Next-Generation Linear Colliders

Tor Raubenheimer
SLAC

- World scene
- Parameter choices
- Designs and Test Facilities

Why Linear Colliders?

- Electron-positrons are stable leptons however they radiate synchrotron radiation when deflected

$$U_0[GeV] = 8.85 \times 10^{-5} \frac{E^4[GeV]}{R[m]}$$

- The rf system must replace this energy loss and thus in a storage ring cost and size scale as the energy squared

	Length [km]	Energy [GeV]	ΔE [MeV]
LEP2	27	96	2500
SLC arcs	1.2	46	1000
PEP-II	2.2	9	4
SLC DR	0.035	1.2	0.09

Linear Collider World Picture

PROPOSED DESIGN	LABORATORY	TEST FACILITY
TESLA	DESY	TTF
SBLC	DESY	SBLC TF
JLC(C)	KEK	RF SYSTEMS
JLC(X)	KEK	ATF
NLC(X)	SLAC	SLC, FFTB, NLCTA
	LBNL	RTA
	LLNL	
VLEPP(J)	BINP	VTF
CLIC	CERN	CTF

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Interlaboratory Collaboration for R&D Towards TeV-scale Electron-Positron Linear Colliders

Technical Review Committee

ILC-TRC

This site contains updated information and the original tables, text and drawings found in the first ILC-TRC Report published in December, 1995.

- 12/98 Updated Megatable 1.1 - Overall and Final Focus Parameters - 500 GeV (c.m.)
- 12/98 Updated Megatable 1.2 - Pre-linacs, Damping Rings and Main Linac Parameters - 500 GeV (c.m.)
- 12/98 Updated Megatable 3.1 - Overall and Final Focus Parameters - 1 TeV (c.m.)
- 12/98 Updated Megatable 3.2 - Pre-linacs, Damping Rings and Main Linac Parameters - 1 TeV (c.m.)
- 12/98 Updated Machine Drawings
- 1/98 Updated Chapter 2.6 Experimentation Status
- 12/98 Updated Table 4.1 - Progress from LC Test Facilities
- Original Table 4.1 - Progress from LC Test Facilities
- Table 2.1.2 - Positron Sources
- On-line Update Forms - send in your updated machine information
- Original charge to the ILC-TRC
- Members of the Interlaboratory Collaboration Council
- ILC-TRC Working Group Members
- The original ILC-TRC Report December 1995:
  Table of contents and how to view/print a copy of the report in the following formats:
  - PDF
  - PostScript

www.slac.stanford.edu/xorg/ilc-trc/ilc-trchome.html

ILC-TRC

Table 3.1
Linear Colliders: Overall and Final Focus Parameters - 1 TeV (c.m.)

