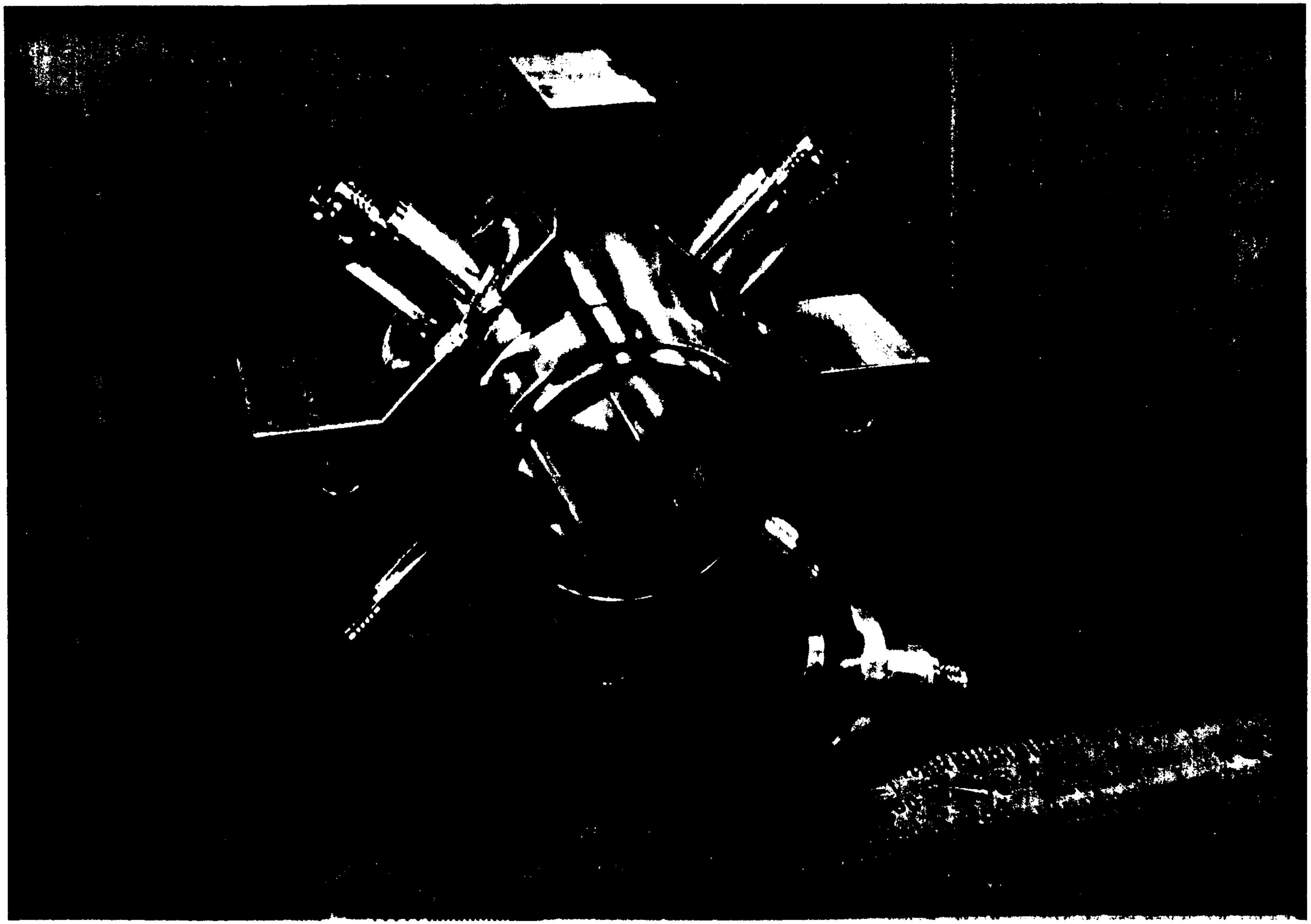




18 Vacuum chambers were completed
No photon marks



connected each other by shielded stainless bellows



Beam sees only small slits on the surface of 24φ duct.

Terunuma

Calculated impedance is 0.331Ω

	$\lvert Z/n\rvert$/unit (mΩ)	Number of units	$\lvert Z/n\rvert$/ring (mΩ)
Rf cavities	40	5	200
Vacuum pump slots	6×10^{-4}	3600	2
Monitor electrodes	0.02	4×100	8
Bellows	0.4	80	32
Septum chamber	0.7	2	1
Rf quadrupoles	6.4	2	13
Tapered transitions	1.5	4	6
Clamp flanges	0.04	60	2
Gate valves	0.8	6	5
Photon masks	0.5	20	10
Kicker chambers	2.1	2	4
Rf absorbers			≈ 50
Total			331

6. Multi-bunch Instabilities

The thresholds of longitudinal and transverse coupled-bunch instability caused by a higher-order resonance with impedance $R_{\parallel}$ and $R_{\perp}$ at the resonant frequency f_r are roughly estimated by the formulae

$$\begin{aligned} R_{\parallel,\mathrm{th}} &= \frac{E\nu_z}{I\tau_z\alpha_p f_r} \\ R_{\perp,\mathrm{th}} &= \frac{ET_0}{I\tau_\beta\beta}\ , \end{aligned} \tag{2}$$

where β is the beta function at cavities. Equation (2) assumes a uniform distribution of the bunches and the worst case the coupled-mode hits the resonance exactly. In the case of the ATF damping ring, this threshold becomes

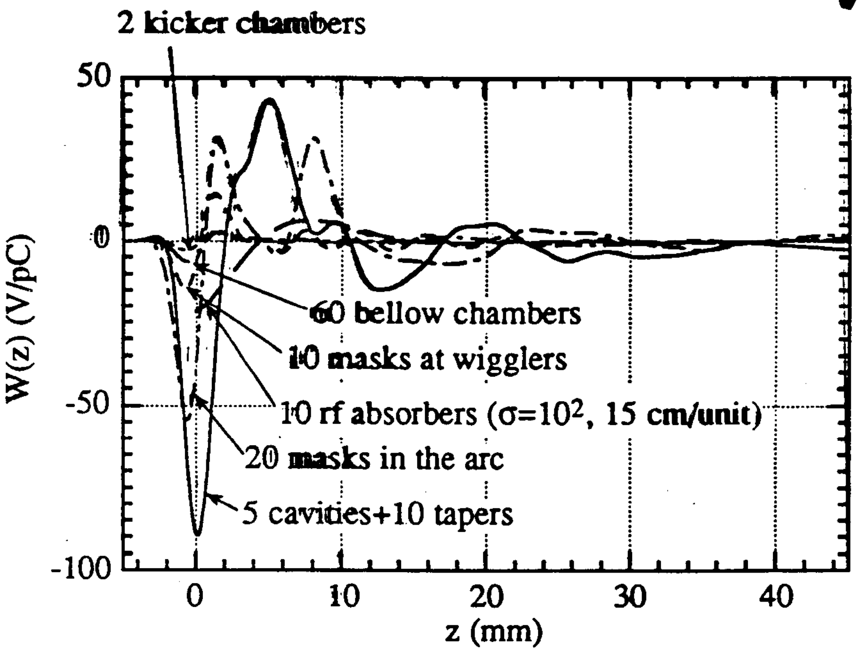
$$\begin{aligned} R_{\parallel,\mathrm{th}} &= 1.4\left(\frac{1\ \mathrm{GHz}}{f_r}\right)\mathrm{k}\Omega \\ R_{\perp,\mathrm{th}} &= 16\ \mathrm{k}\Omega/\mathrm{m} \end{aligned}\ , \tag{3}$$

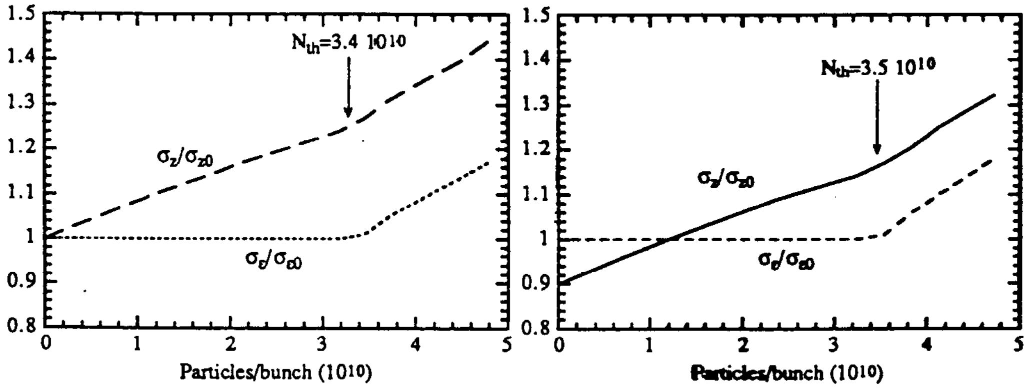
where we have used $\beta = 8$ m and $\tau_\beta = \tau_y = 9.2$ ms. The longitudinal threshold

Calculated longitudinal impedance threshold

3.5×10^{10}

K. Oide





is satisfied by the damped cavity in the longitudinal direction as discussed later. The transverse is cured by the damped cavity together with bunch-to-bunch tune spread $\Delta\nu_\beta \sim 10^{-3}$ introduced by an rf quadrupole. According to the tune-spread, the transverse threshold is effectively increased N_b times bigger than Eq. (3).

The actual threshold with the real bunch/batch distribution including transient phenomena has been studied by multi-rigid-bunch simulations. The results show the condition (2) and (3) are all right for the threshold.

Resistive wake of the vacuum chamber is another source of the coupled-bunch combined function FODO cell

to minimize the equilibrium emittance.

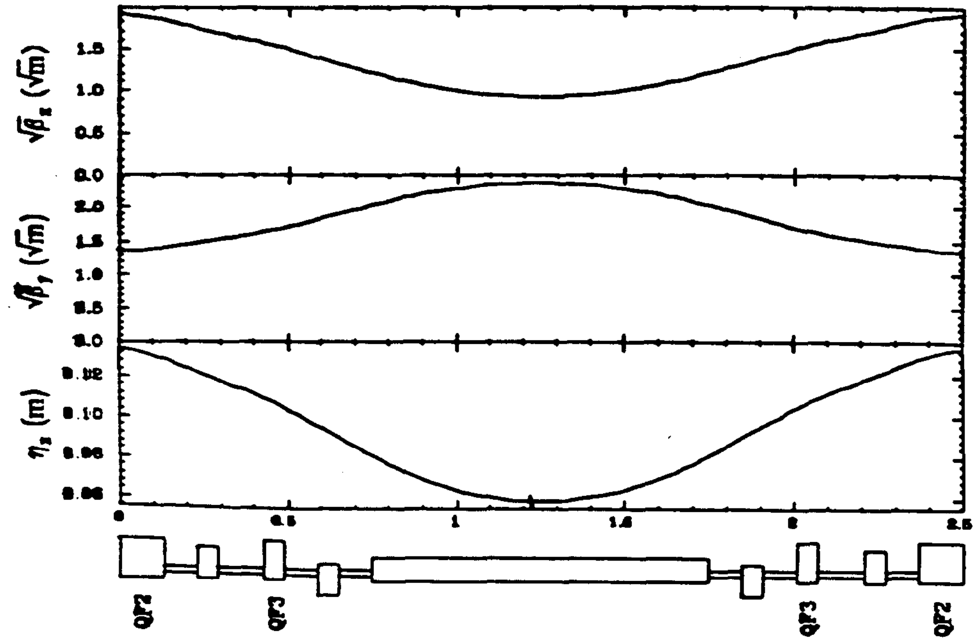


Figure 4.22: Lattice parameters of a single normal cell.

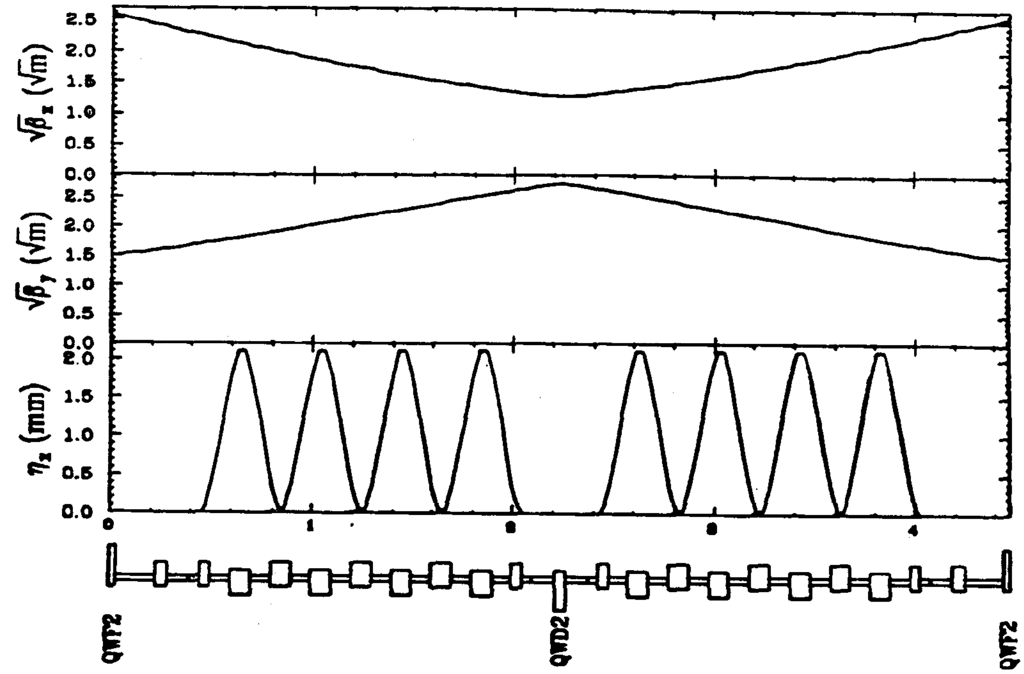


Figure 4.23: Lattice parameters of a wiggler cell.

Summary

The technical R&D for the damping ring is enough and gradually upgraded for the application to the bunch compressor and the main linac.

In the viewpoint of beam tuning, we need to operate very flat and short multi-bunch beam in the damping ring and bunch compressor as the total system test.

We need the precise mover system with the accuracy of 1μrad for single-stage bunch compressor.

Single-stage bunch compressor is very challeging and attractive.

Simple is best but not easy.

We must be challenging to develop new idea and technology.

Damping Rings

Injected beams

e^- $\gamma\epsilon_{rms} = 1\times10^{-4}$ $|\delta_p/p| < 1\%$

e^+ $\gamma\epsilon_{edge} = 6\times10^{-2}$ $|\delta_p/p| < 2\%$

Repetition Rate $\leq$ 180 Hz

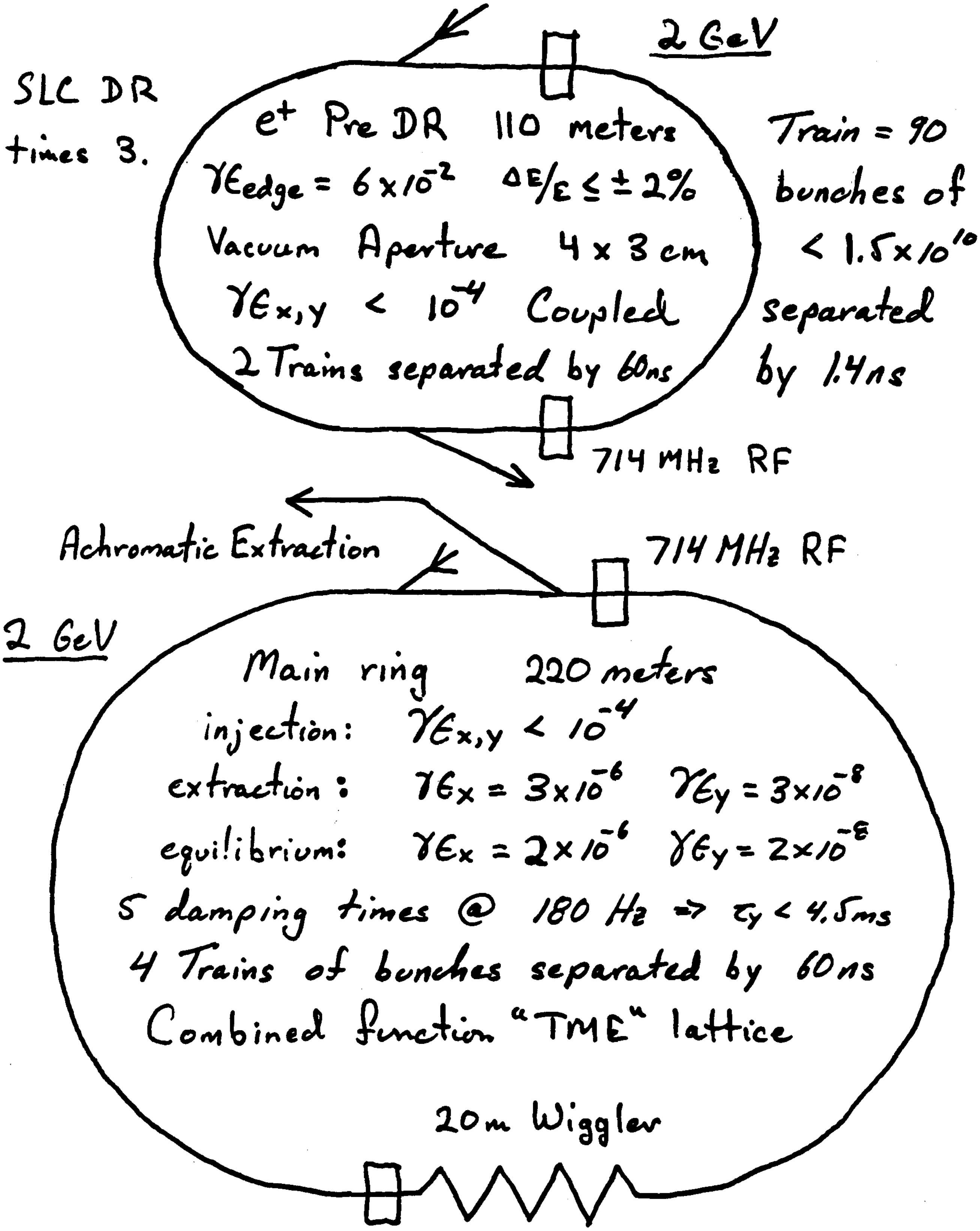
$N_{bunch} \leq 90$ $\Delta T = 1.4ns$ $\Rightarrow$ $T_{train} \leq 130ns$
plus $60^+ ns$ for
kickers

$$\gamma\epsilon_{ext} = \gamma\epsilon_{inj}\, e^{-2t/\tau} + (1 - e^{-2t/\tau})\, \gamma\epsilon_{eq}$$

	$\gamma\epsilon_{eq}$	$\gamma\epsilon_{inj}\, e^{-2t/\tau}$	$N_{d.t.}\ e^+$	$N_{d.t.}\ e^-$
(1)	2.7×10^{-8}	3×10^{-9}	8.4	5.2
⇒(2)	2×10^{-8}	1×10^{-8}	7.8	4.6

⇒ Pre DR for e^+

Main ring with 15kG bends ⇒ ½ damping
use wigglers for the other ½.