>

Click here to update your machine information for Table 3.1.	TESLA TRC 12/95	TESLA Updated* 8/98	SBLC TRC 12/95	SBLC Updated* 10/96	JLC (C) TRC 12/95	JLC (C) Updated* 4/98	JLC (X) TRC 12/95	NLC TRC 12/95	JLC/NLC** Updated* 12/98	VLEPP TRC 12/95	VLEPP Updated* 10/96	CLIC** TRC 12/95	CLIC** Updated* 9/98	
Initial energy (c.m.) (GeV)	1000	800	1000		1000		1000	1000	1000	1000		1000		Initial energy (c.m.) (GeV)
RF frequency of main linac (GHz)	1.3		3		5.7		11.4	11.4	11.4	14		30		RF frequency of main linac (GHz)
Nominal luminosity (10^{33} cm^{-2} s^{-1})†	7.48	27.5	3.25		6.4	5.53	10	10.4	9(7.5)	17.3		1.7-7.6	9.5(7.7)	Nominal luminosity (10^{33} cm^{-2} s^{-1})†
Actual luminosity (10^{33} cm^{-2} s^{-1})†	12.8	50	6.3		6.3	8.2	9.17	14.5	12.9(10.75)	13	11.5	2.20-10	13.6(11)	Actual luminosity (10^{33} cm^{-2} s^{-1})†
Linac repetition rate (Hz)	5	3	50		50		150	120	120(100)	300		4000-1800	150	Linac repetition rate (Hz)
No. of particles/bunch at IP (10^{10})	1.8	1.41	2.9		1.44	1.39	.7	1.1	.95	20		.8	.4	No. of particles/bunch at IP (10^{10})
No. of bunches/pulse	2260	4500	50		72		85	75	95	1		1-10	150	No. of bunches/pulse
Bunch separation (nsec)	354	189	10		2.8		1.4	1.4	2.8			67		Bunch separation (nsec)
Beam power/beam (MW)	16.5	12.2	5.8		4.2	4	6.4	7.9	8.7	4.8		2.6-11.7	7.21	Beam power/beam (MW)
Damping ring energy (GeV)	4	3.2	3.15		2	1.98	2	2	1.98	3		2.15	1.98	Damping ring energy (GeV)
Unloaded/loaded†† (MV/m)	25/25	34/34	42/36		58/47	56/47.1	73/58	85/63	72.3/55	100/91		80/78	122/100	Unloaded/loaded (MV/m) ††
Total two-linac length (km)	58	30	33		26.6		21.8	18.7	18	14		17.6	13.5	Total two-linac length (km)
Total beam delivery length (km)	4	2.5	4		6		6	6.8	NA	4		2.4	2.0	Total beam delivery length (km)
$\gamma\varepsilon_x / \gamma\varepsilon_y$ (m-rad × 10^{-6})	14/.06	8/.01	10/.1		3.3/.05		3.3/.05	5/.05	4.5/.1	20/.08		3.9/.2	1.48/.07	$\gamma\varepsilon_x / \gamma\varepsilon_y$ (m-rad × 10^{-6})
β_x^* / β_y^* (mm)	25/.7	15/.3	32/.8		41/.1	30/.2	10/.1	25/.1	12/.15	200/.1		10/.18	10/.1	β_x^* / β_y^* (mm) (mm)
σ_x^* / σ_y^* (nm) before pinch	598/6.5	391/2	572/9		372/2.2	318/3.14	184/2.2	360/2.3	234/3.9	2000/2.7		200/6	123/2.7	σ_x^* / σ_y^* (nm) before pinch
σ_z^* (μm)	500	300	500		120	200	90	100	120	750		200	50	σ_z^* (μm)
Crossing Angle at IP (mrad)	0		3		6	8	6.1	20	20(8)	6		1	5	Crossing Angle at IP (mrad)
Disruptions D_x / D_y	.2/14	.2/37	.26/16.2		.07/12.1	.16/15.9	.1/8.6	.05/7.6	.12/7.2	.2/165		.22/7.4	07/2.26	Disruptions D_x / D_y
H_D	1.64	1.8	1.68		1.32	1.6	1.42	1.35	1.46	2		1.32	1.54	H_D
Upsilon sub-zero	.053		.06		.28	.5	.33	.27	.3	.12		17		Upsilon sub-zero
Upsilon effective	.053		.06		29		.33	.27	.3	.15		.18	.57	Upsilon effective
δ_B (%)	2.5	4.7	6.5		9.6	8.34	9	7.4	10.3	26.6		7.7	9.2	δ_B (%)
n_γ (no. of γ's per e)	1.2		1.4		1.4	1.73	1.2	1.1	1.43	5		1.52	1.1	n_γ (no. of γ's per e)
N_{pairs} (p_T^{min} = 20 MeV / c, Θ_{min} = 0.15)	7.3	28	7.6		13.8	38.5	4.9	7	18.4	?	10.4	3.4	7.7	N_{pairs} (p_T^{min} = 20 MeV / c, Θ_{min} = 0.15)
$N_{hadrons}$ / crossing	.16	.19	.19		.55	61	.19	.25	.33	?	19.9	.13	.15	$N_{hadrons}$ / crossing
$N_{jets} \times 10^{-2}$ (p_T^{min} = 3.2 GeV / c)	.66	.66	.8		5.3	3.5	1.9	2.3	2.3	?	94.7	.95	1.27	$N_{jets} \times 10^{-2}$ (p_T^{min} = 3.2 GeV / c)
Click here to update your machine information for Table 3.1	TESLA TRC 12/95	TESLA Updated* 8/98	SBLC TRC 12/95	SBLC Updated* 10/96	JLC (C) TRC 12/95	JLC (C) Updated* 4/98	JLC (X) TRC 12/95	NLC TRC 12/95	JLC/NLC** Updated* 12/98	VLEPP TRC 12/95	VLEPP Updated* 10/96	CLIC** TRC 12/95	CLIC** Updated* 9/98	