SLC DR times 3.
2 GeV
e^+ Pre DR 110 meters
$\gamma\epsilon_{edge} = 6\times10^{-2}$ $\Delta E/E \leq \pm 2\%$
Vacuum Aperture 4 x 3 cm
$\gamma\epsilon_{x,y} < 10^{-4}$ Coupled
2 Trains separated by 60ns
Train = 90 bunches of $< 1.5\times10^{10}$ separated by 1.4ns
714 MHz RF
Achromatic Extraction
714 MHz RF
2 GeV
Main ring 220 meters
injection: $\gamma\epsilon_{x,y} < 10^{-4}$
extraction: $\gamma\epsilon_x = 3\times10^{-6}$ $\gamma\epsilon_y = 3\times10^{-8}$
equilibrium: $\gamma\epsilon_x = 2\times10^{-6}$ $\gamma\epsilon_y = 2\times10^{-8}$
5 damping times @ 180 Hz $\Rightarrow$ $\tau_y < 4.5$ms
4 Trains of bunches separated by 60ns
Combined function "TME" lattice
20m Wiggler

Damping Rings

Parameters for Pre-Damping Ring

Energy	2 GeV
Circ.	114 m
Current[a]	1 Amp
ν_x, ν_y	10.18, 5.18
$\gamma\epsilon_{x,y}$[b]	27 mm-mrad
σ_ϵ	0.1%
σ_z	5.4 mm
$\tau_{x,y}$[b]	3.5 ms
$\mathcal{J}_x$	1.34
α	0.005
V_{RF}	2.5 MV
f_{RF}	714 MHz
$\Delta E/E_{RF}$[c]	2%
Lattice	30 FOOF Cells
Vacuum Aperture[c]	4.0 cm by 3.2 cm
Dynamic Aperture[d]	> 0.1 m-rad at ±2%

→ 1.5 MV
w/ energy comp.

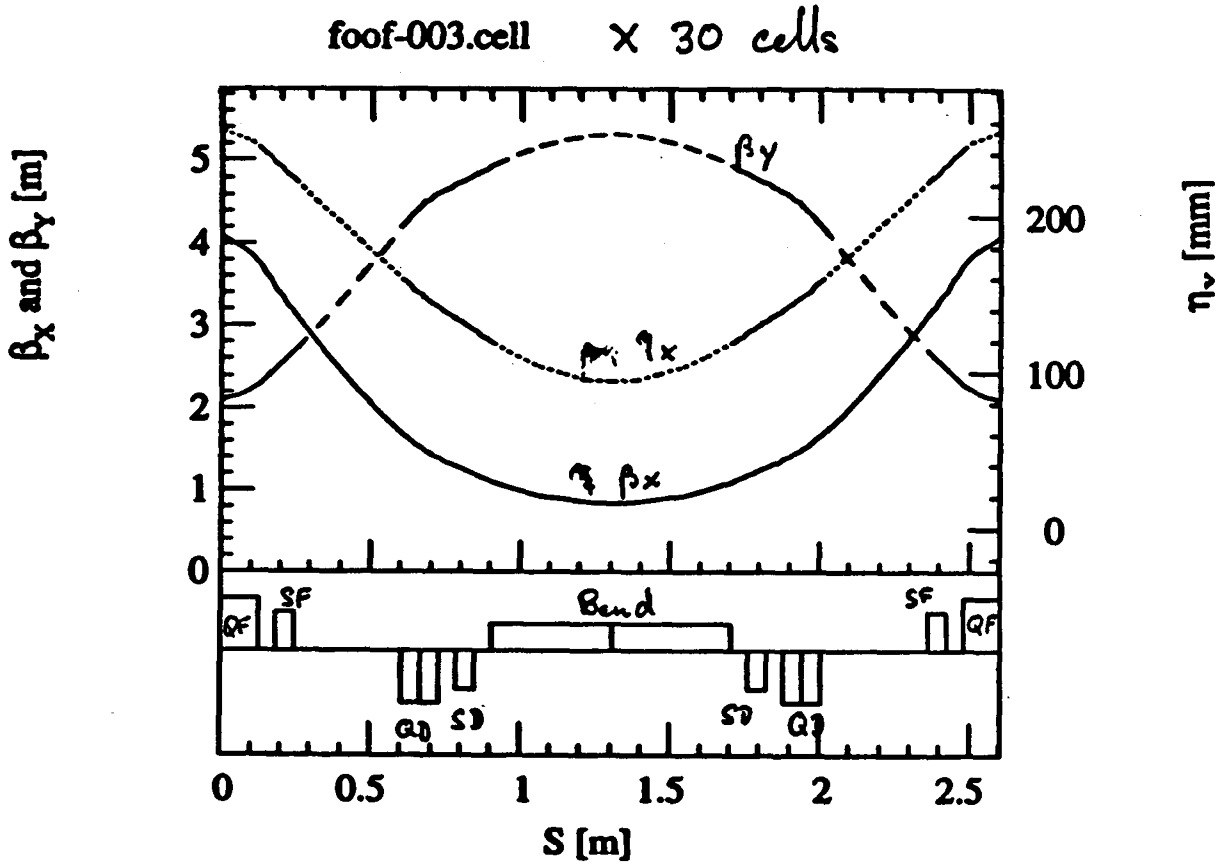
---

[a] Assuming two trains of 75 bunches of 1.5×10^{10} — the maximum train length is 90 bunches with a 1.4 ns spacing (126 ns) leaving 60 ns for the kickers.

[b] Assuming the ring is coupled.

[c] Full aperture — this provides room for a hard edge emittance and energy spread of 0.06 m-rad and ±2% with a 3 ± mm clearance.

[d] Aperture defined as $\gamma\hat{x}^2/2\beta$.



$E_0 = 2$ GeV

$\gamma\epsilon_x = 27$ mm-mrad coupled

$B_0 = 17.5$ kG

$B_1 = 33$ kG/m

Pre–DR Aperture

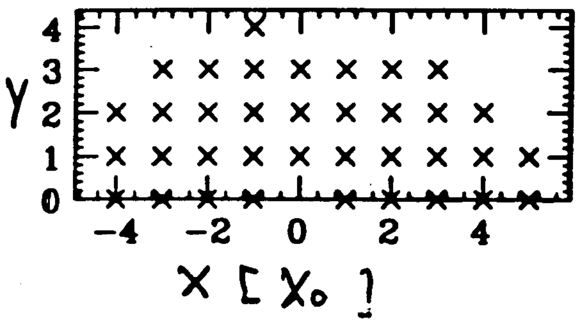
1000 Turns

No errors

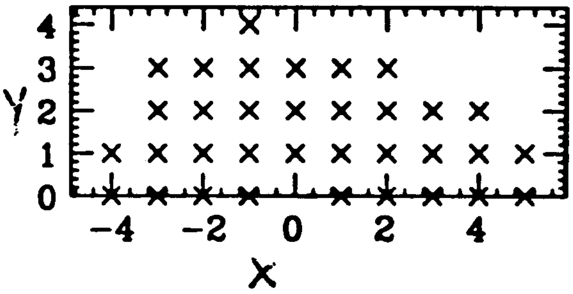
$X_0 = \sqrt{2\gamma\epsilon\beta_x/\gamma}$

$\gamma\epsilon = 0.06$

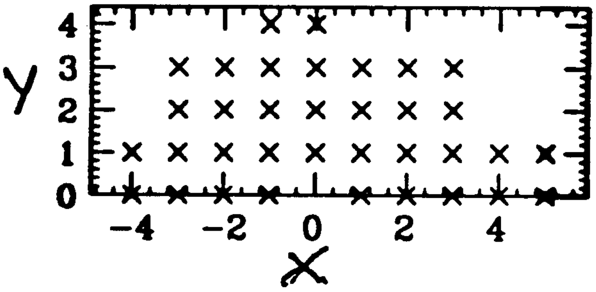
delta=0



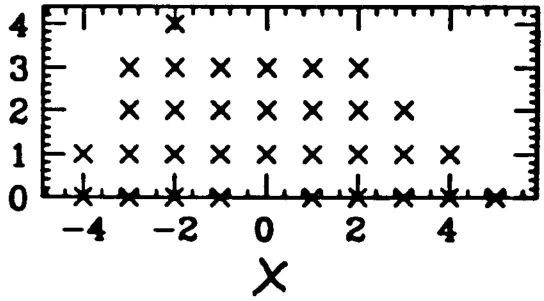
delta=1%



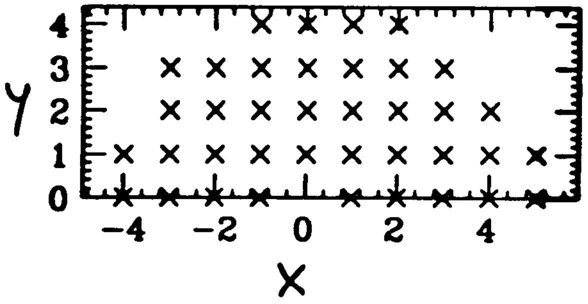
delta=–1%



delta=2%



delta=–2%



Pre-DR Inject/Extract

$$\gamma\epsilon_{edge} = 6\times10^{-2} \Rightarrow x_{edge} = \sqrt{2\epsilon\beta} = 1.2\text{cm} \text{ @ } \beta = 5\text{m}$$

$$\Delta x_{inj} = \underset{\text{(beam size)}}{(2)\ 1.2\text{cm}} + \underset{\text{(septum)}}{0.3\text{cm}} + \underset{\text{(space)}}{(2)\ 0.5\text{cm}} + \underset{(\Delta\theta/\theta)}{0.3\text{cm}}$$

$$\Delta x_{inj} = 4.0\text{ cm} \quad \text{and} \quad x_{aperture} > 5.5\text{cm}$$

$$\text{With} \quad R_{12} = 5\text{m} \Rightarrow \theta_{kick} = 8\text{mrad (inject)}$$

$$B\cdot l = 0.54\text{ kG-m}$$

$$\theta_{kick} = 6\text{mrad (extract}$$

Field Tolerances

$$\text{(inject)} \quad \frac{\Delta\theta}{\theta_{edge}} \lesssim 6\% \Rightarrow \frac{\Delta\theta}{\theta} \lesssim 1\%$$

$$\text{(ext)} \quad \frac{\Delta\theta}{\theta_{ext}} \lesssim 10\% \Rightarrow \frac{\Delta\theta}{\theta} \lesssim 0.1\%$$

Parameters for Main Damping Ring

Energy	2 GeV
Circ.	220 m
Current[a]	1 Amp
ν_x, ν_y	23.81, 8.62
$\gamma\epsilon_x, \gamma\epsilon_y$[b,c]	2.3 mm-mrad, 0.02 mm-mrad
σ_ϵ[c]	0.09%
σ_z[c]	3.5 mm
τ_x, τ_y[c]	4.2 ms, 4.8 ms
$\mathcal{J}_x$	1.15
α	0.0005
V_{RF}	1.5 MV
f_{RF}	714 MHz
$\Delta E/E_{RF}$	3%
Lattice	40 TME Cells
Vacuum Aperture[d]	2 cm?
Vacuum Pressure	1 nTorr?
Dynamic Aperture[e]	> 0.009 m-rad at ±1%
L_{bend}	68.4 cm
$B_{0\,bend}$	15.3 kG
$B_{1\,bend}$	133 kG/m
$L_{wiggler}$	20 m
B_{eff}	15.6 kG
B_{peak}	22 kG

---

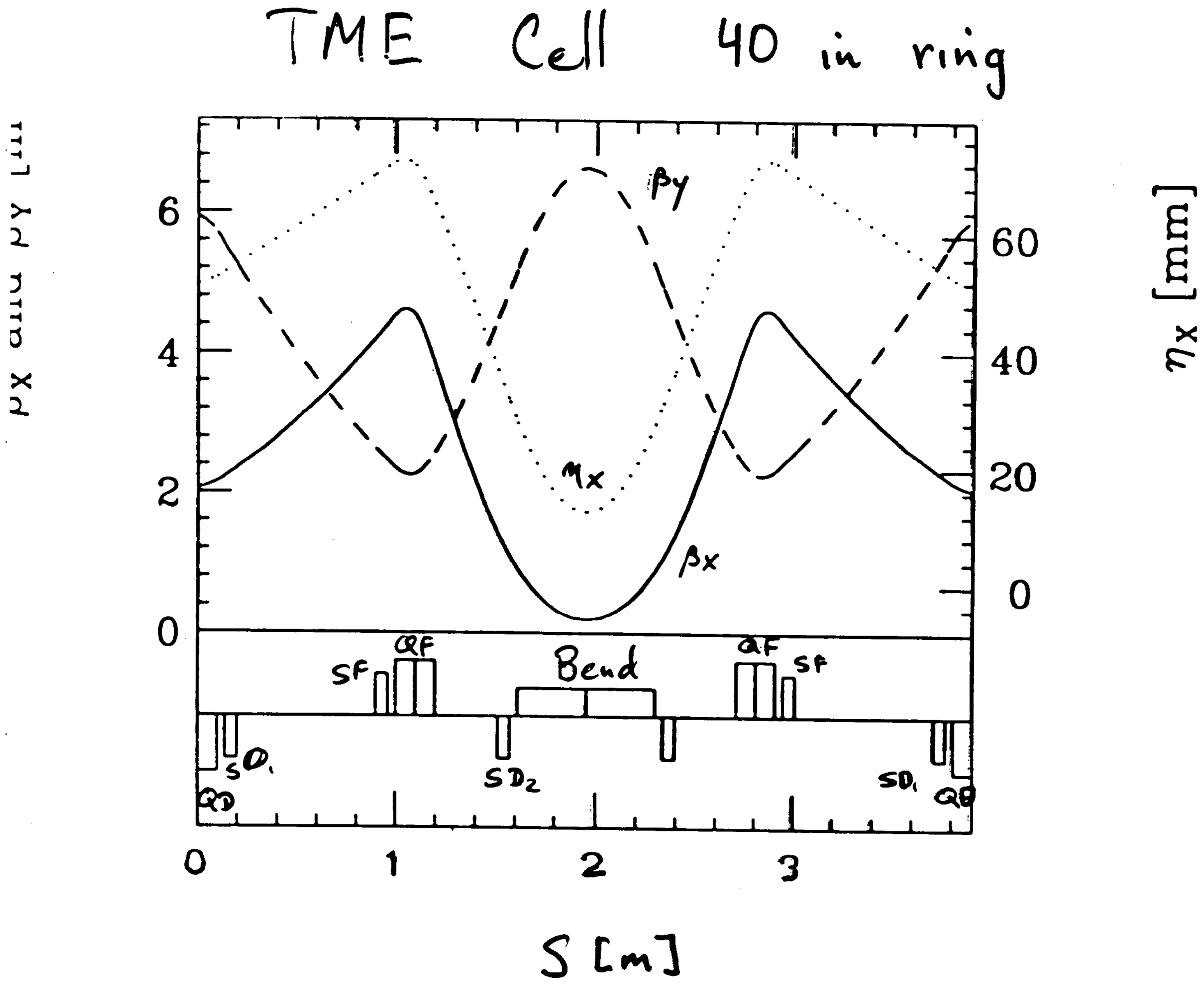
[a] Assuming four trains of 75 bunches of 1.5×10^{10} — the maximum train length is 90 bunches with a 1.4 ns spacing (126 ns) leaving 60 ns for the kickers.

[b] Before IBS has been included.

[c] With 20 meters of wiggler.

[d] Full aperture — this needs to be determined by the transverse and longitudinal dynamics and the vacuum pressure.

[e] Aperture defined as $\gamma \hat{x}^2/2\beta$ — this is without a proper injection/extraction region.

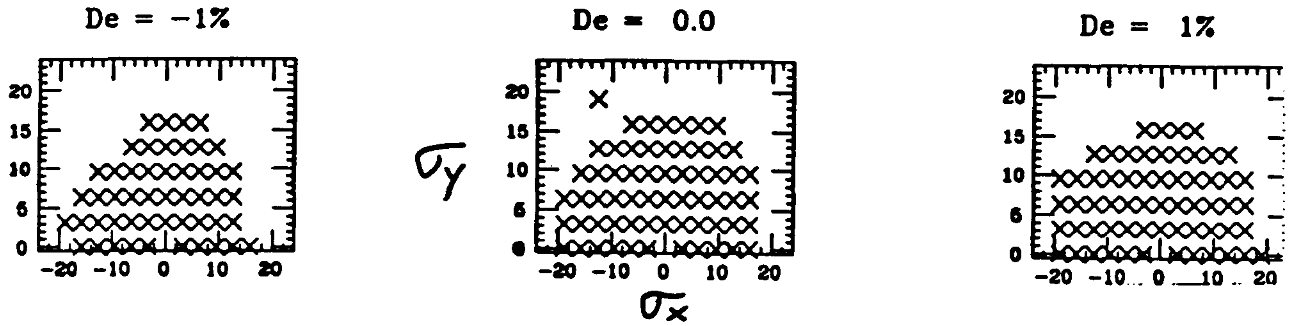


TME Cell 40 in ring

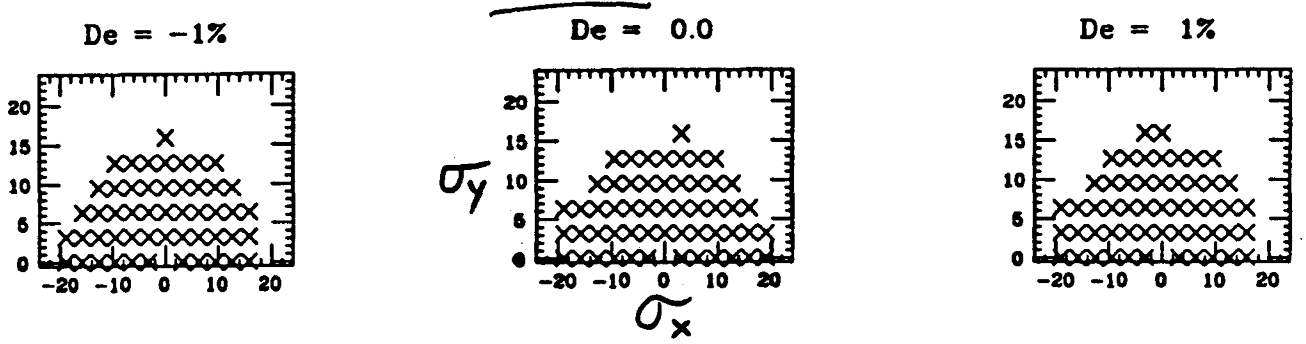
No errors

TME

$\gamma \underset{\text{rms}}{\epsilon_i} = 1 \times 10^{-4}$



FooF



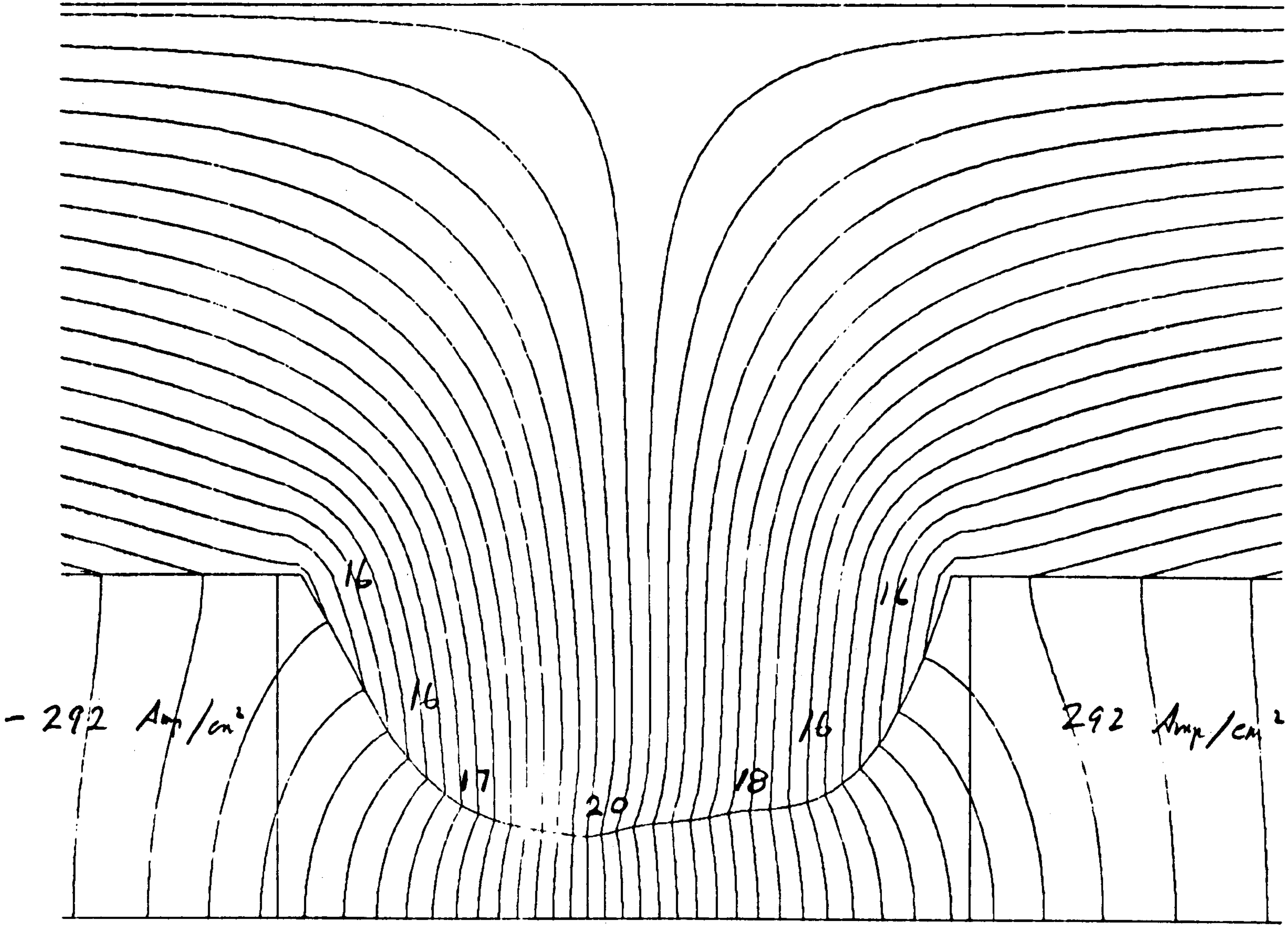
Worst case from 5 trackings w/ 100μm random errors in all elements

⇒ aperture reduced by less than $\sqrt{2}$ in X and Y.

MIRTX4 – OPTIMIZE POLE w/ WIDER BUMP, 11/29/94

15:59: 0 11/30/1994

Fields in Iron – Kgauss



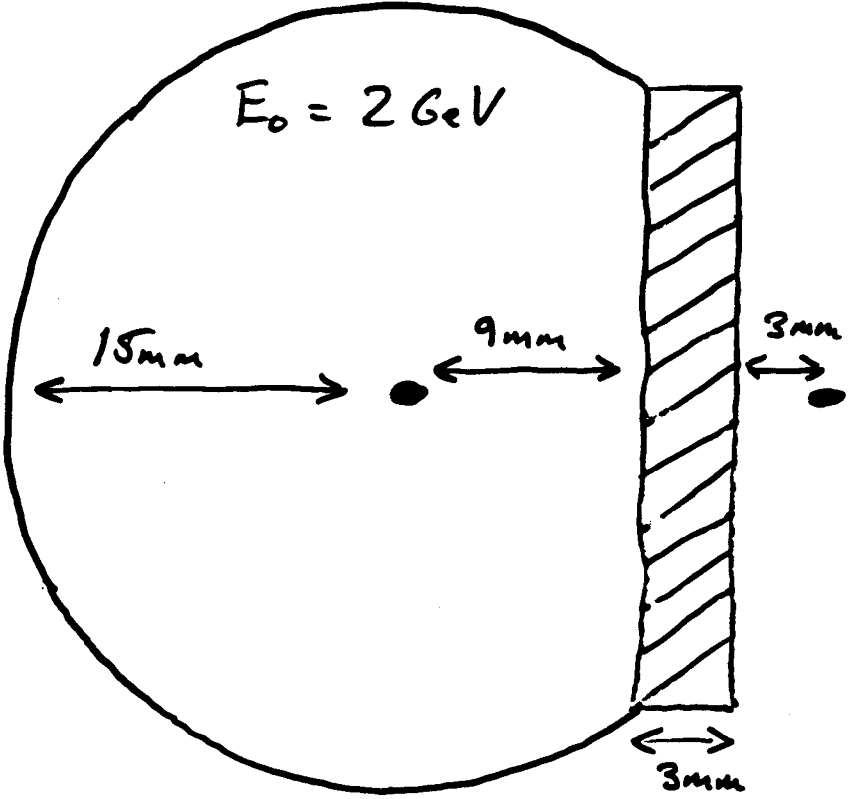
Main Ring Injection/Extraction

$\gamma\epsilon_{inj} = 1\times10^{-4}$

$\gamma\epsilon_{ext} = 3\times10^{-6}$

Space for septum = 2.5m+

Space for kicker = 2.5m+



$\gamma\epsilon_{inj} = 1\times10^{-4}$ ⇒ $\sigma_x = 0.5mm$ @ $\beta_x = 10m$

With $R_{12} = 6m$ ⇒ $\theta_{kick} = 2.5\,mrad$

$B\cdot l = 0.167\,kG\text{-}m$

Rise time = 60 ns

Fall time = 60ns

Flat top = 130 ns

With $\beta x = 4m$ @ kicker

and $\Delta\theta/\sigma_x' \lesssim 10\%$

⇒ $\Delta\theta/\theta \lesssim 5\times10^{-4}$

K. Kubo

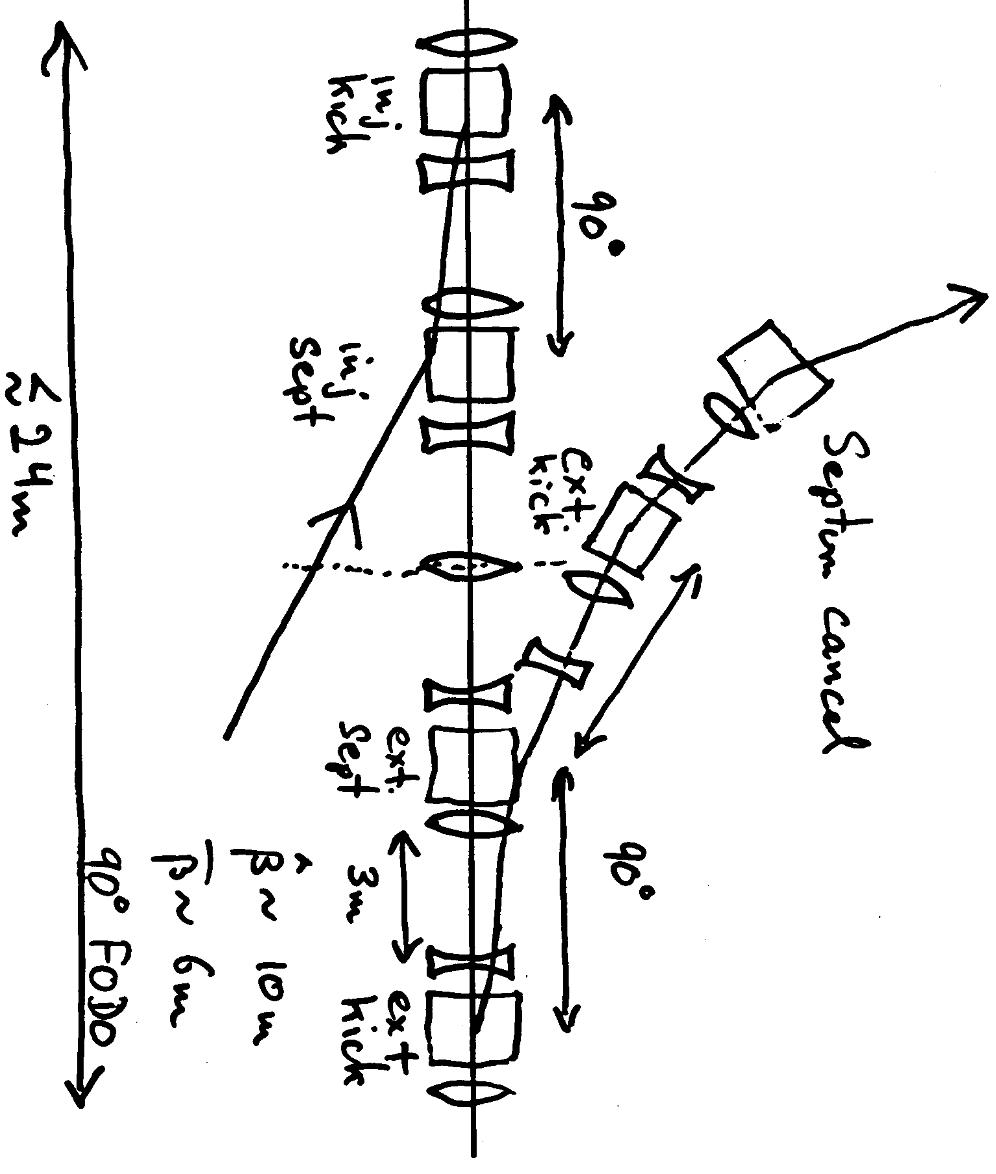
(4) 3 Kicker System for DR

Two kickers 180° apart for extraction
(one inside and one outside ring)

Two bends (septum and dipole) 180° apart

Injection kicker 360° from extraction.

Transparant to RF system



NLC DR: SR POWER FOR VARIOUS MACHINES

10/12/94
BDS

	NLC DR		PEP II HER	PEP II LER	SLC DR	PEP	SPEAR
E(GeV)	2.0	2.0	9.0	3.1	1.2	15.0	3.0
I(mA)	1000.0	1000.0	3000.0	3000.0	136.2	200.0	200.0
RAD(M)	4.4	8.7	165.0	30.6	2.0	165.5	12.7
CIRCUMFERENCE -- TOTAL M)	220.0	220.0	2,200.0	2,200.0	35.3	2,200.0	234.0
-- ARCS (M)	156.4	156.4	1,459.0	1,459.0	30.9	1,497.5	189.0
TOTAL BEND MAGNETS	40	40	192	192	40	192	36
POWER -- BEAM (KW)	325	162	10,557	802	13	5,414	113
-- BEND MAGNET (KW)	8.1	4.1	55.0	4.2	0.3	28.2	3.1
-- METER CIRC (KW)	1.5	0.7	4.8	0.4	0.4	2.5	0.5
N(gamma)=7.08E17*E*I (TOT. PHOTON/SEC)	1.6E+21	1.6E+21	2.2E+22	7.5E+21	1.3E+20	2.4E+21	4.8E+20
N(flux) (MOL/PHOTON)	**2.0E-06**	**2.0E-06**	**2.0E-06**	**2.0E-06**	**2.0E-06**	**2.0E-06**	**2.0E-06**
N1 (PHOTON/WATT)	5.0E+15	1.0E+16	2.1E+15	9.4E+15	1.0E+16	4.5E+14	4.3E+15
N3 (MOL/WATT)	1.0E+10	2.0E+10	4.1E+09	1.9E+10	2.1E+10	9.0E+09	8.6E+10
Q (TL/S/WATT)	3.0E-10	6.0E-10	1.2E-10	5.6E-10	6.3E-10	2.7E-10	2.6E-09
Qtotal = 3E-20*N(g)*N(f) for ring (TL/S)	9.7E-05	9.7E-05	1.3E-03	4.5E-04	8.0E-06	1.5E-03	2.9E-04
DESIGN PRESSURE (TORR)	1.0E-09	1.0E-09	1.0E-08	1.0E-08	1.0E-09	2.0E-08	1.0E-08
CALC. -- PUMP SPEED IN ARCS (L/S)	96,960	96,960	130,896	45,086	7,990	72,720	29,088
ACTUAL -- SPEED IN ARCS (L/S)			173,760	42,240		165,000	29,520
CALC. SPEED -- PER METER OF ARC	620	620	90	31	259	49	154
-- PER BEND MAG.	2,424	2,424	682	235	200	379	808

SRCOMPAR.XLS

Ions in Linacs of Future LC

Future linear colliders have long trains of bunches and/or very dense bunches

⇒ Significant ion densities thru
Tunnelling ionization
or
Collisional ionization and trapping

Effects

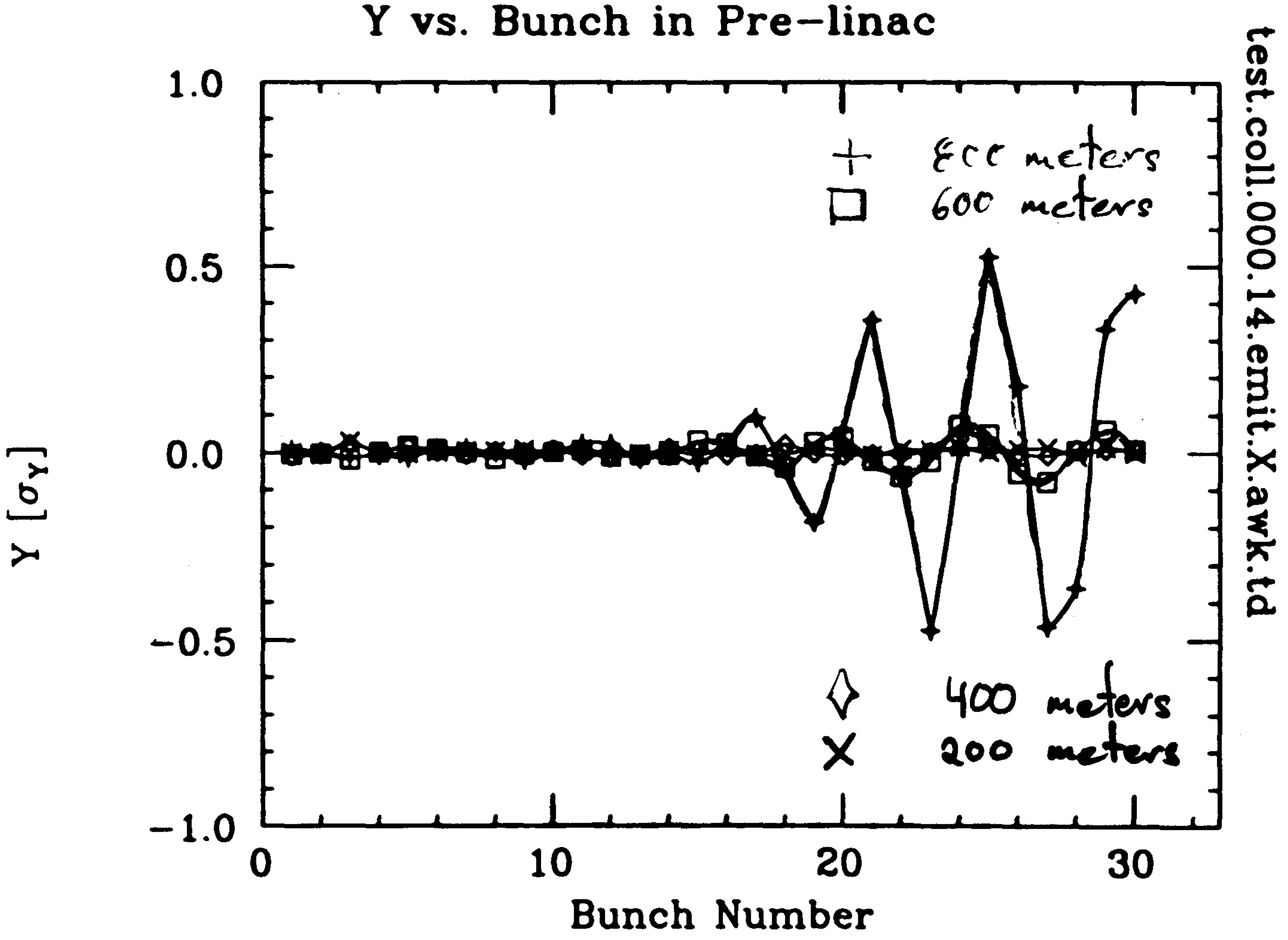
(1) Non-uniform distribution
⇒ skew fields and β-coupling

→ (2) Focusing variation between bunches
⇒ filamentation of ϵ dilutions

→ (3) Bunch-to-bunch coupling
⇒ two stream instability

(4) $Y-Z$ correlation
⇒ kicks to beam tail

(5) Generation of beam halo
⇒ Similar to intense ion beams



1st 30 bunches in NLC- pre linac with 10^{-7} Torr CO gas. Starts from noise in the bunch train positions. Expodential growth with $\sqrt{\text{distance}}$ s.t. $\propto e^{k\sqrt{s}}$

$k \propto \frac{N^{3/2}P}{\sigma_x \sigma_y}$

Damping Rings

- Optics
  - Finish the optics design
  - Design injection and extraction systems
  - Physical layout and Verify magnet specs.

Kickers

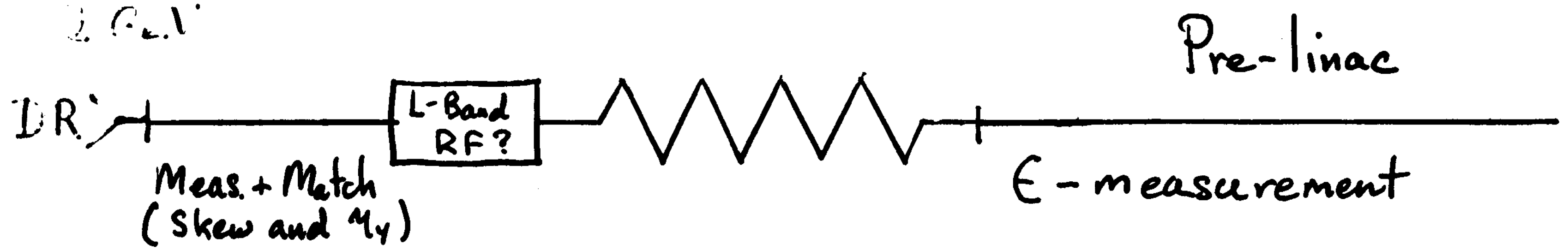
- RF system design
  - Large beam loading $I \sim 1 Amp$
  - Damped cavities for multiple bunches
- Vacuum chamber design
  - Bunch lengthening / Sawtooth??
  - 10^{-9} Torr / SR power
  - Multibunch effects

Impedance

Instabilities

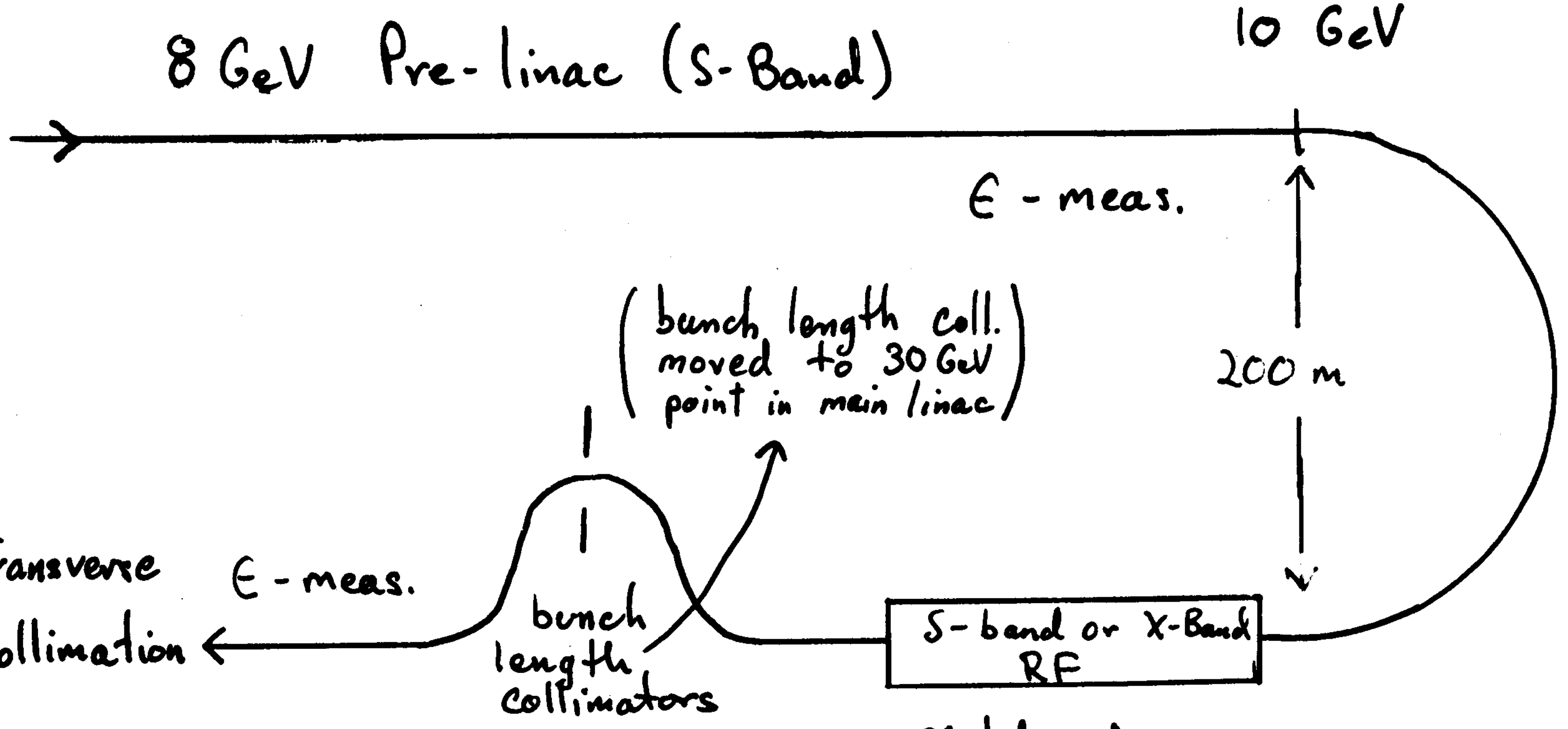
Ions

- Transfer lines
  - Energy compressors
  - Emittance and train diagnostics
- Tuning techniques and feedback
  - Diagnostic requirements
  - Dynamic aperture and vertical emittance
  - Intensity feedforward / collimation
  - Coupling correction
  - Extraction position
- Tolerances and stability
  - RF system
  - Jitter
  - Alignment
  - Supports



Rotate δ-z space by ~ 90°

$\Rightarrow \Delta\phi_{DR} \neq \Delta\phi_{pre\text{-}linac}$



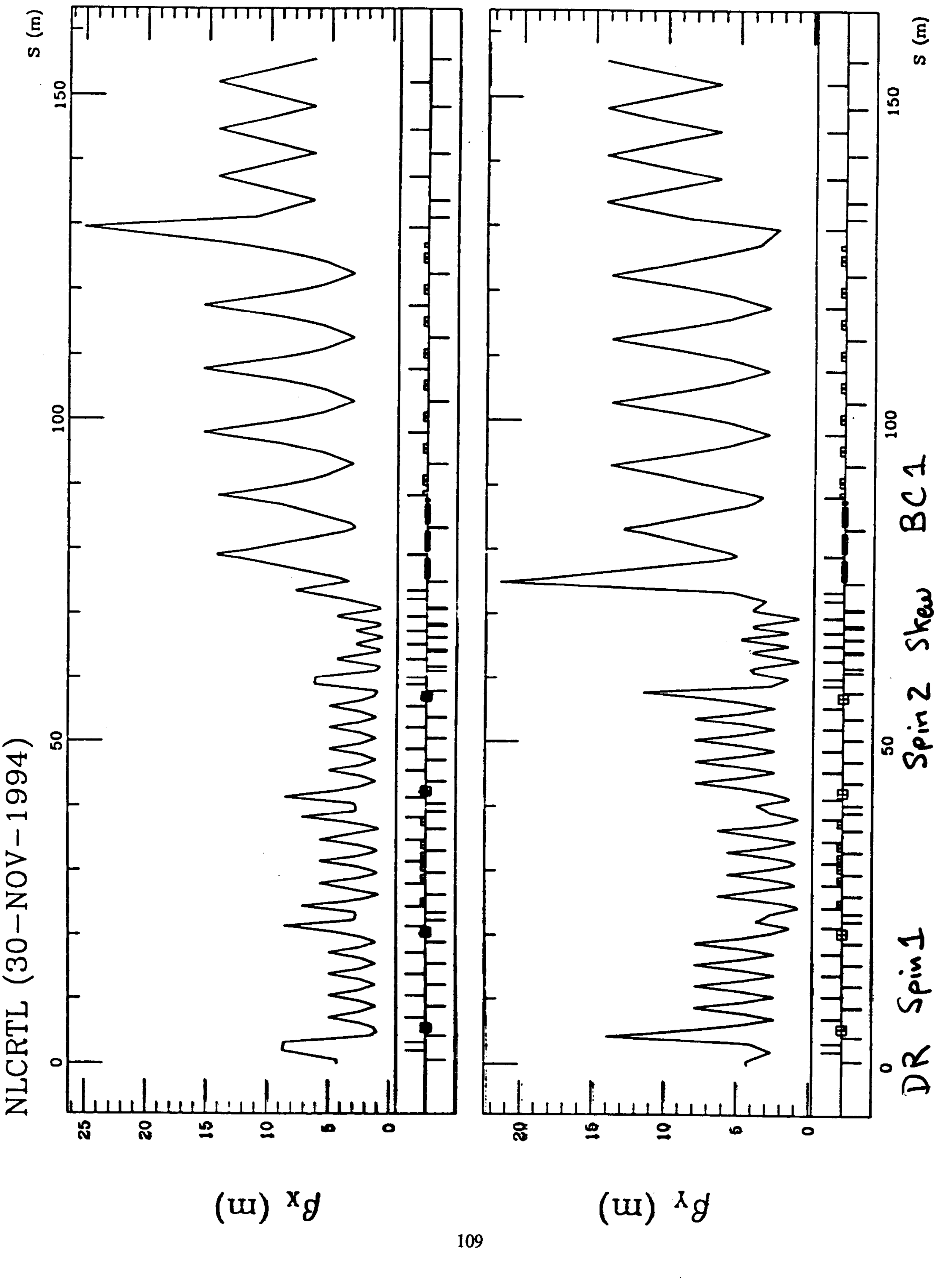
Rotate δ-z space by 360° $\Rightarrow \Delta E_{prelinac} \neq \Delta\phi_{main\ linac}$

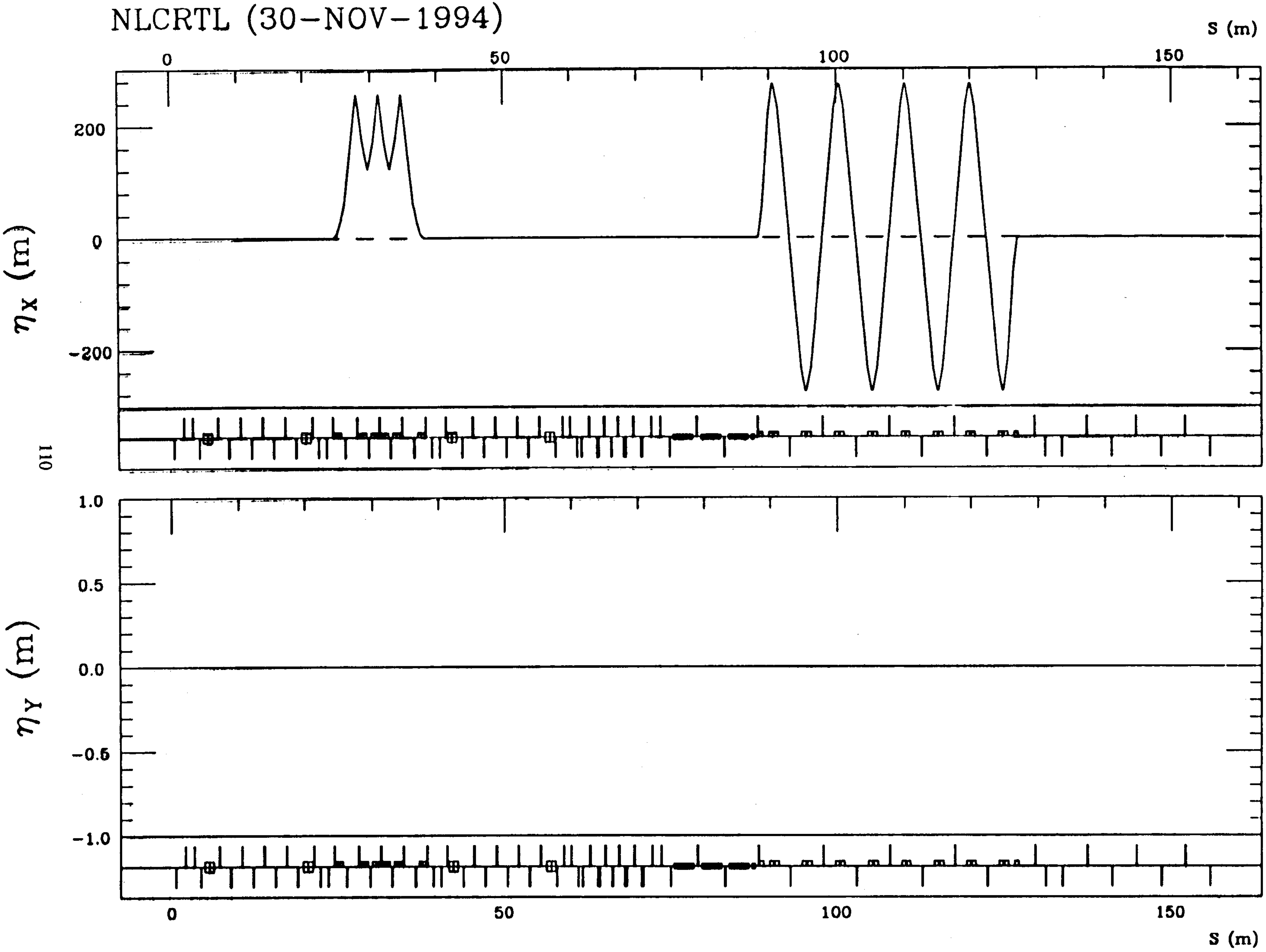
Table 1 Parameters of the low energy compressor

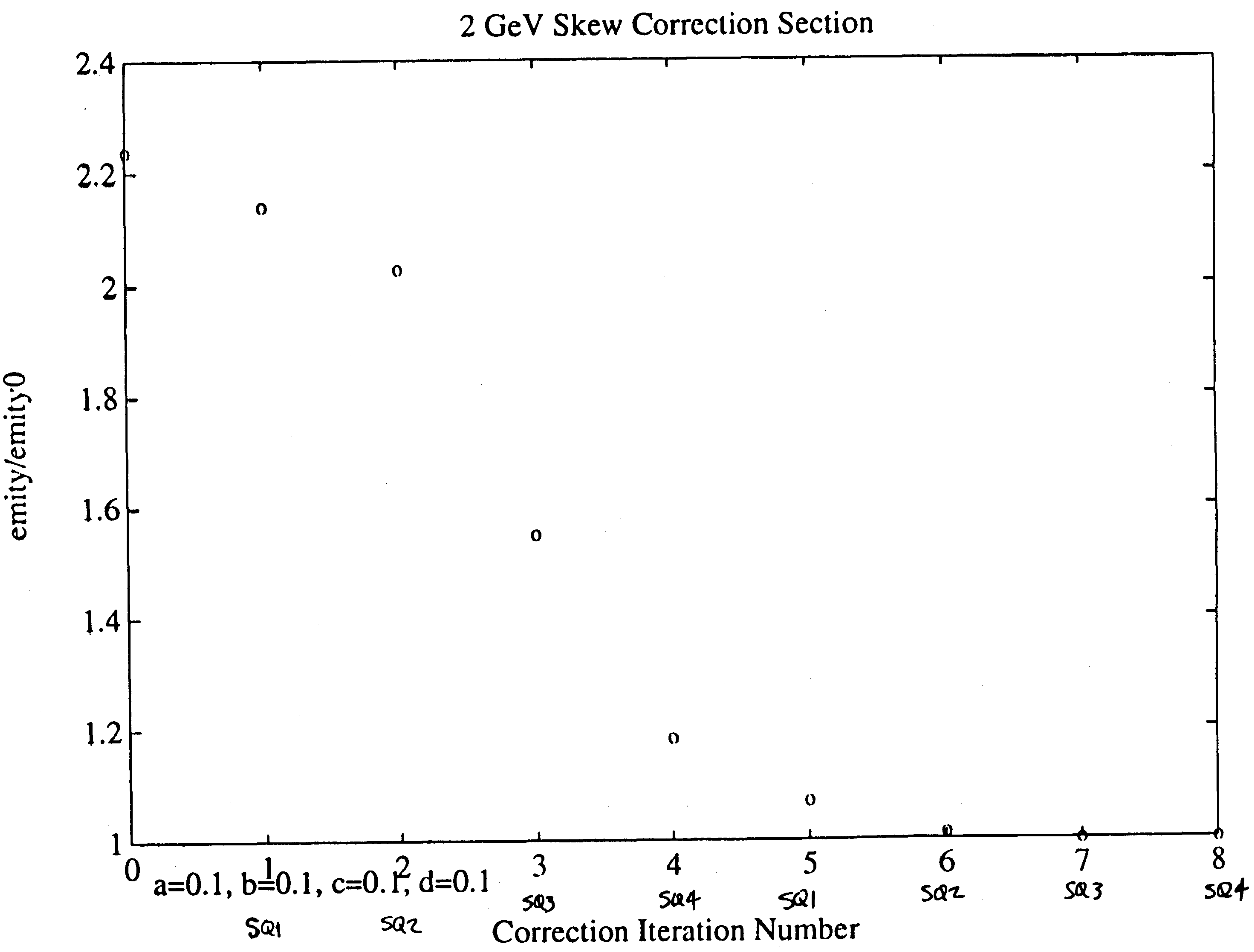
V_{RF}	67 MV	130 MV
f_{RF}	2.8 GHz	1.4 GHz
R_{56}	0.5 m	
Bunch Length	5 mm → 500 μm	
Energy Spread	0.1% → 1%	

Table 2 Parameters of the high energy compressor

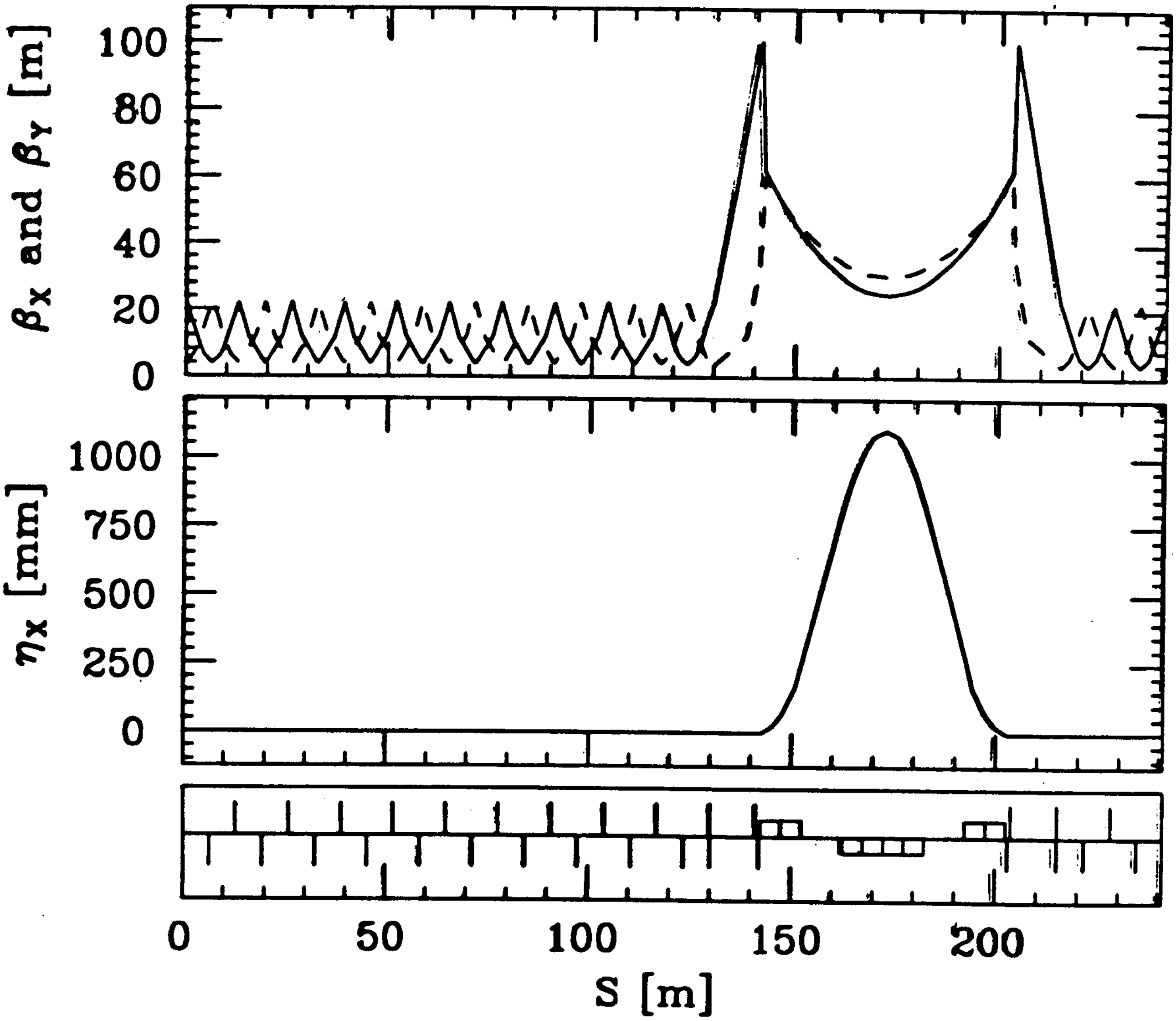
Pre-linac V_{RF}	8.3 GV	
Pre-linac f_{RF}	2.8 GHz	2.8 GHz
180° arc R_{56}	- 0.5 m	-0.25
2nd V_{RF}	1.3 GV	4 GV
2nd f_{RF}	2.8 GHz	2.8 GHz
Chicane R_{56}	0.1 m	0.036
$\Delta\epsilon_{SR}/\epsilon$ @ 10 GeV	0.2%	
Bunch Length	500 μm → 100 μm	
Energy Spread	0.2% → 1%	


NLCRTL (30-NOV-1994)
βx (m)
βy (m)
s (m)
0
50
100
150
0
5
10
15
20
25
DR
Spin1
Spin2
Skew
BC1


NLCRTL (30-NOV-1994)
S (m)
0
50
100
150
200
0
-200
η_X (m)
1.0
0.5
0.0
-0.5
-1.0
η_Y (m)
0
50
100
150
S (m)


2 GeV Skew Correction Section
emity/emity0
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0
1
2
3
4
5
6
7
8
a=0.1, b=0.1, c=0.1, d=0.1
SQ1
SQ2
SQ3
SQ4
SQ1
SQ2
SQ3
SQ4
Correction Iteration Number

High Energy Compressor – RF + Chicane



Bunch Compressors

Two stage system Compensate ±20ps in DR
90° rotation from DR
360° rotation @ 10 GeV

Reduces energy spread
space charge
wakefields

Problem Non linearity in long. optics T_{566}

Solutions
(1) Optically – strong sextupoles
(2) RF – add compensating voltage $V_c = 3 \frac{V^2}{E} \left(\frac{\lambda_c}{\lambda}\right)^2$
(3) Compensate δE in pre-linac
(4) Single stage system with higher damping ring energy.

F. Zimmermann

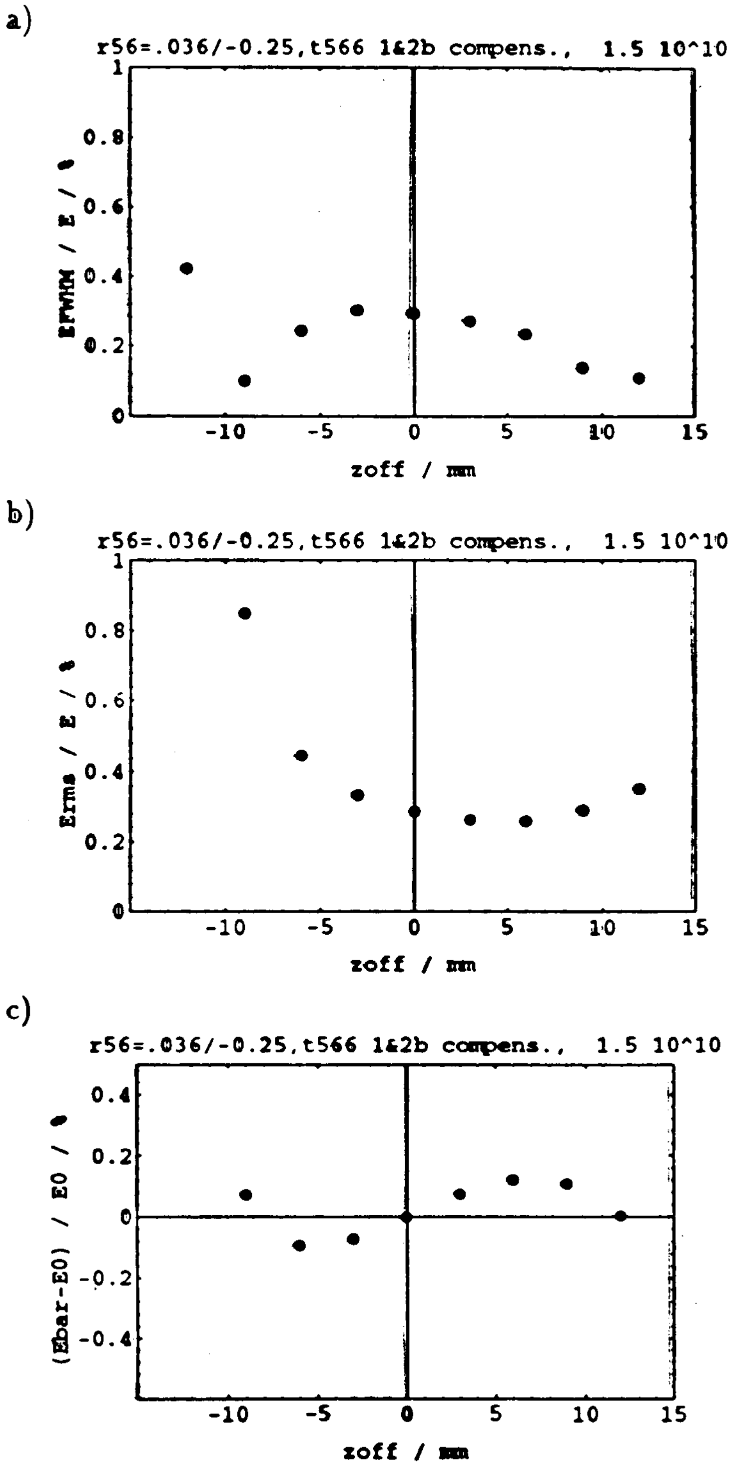


Figure 3: Beam energy at the end of the main linac as a function of initial phase error for $N_e = 1.5 \cdot 10^{10}$; a) full-width-half-maximum energy spread; b) rms-energy spread; c) mean energy.

JLC Instrumentation ('94 update)

H. Hayano (KEK)
Dec./94 KEK/SLAC mini workshop

1. Instrumentation R&D Goal/achievement

2. JLC(ATF) Instrumentation R&D this year

JLC Instrumentation Table Update Nov. '94

by H. Hayano 11/30/94

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
X,Y	Beam Position	Injector /Pre-Linac	<1μm	<50μm	average	150	strip line BPM
		Damping Ring	<1μm	<50μm	av.	300	button BPM
		Bunch Compressor	<1μm	<10μm	av./each	100	strip line BPM
		Main Linac	<1μm	<10μm	av./each	3000	strip line BPM
		Final Focus	<10nm	<10nm	av.	40	cavity BPM
Z	Bunch Spacing	Bunch Compressor	0.01mm(0.03ps)	0.03mm(0.1ps)	each	2	streak camera
		Main Linac	0.01mm(0.03ps)	0.03mm(0.1ps)	each	10	streak camera
$\sigma x,\sigma y$	Transverse Spread	Injector /Pre-Linac	50μm		av./each	30	wire scanner
		Damping Ring	20μm for σx 2μm for σy		av./each	3	synchrotron radiation
		Bunch Compressor	1μm		av./each	20	wire scan/synchrotron
		Main Linac	1μm		av./each	100	wire scanner
		Final Focus	1μm		av./each	20	wire scanner
		Final Focus	3~30nm		each.	2	Compton scattering
		Final Focus	<1nm		each	1	Compton scattering
σz	Bunch Length	Injector /Pre-Linac	0.5mm(1.7ps)		each	4	streak camera
		Damping Ring	0.5mm(1.7ps)		each	3	streak camera
		Bunch Compressor	0.01mm(0.03ps)		av.	8	synch. rad. spectrum
		Main Linac	0.01mm(0.03ps)		av.	10	synch. rad. spectrum
		Final Focus	0.01mm(0.03ps)		av.	2	synch. rad. spectrum
Nb	Number of Charge	Injector /Pre-Linac	0.1%	1%	each	40	wall current
		Damping Ring	0.1%	1%	each	12	wall current
		Bunch Compressor	0.1%	1%	each	16	wall current
		Main Linac	0.1%	1%	each	250	wall current
		Final Focus	0.1%	1%	each	10	wall current

1. Transverse Beam Position

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
X,Y	Beam Position	Injector /Pre-Linac	<1μm	<50μm	average	150	strip line BPM
		Damping Ring	<1μm	<50μm	av.	300	button BPM
		Bunch Compressor	<1μm	<10μm	av.	100	strip line BPM
		Main Linac	<1μm	<10μm	av./each	3000	strip line BPM
		Final Focus	<10nm	<10nm	av.	40	cavity BPM

Achievement

Strip Line BPM : FFTB
Cavity BPM (in laboratory) : VLEPP , CLIC (JLC, TESLA ....)
Button BPM (in laboratory) : JLC-ATF

R&D

Cavity BPM (in laboratory) : JLC, TESLA ....
Cavity BPM beam test : FFTB
multi-bunch BPM : NLC , JLC

2. Bunch Spacing

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
Z	Bunch Spacing	Bunch Compressor	0.01mm(0.03ps)	0.03mm(0.1ps)	each	2	streak camera
		Main Linac	0.01mm(0.03ps)	0.03mm(0.1ps)	each	10	streak camera

Achievement

(0.2ps resolution streak camera by Hamamatsu July '93)

R&D

waiting very fast streak camera

3. Transverse Spread

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
$\sigma x,\sigma y$	Transverse Spread	Injector /Pre-Linac	50μm		av./each	30	wire scanner
		Damping Ring	20μm for σx 2μm for σy		av./each	3	synchrotron radiation
		Bunch Compressor	1μm		av./each	20	wire scan/synchrotron
		Main Linac	1μm		av./each	100	wire scanner
		Final Focus	1μm		av./each	20	wire scanner
		Final Focus	3~30nm		each.	2	Compton scattering
		Final Focus	<1nm		each	1	Compton scattering

Achievement

Wire scanner : SLC , FFTB , JLC-ATF
Synchrotron Monitor(20μm) : SLC-DR , JLC-ES
Compton Scatter Monitor : FFTB

R&D

Carbon wire scanner : JLC-Kyoto
Laser Wire Scanner : SLC
Synchrotron Monitor(2μm) : KEK-PF

4. Bunch Length

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
σ_z	Bunch Length	Injector /Pre-Linac	0.5mm(1.7ps)		each	4	streak camera
		Damping Ring	0.5mm(1.7ps)		each	3	streak camera
		Bunch Compressor	0.01mm(0.03ps)		av.	8	synch. rad. spectrum
		Main Linac	0.01mm(0.03ps)		av.	10	synch. rad. spectrum
		Final Focus	0.01mm(0.03ps)		av.	2	synch. rad. spectrum

Achievement

Streak Camera (0.2-0.5ps) : SLC , JLC-ATF (Hamamatsu co.)

R&D

Synch. rad. Spectrum monitor : Happek, Nakazato

5. Number of Charge

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
Nb	Number of Charge	Injector /Pre-Linac	0.1%	1%	each	40	wall current
		Damping Ring	0.1%	1%	each	12	wall current
		Bunch Compressor	0.1%	1%	each	16	wall current
		Main Linac	0.1%	1%	each	250	wall current
		Final Focus	0.1%	1%	each	10	wall current

Achievement

wall current monitor : every Laboratory

R&D

precise charge meas. by WCM : JLC-ATF

JLC Instrumentation Table Update Nov. '94

by H. Hayano 11/30/94

Meas.		location	resolution	accuracy	bunch train	# of unit	possible candidates
X,Y	Beam Position	Injector /Pre-Linac	<1µm	<50µm	average	150	strip line BPM
		Damping Ring	<1µm	<50µm	av.	300	button BPM
		Bunch Compressor	<1µm	<10µm	av./each	100	strip line BPM
		Main Linac	<1µm	<10µm	av./each	3000	strip line BPM
		Final Focus	<10nm	<10nm	av.	40	cavity BPM
Z	Bunch Spacing	Bunch Compressor	0.01mm(0.03ps)	0.03mm(0.1ps)	each	2	streak camera
		Main Linac	0.01mm(0.03ps)	0.03mm(0.1ps)	each	10	streak camera
$\sigma x,\sigma y$	Transverse Spread	Injector /Pre-Linac	50µm		av./each	30	wire scanner
		Damping Ring	20µm for σx 2µm for σy		av./each	3	synchrotron radiation
		Bunch Compressor	1µm		av./each	20	wire scan/synchrotron
		Main Linac	1µm		av./each	100	wire scanner
		Final Focus	1µm		av./each	20	wire scanner
		Final Focus	3~30nm		each.	2	Compton scattering
		Final Focus	<1nm		each	1	Compton scattering
σz	Bunch Length	Injector /Pre-Linac	0.5mm(1.7ps)		each	4	streak camera
		Damping Ring	0.5mm(1.7ps)		each	3	streak camera
		Bunch Compressor	0.01mm(0.03ps)		av.	8	synch. rad. spectrum
		Main Linac	0.01mm(0.03ps)		av.	10	synch. rad. spectrum
		Final Focus	0.01mm(0.03ps)		av.	2	synch. rad. spectrum
Nb	Number of Charge	Injector /Pre-Linac	0.1%	1%	each	40	wall current
		Damping Ring	0.1%	1%	each	12	wall current
		Bunch Compressor	0.1%	1%	each	16	wall current
		Main Linac	0.1%	1%	each	250	wall current
		Final Focus	0.1%	1%	each	10	wall current

- 10µm Accuracy stripline BPM
- multi bunch BPM
- Cavity BPM
- high resolution streak camera
- 2µm resolution synch. light monitor
- 10µm resolution BLM
- precise multibunch WCM

2. JLC(ATF) Instrumentation R&D this year

ATF

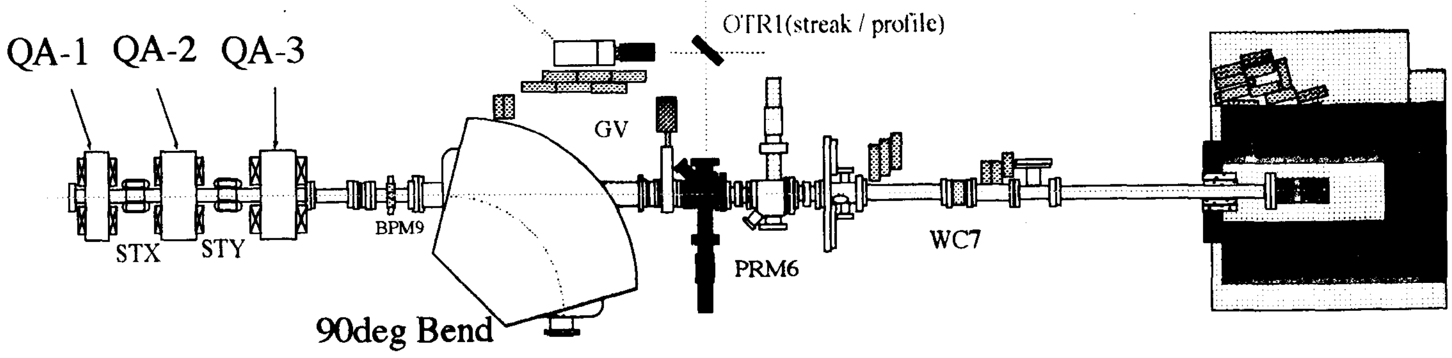
OTR monitors	beam size, emittance energy spread bunch length
Wire scanner	multi-bunch emittance
Button BPM	calibration/beam test

ES-KEK

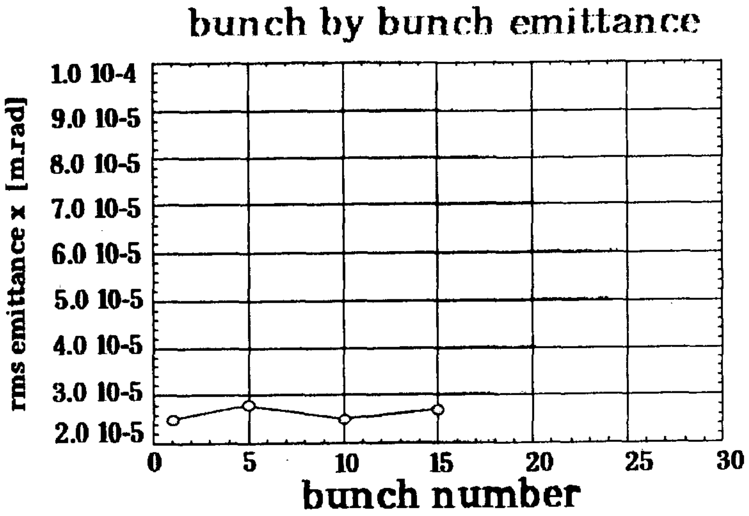
Synch. rad. monitor
gated camera & streak camera

Beam Size & Emittance by OTR monitor

I.I. gate Camera
with 3ns gate

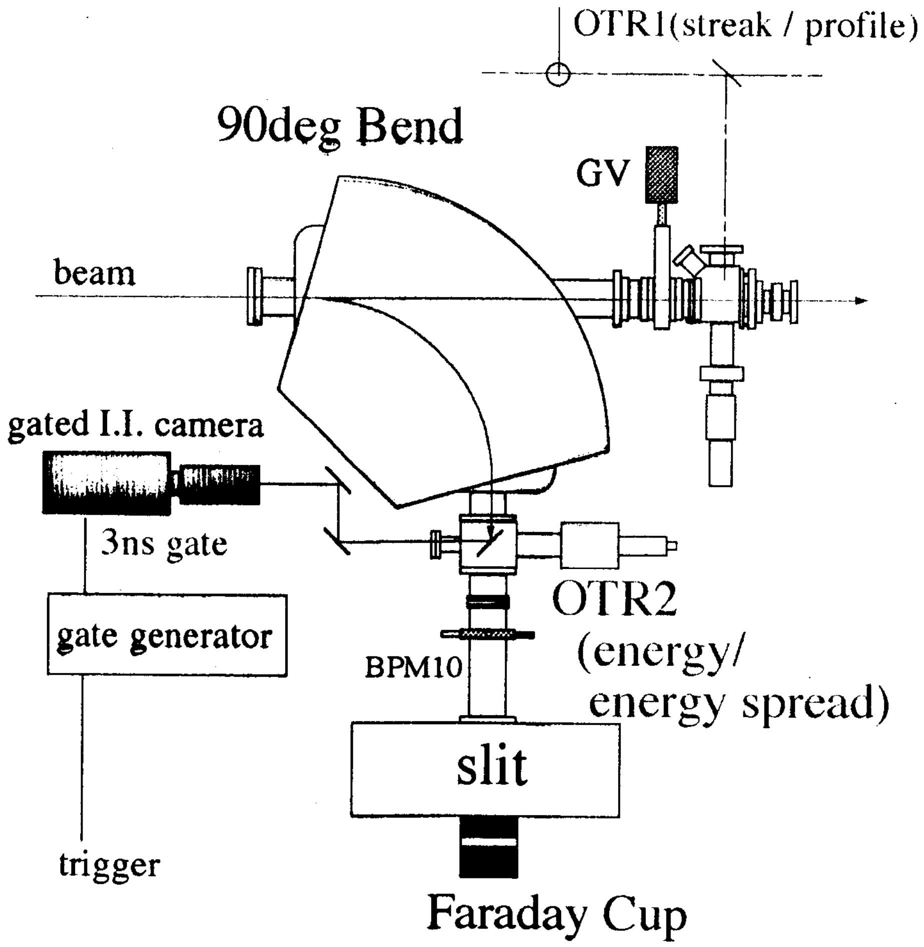


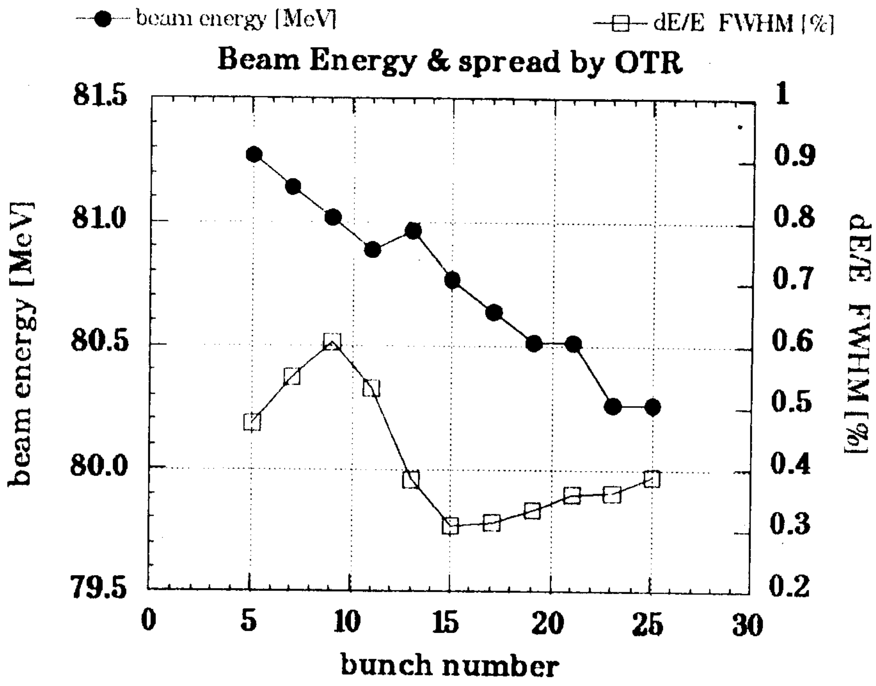
Profile examples



ATF LINAC 80MeV Injector Aug. '94

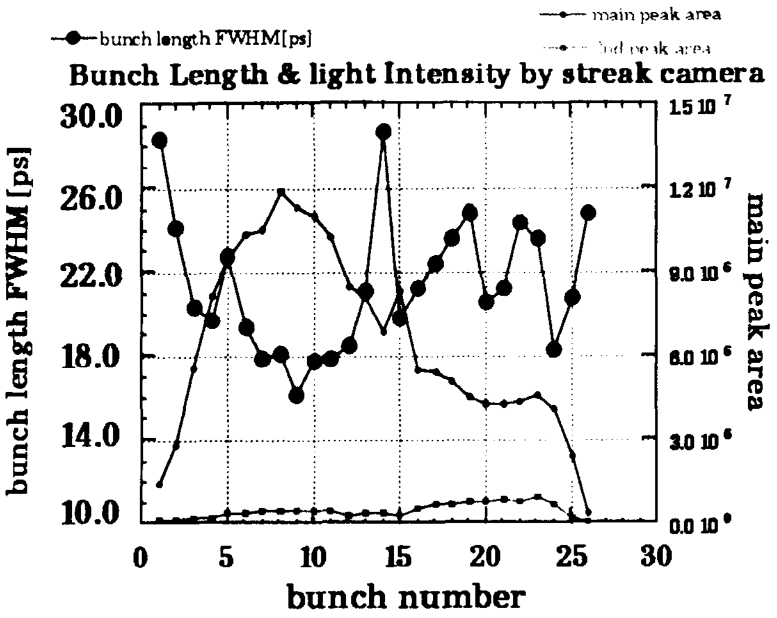
Energy and Energy Spread by OTR & gated Camera



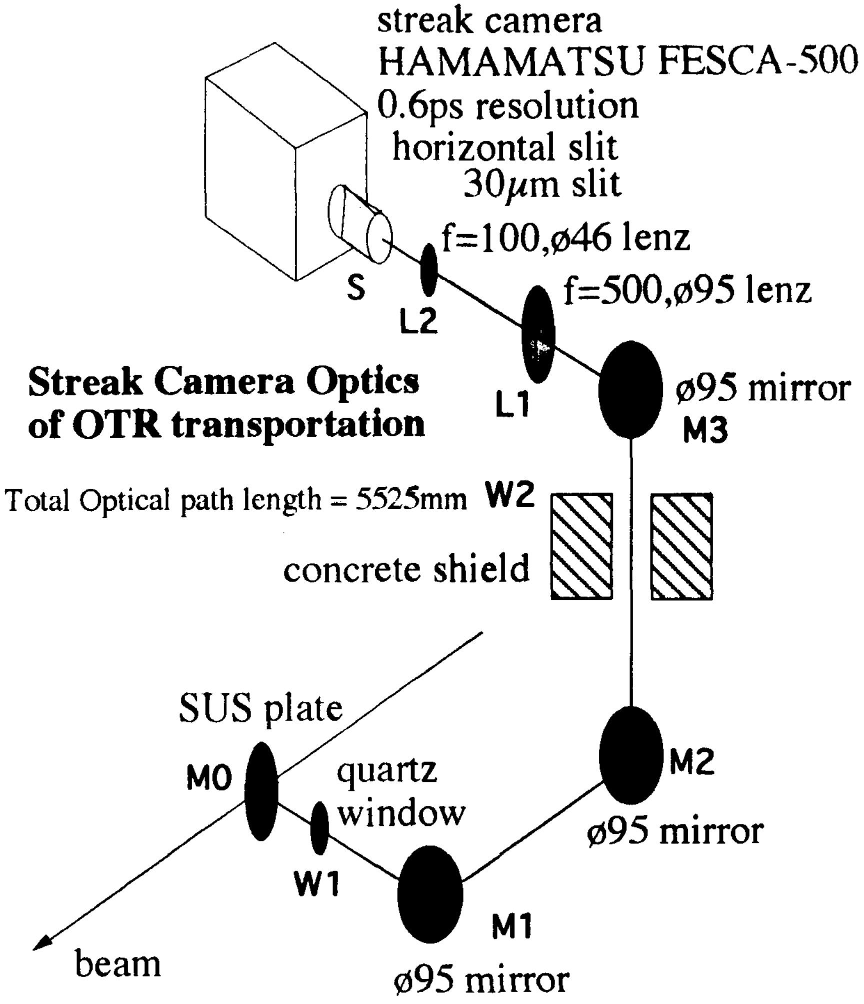


ATF LINAC 80MeV injector Aug. '94

Bunch Length
by OTR & Streak Camera



Bunch Length & light Intensity by streak camera

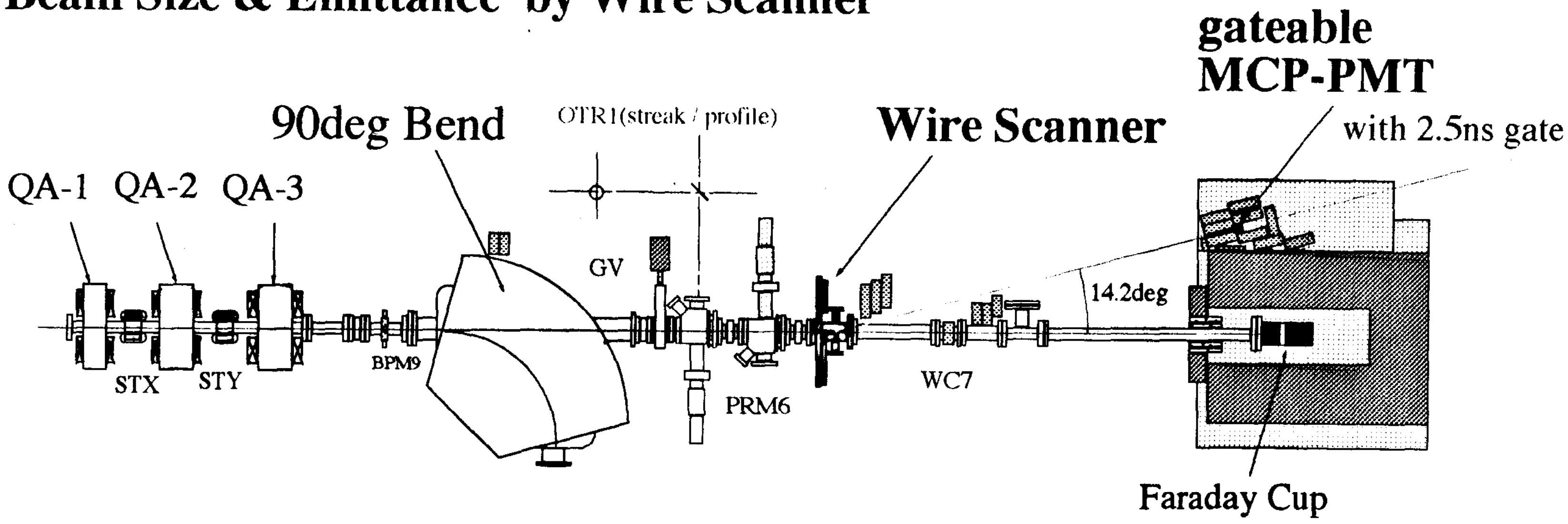


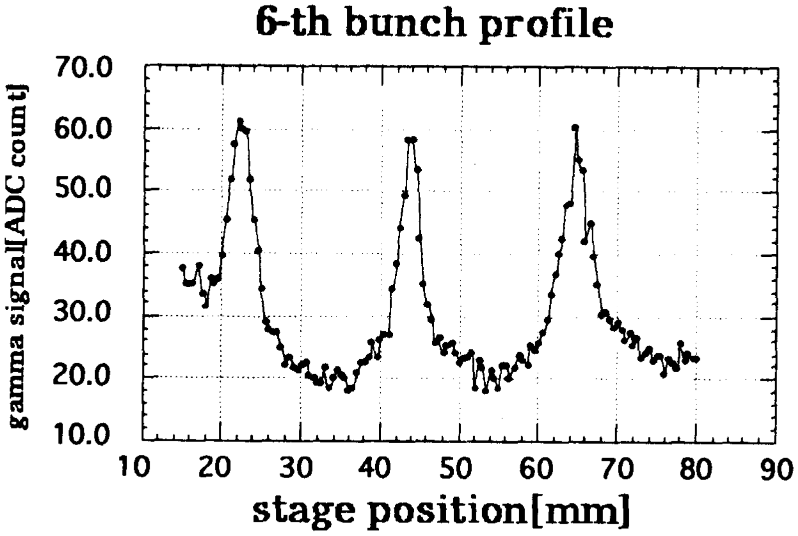
Streak Camera Optics of OTR transportation

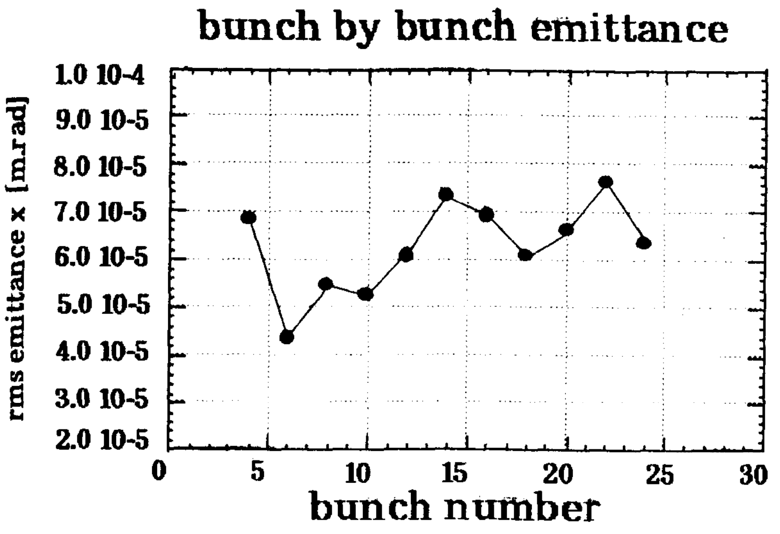
Total Optical path length = 5525mm

ATF LINAC 80MeV Injector Aug. '94

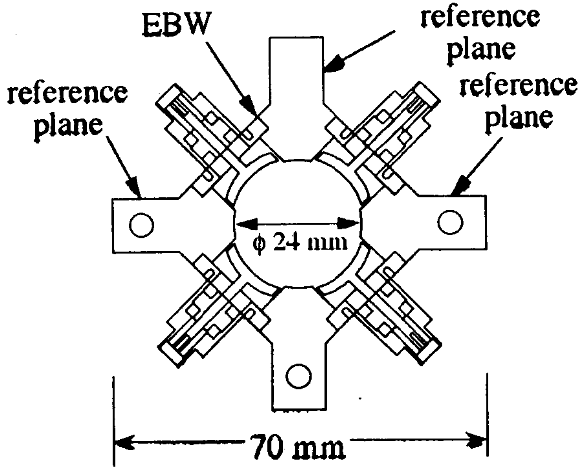
Beam Size & Emittance by Wire Scanner

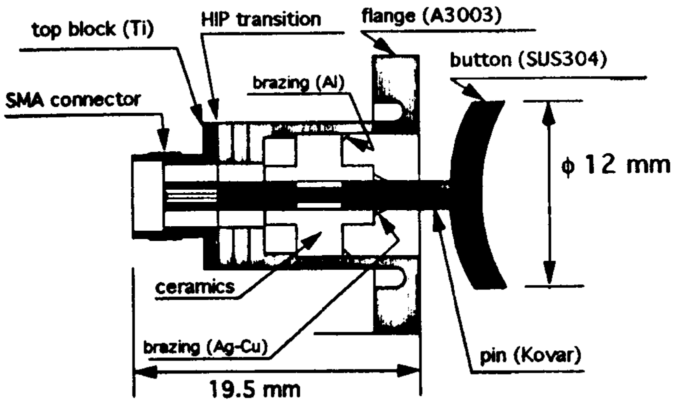


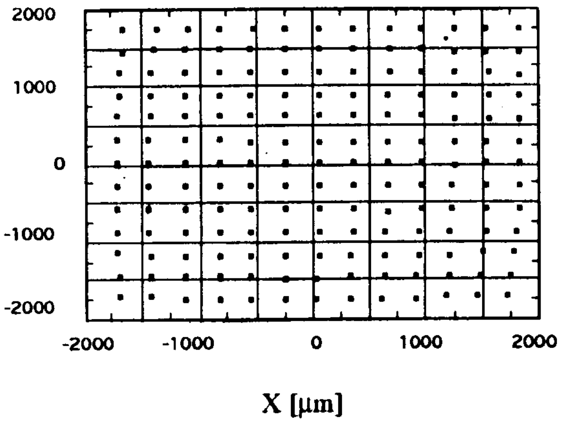




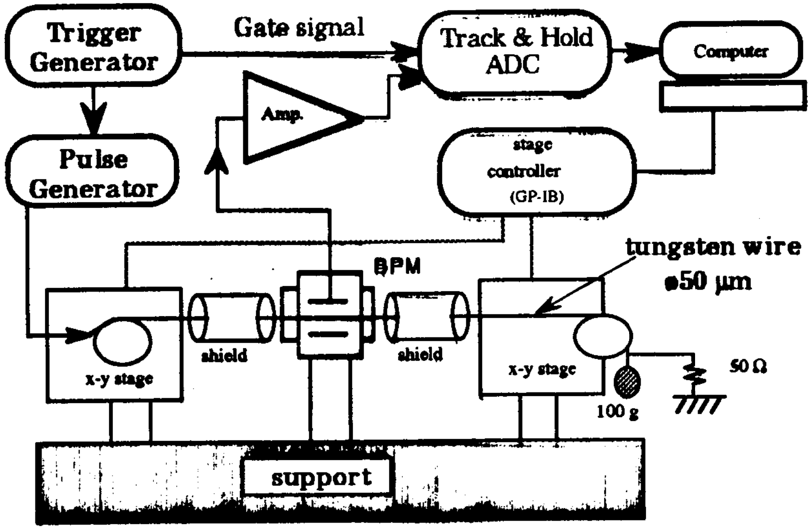
ATF DR Button BPM



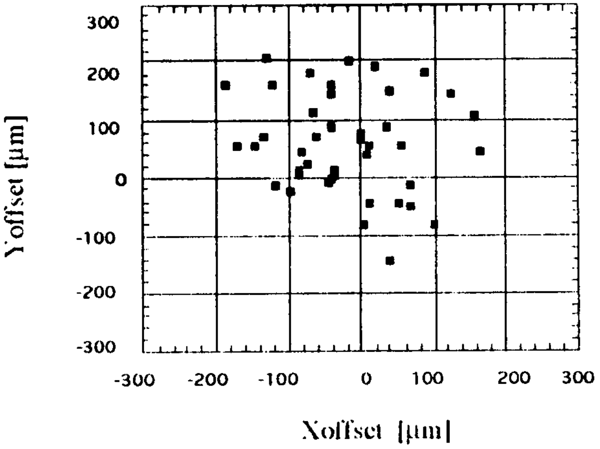




mapping



Calibration Stand

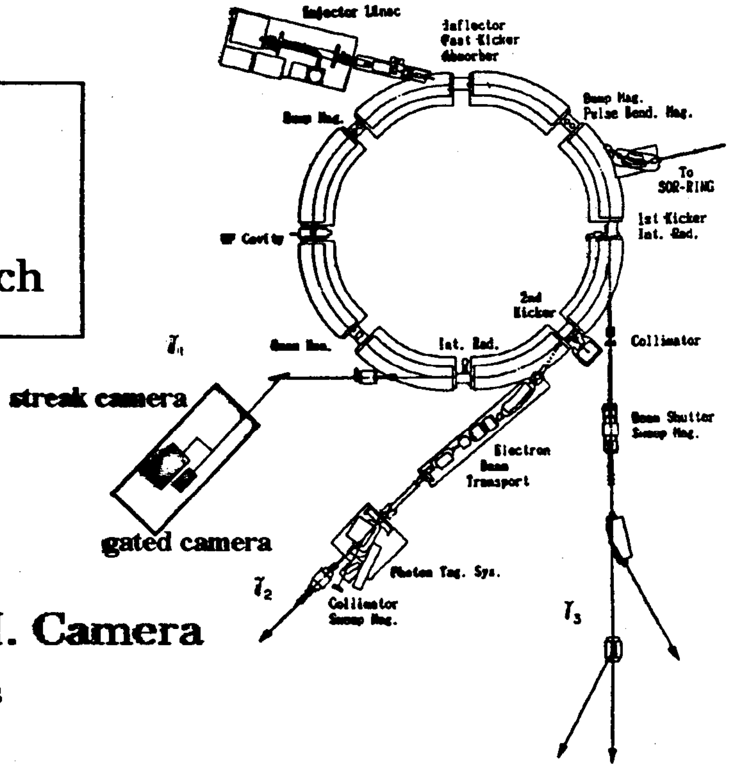


electrical offset

Synchrotron Light Monitor Development

ES

E top = 1.2 GeV
rep. rate = 21 Hz
16 bunches
1e9 electron/bunch



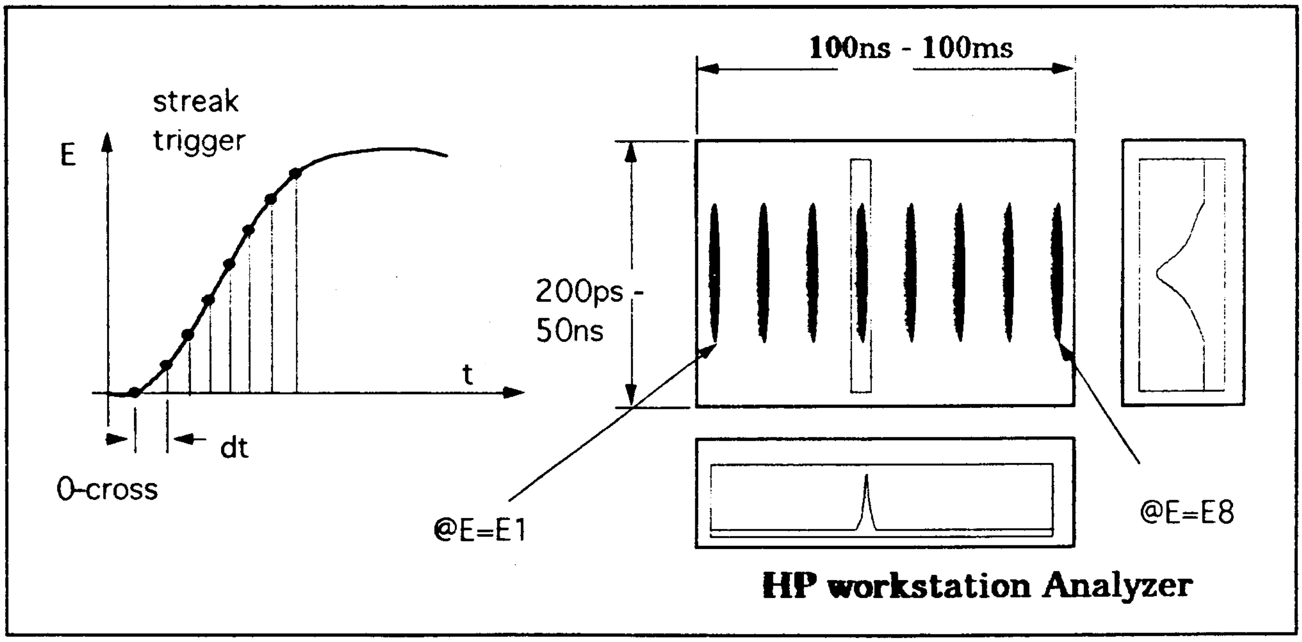
Tokyo Univ. Electron Synchrotron(ES)

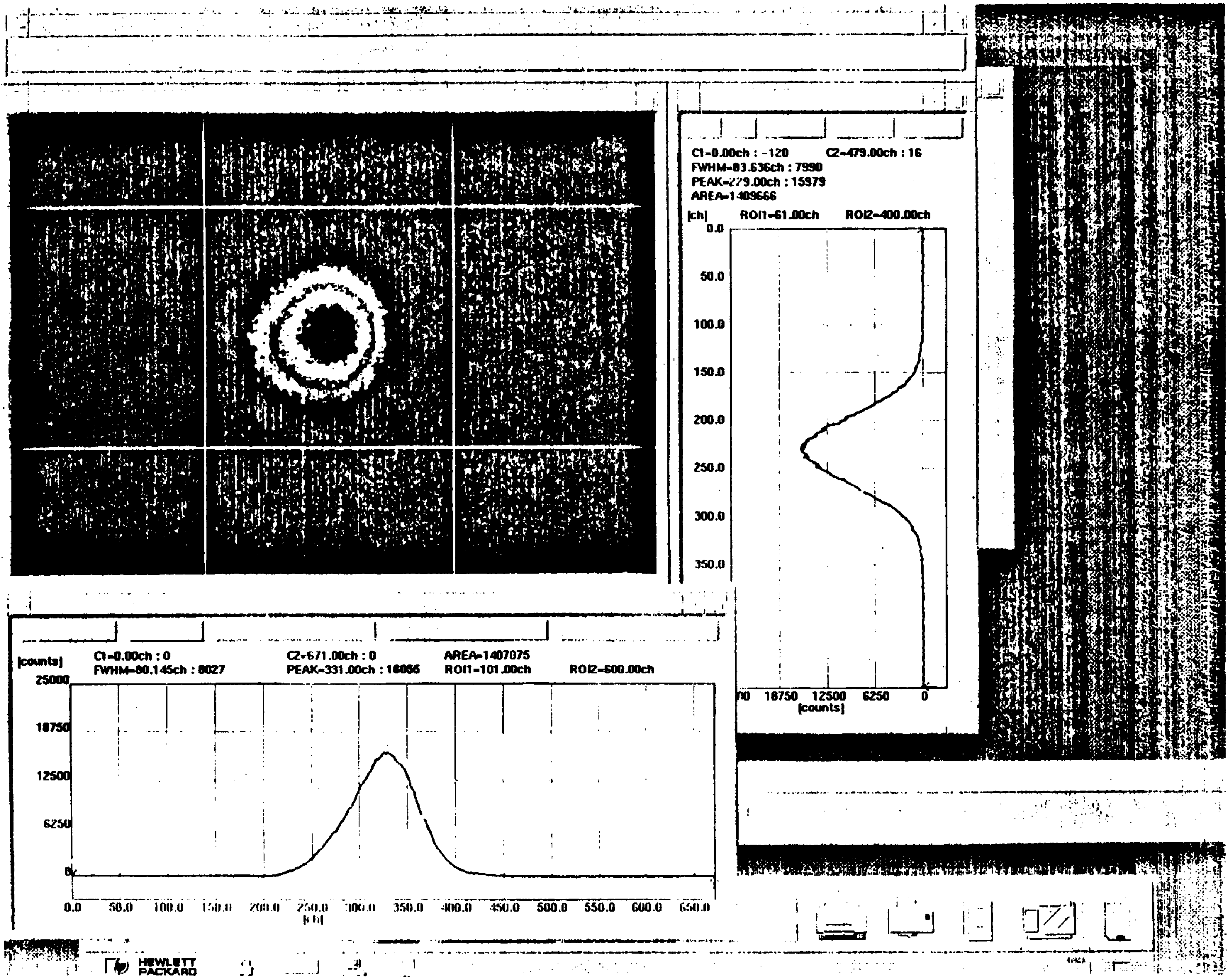
Hamamatsu gate I.I. Camera

minimum gate = 3 ns

Hamamatsu
dual time base Streak Camera

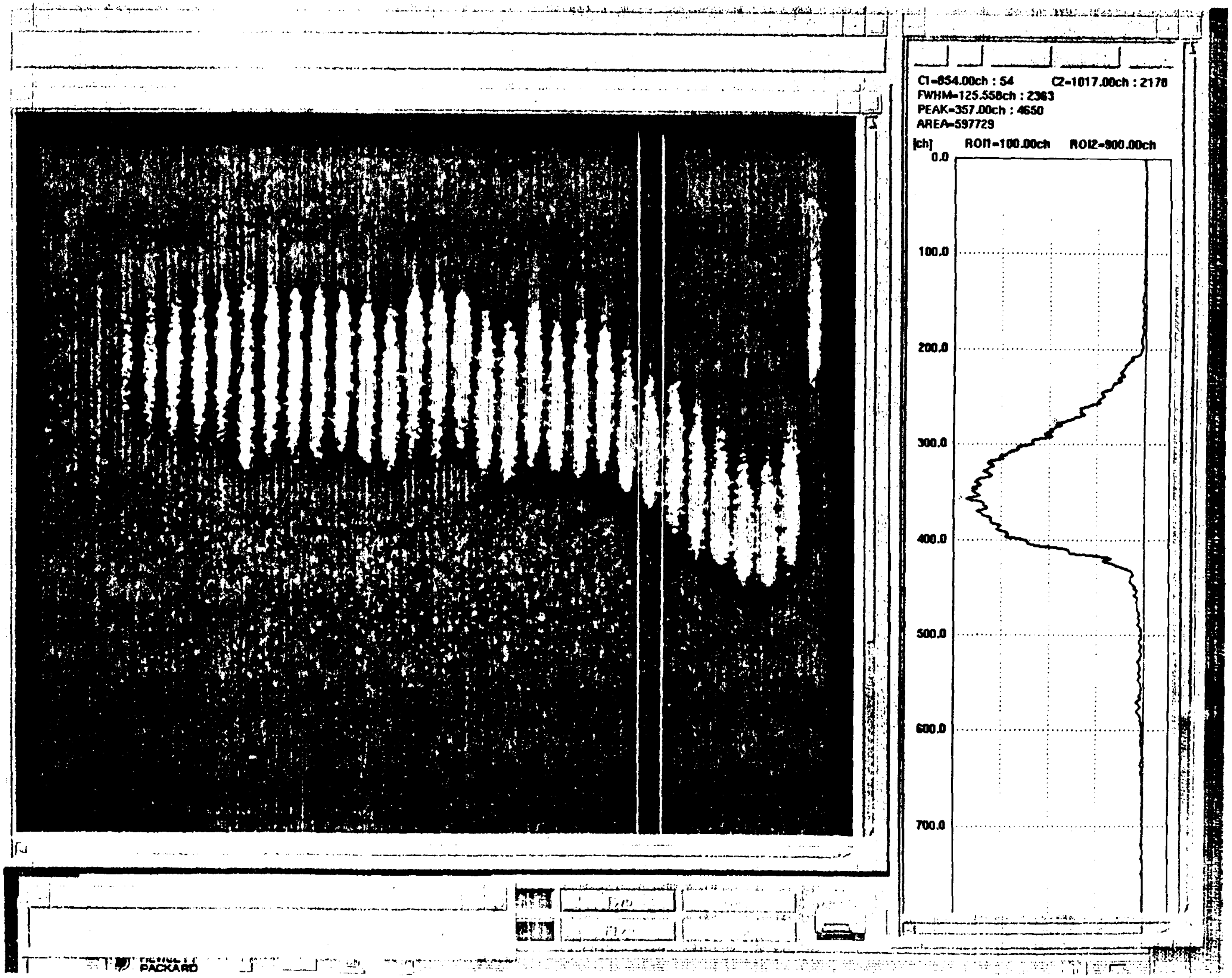
synchro-scan / single fast scan
resolution < 2 ps





C1=0.00ch : -120 C2=479.00ch : 16
FWHM=83.636ch : 7990
PEAK=279.00ch : 15979
AREA=1409666
ROI1=61.00ch ROI2=400.00ch

C1=0.00ch : 0 C2=671.00ch : 0 AREA=1407075
FWHM=80.145ch : 8027 PEAK=331.00ch : 16056 ROI1=101.00ch ROI2=600.00ch



```
C1=854.00ch : 54          C2=1017.00ch : 2178
FWHM=125.558ch : 2363
PEAK=357.00ch : 4650
AREA=597729
[ch]     ROI1=100.00ch    ROI2=900.00ch
```

NLC Instrumentation

December 5, 1994, M. Ross

Define and describe:

- NLC feedback systems
  - both beam-based and non-beam based
    - Centroid (SLC type)
    - Multi-bunch and phase space
    - Special loops
- Instrumentation
  - Intensity, Centroid, Phase space
  - Other
- Machine Protection
  - Mechanical design
  - Device controller
  - Control system
- Controls Architecture
  - Integration of feedback
  - Timing/scheduling
  - RF Control
  - Non-beam based instrumentation
  - Conventional

Beam based feedback should be considered a possible engineering solution for all tight tolerances in it's bandwidth

NLC beam size monitors - transverse

Wire scanners for $I/\sigma^2 < 10^{10}/2\text{x}2\ \mu m^2$

May be ok in injector, e+, but probably not anywhere else

Multi-bunch possible

Laserwire

Resolution depends on signal strength, background and laser spot aberrations

Best about 1/3 λ for simple (00 and 01) systems

1/20 λ for retro-reflector systems

+

Timing

wide dynamic range/thickness

other, parasitic, laser uses

-

cost

systematics from laser spot aberrations

High power required

Should be ubiquitous in NLC ring->linac ->FF systems

Simple system for DR

Laserwire costs for 200nm system:

1994 comparison:

Laser:

cost about 5 completed wire scanners (WSE)

RD needed to reduce

Transport:

Geometry

UHV required

Radiation hardness

Profile monitors and steering included

may cost about 4 WSE

IP:

cost ~ 1 WSE for two planes

Radiation hardness issues

Profile monitors/position monitors included

Distribute these costs over sets of scanners; combine diagnostics - 2 to 3 times more expensive than wire scanners. Testing/experience needed to reduce costs.

Key Laserwire parameters:

Angular Divergence (F number) vs. aperture

F2 optics chosen for SLD/SLC 90% transmission

Trade off between low angular div. and diffraction fringes

How do fringes change 01mode performance?

Sets Rayleigh range - length of spot (important for extreme aspect ratios)

Optical Damage issues

Vacuum, contamination, dust

Mechanical stability

Optical surface tolerances

impact of aberrations

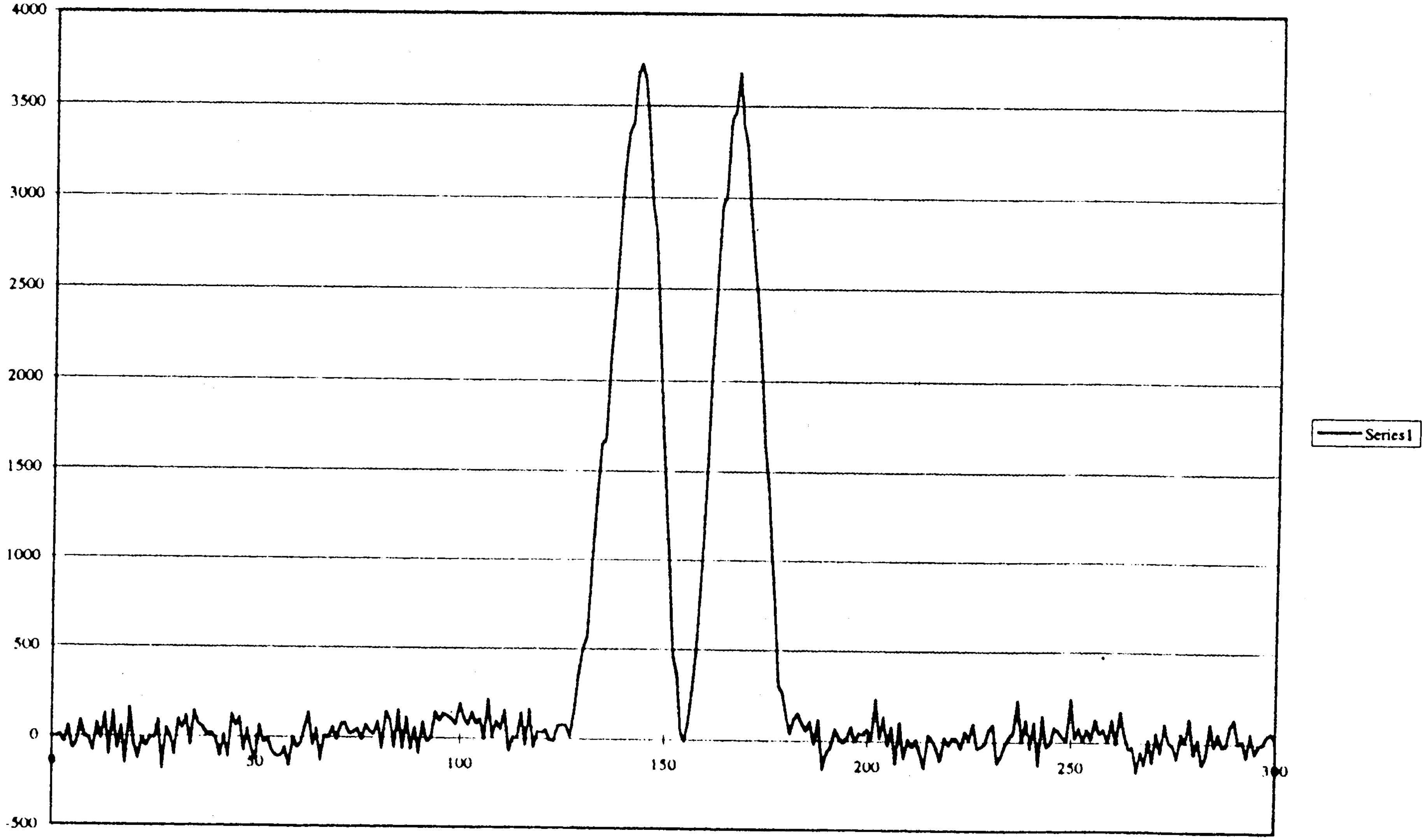
Detection system and count rates

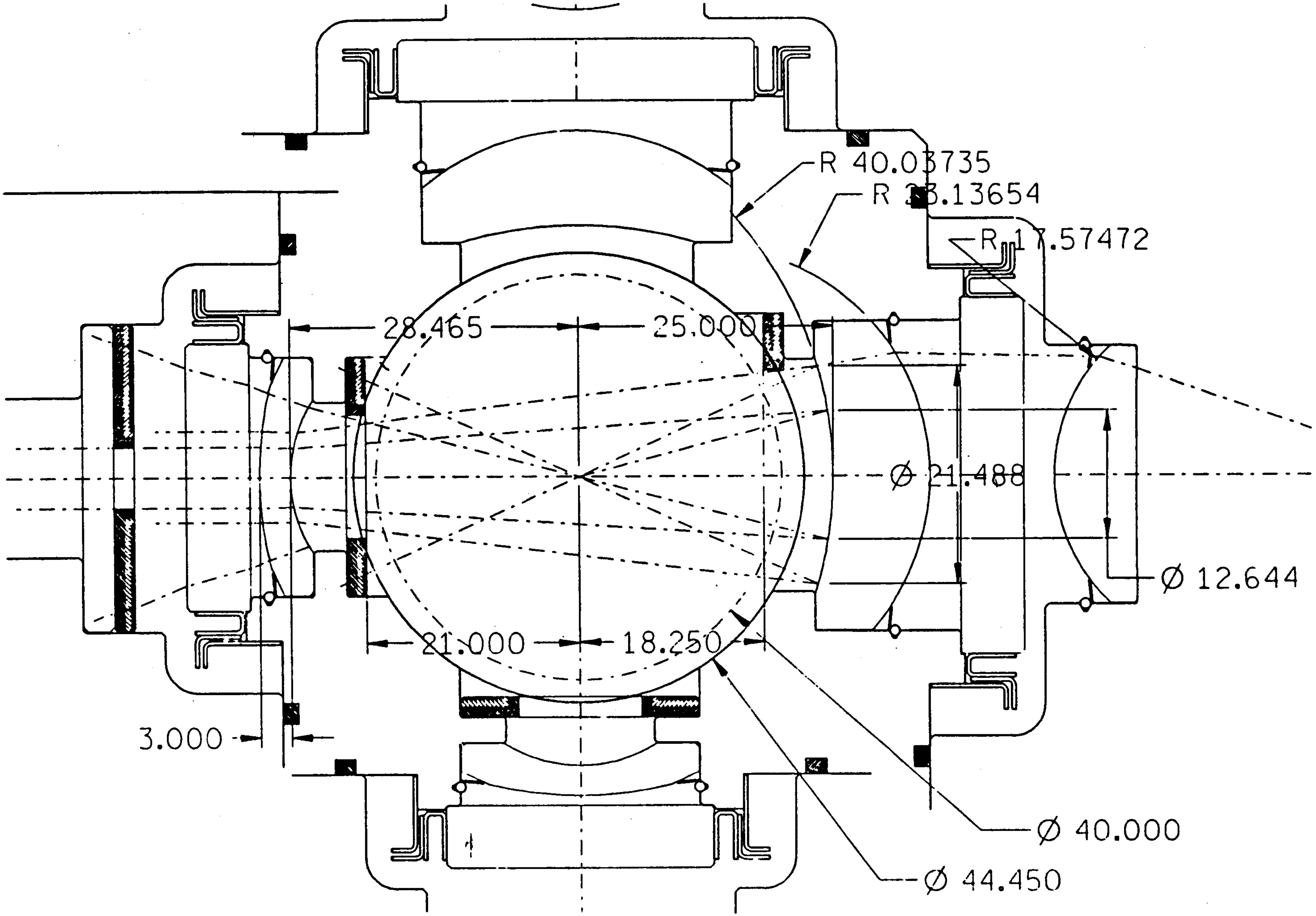
Ideal at SLC - may be harder in a linac

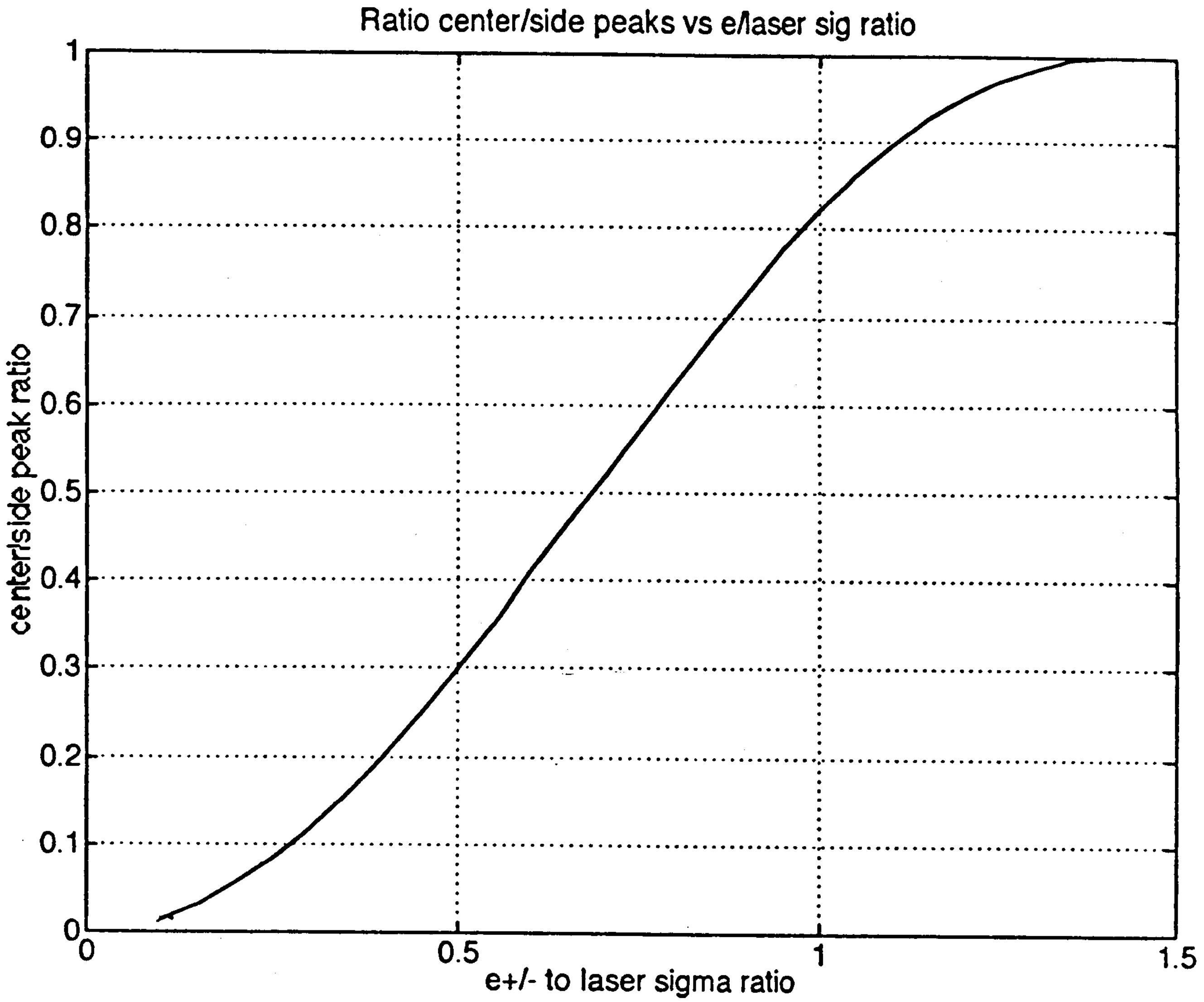
Diagnostics

Simplest optics (selected for SLD/SLC) is not transmission optics -> no good post-IP image is possible

TEM01 Laser Spot Profile "Gradient lens"
Max/Min -> 100




R 40.03735
R 33.13654
R 17.57472
28.465
25.000
Ø 21.488
Ø 12.644
21.000
18.250
3.000
Ø 40.000
Ø 44.450



01 mode conversion

expected laser σ for 01 mode ≈ 640nm

(00 mode ≈ 380nm)

Longitudinal

Coherent transition radiation/synchrotron radiation

resolution best for $\sigma_z \leq 1$mm

Needs more careful testing at FFTB
Foil survivability

BPM

Broadband transient recorder
Narrow band TM110
B-factory comb filter
Structure

BPM's will cost about 40 to 50% of the instrumentation budget (SLC costs)
Testing is needed

Machine Protection System

MPS in layers - mechanical, device controller, thermal, ion chamber, toroid. Stress non-beam power related controls.

Reduce the impact of the control system
rather than extend it

Use the MPS to produce diagnostic pulses that provide an indication of the failure so that tuning systems can recover.

Provide beam power ramping with more
than one technique.

Provide redundant device controller MPS.

Redundant -> require <u>more</u> than one <u>sensor</u>
before tripping.

Logic to allow partial operation

Feedforward protection.

Done by 'veto' system at SLC that inhibits
low I pulses from reaching FF

Linac Structure Protection

At typical sizes and train intensities a single pulse targeted on the structure will be catastrophic.

$5 \times 10^{11} > 0.7\ \text{mm}^2$ to survive(Cu)
for W 10x less
(SLC W target $.7 \times 10^{11} > 0.6\text{mm}^{2)}$

typical at the end of the 0.5 TeV $5 \times 10^{-6}\ \text{mm}^2$
5 orders of magnitude needed

<u>Proposal</u>: Reduce pulse power by reducing train to one bunch and greatly increasing it's emittance.

Design the structure (and other systems) so that serious single pulse damage is not possible

2 prongs: a) sacrificial thick protection near the irises
b) thin spoilers at half the radius
(work underway)

Reliably increase emittance at several places along the linac

Implications:

How are high repetition rate and full intensity trains handled?

Make the machine static by limiting bandwidth of 'major' field changes

(reduces allowable strength of fast correction systems)

Power density ramp required for any start/re-start

No low repetition rate, full I pulses allowed

Start up sequence:

0) Operation at low repetition rate;
single nominal intensity bunch;
high emittance

1) Raise repetition rate

guarantees static machine

2) reduce emittance

check average power limits

3) increase number of bunches in train

Controls Architecture

- Cost

  Cost of SLC control system was (is) very high in comparison to other machines with similar numbers of components

  Specifying as opposed to doing is often paces tasks

- Extension to higher level control

  'Nuclear' nature of lowest level

  Experiments with different architectures are expensive and difficult to evaluate

- Integration of feedback systems listed above

  Feedback is vital for much more than direct stabilizing

Other considerations:

Data acquisition bandwidth

Scheduling system

Pulse oriented sampling

Special architecture for damping ring applications.