*If a number does not appear in the updated column, this means that the number in the TRC column still holds.

**Numbers in ( ) under JLC/NLC correspond to 100 Hz repetition rate; numbers in ( ) under CLIC correspond to a 20% dilution in σ_y^* and 5% in σ_y^*.

†For the sake of uniformity, the **nominal** luminosity is simply defined as $N^2 / 4\pi\, \sigma_x^* \sigma_y^*$ times the number of crossings per second, and in all cases assumes head-on collisions, no hour-glass effect and no pinch. The actual luminosity incorporates all these effects, including cro applicable. NLC and JLC calculations assume crab-crossing.

†† The loaded gradient includes the effect of single-bunch (all modes) and multibunch beam loading, assuming that the bunches ride on crest. Beam loading is based on bunch charges in the linacs, which are slightly higher than at the IP

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Beam Parameters

500 GeV c.m	TESLA	SBLC	JLC(C)	JLC/NLC(X)	VLEPP	CLIC
f_{rf}(GHz)	1.3	3	5.6	11.4	14	30
f_{rep}(HZ)	5	50	100	120(100)	300	200
n_b/pulse	2820	333	72	95	1	150
N (10^{10})	2	1.1	1.1	.95	20	.4
$P_{B/beam}$ *(MW)*	11.3	7.25	3.1	4.5(3.7)	2.4	4.81
σ_x(nm)	553	335	318	330	2000	206
σ_y(nm)	3	15.1	4.3	4.9	4	5.4
L(10^{33} cm^{-2} s^{-1})	30	5.3	7.18	7(5.8)	9.7	6.3(5)

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Linear Collider Test Facilities

Facility	Location	Goal	Operations
SLC	SLAC	Prototype Collider	1988
ATF	KEK	Injector Damping Ring	1995 1996
SBTF	DESY	S-Band Linac	1996
NLCTA	SLAC	X-Band Linac	1996
TTF	DESY	SuperC Linac	1997
CTF	CERN	2-Beam Linac	1996
FFTB	SLAC	Final Focus Interaction Region	1994

Luminosity

$$L = \frac{f_{rep} \; n_b N_+ N_-}{2\pi \; \Sigma_x \Sigma_y}$$

- In LC, f_{rep} tends to be low and thus the luminosity must be attained through charge and beam size
- Fortunately, there is no beam-beam tune shift

	Lum.	f_{rep}	n_b	$N[10^{10}]$	σ_x [μm]	σ_y [μm]
NLC	1×10^{34}	120 Hz	90	1	0.25	0.004
SLC	2×10^{30}	120 Hz	1	4	1.5	0.5
LEP2	5×10^{31}	10 kHz	8	30	240	4
PEP-II	3×10^{33}	140 kHz	1700	4	155	6

- However small spots mean small emittances and small beta functions: $\sigma = \sqrt{\varepsilon\beta}$

$\Rightarrow$ Two issues for LC: energy and spot size

Luminosity

$$L = \frac{f_{rep}\, n_b N_+ N_-}{4\pi \quad \sigma_x \sigma_y} H_D$$

- In a linear collider, the luminosity can be re-written:

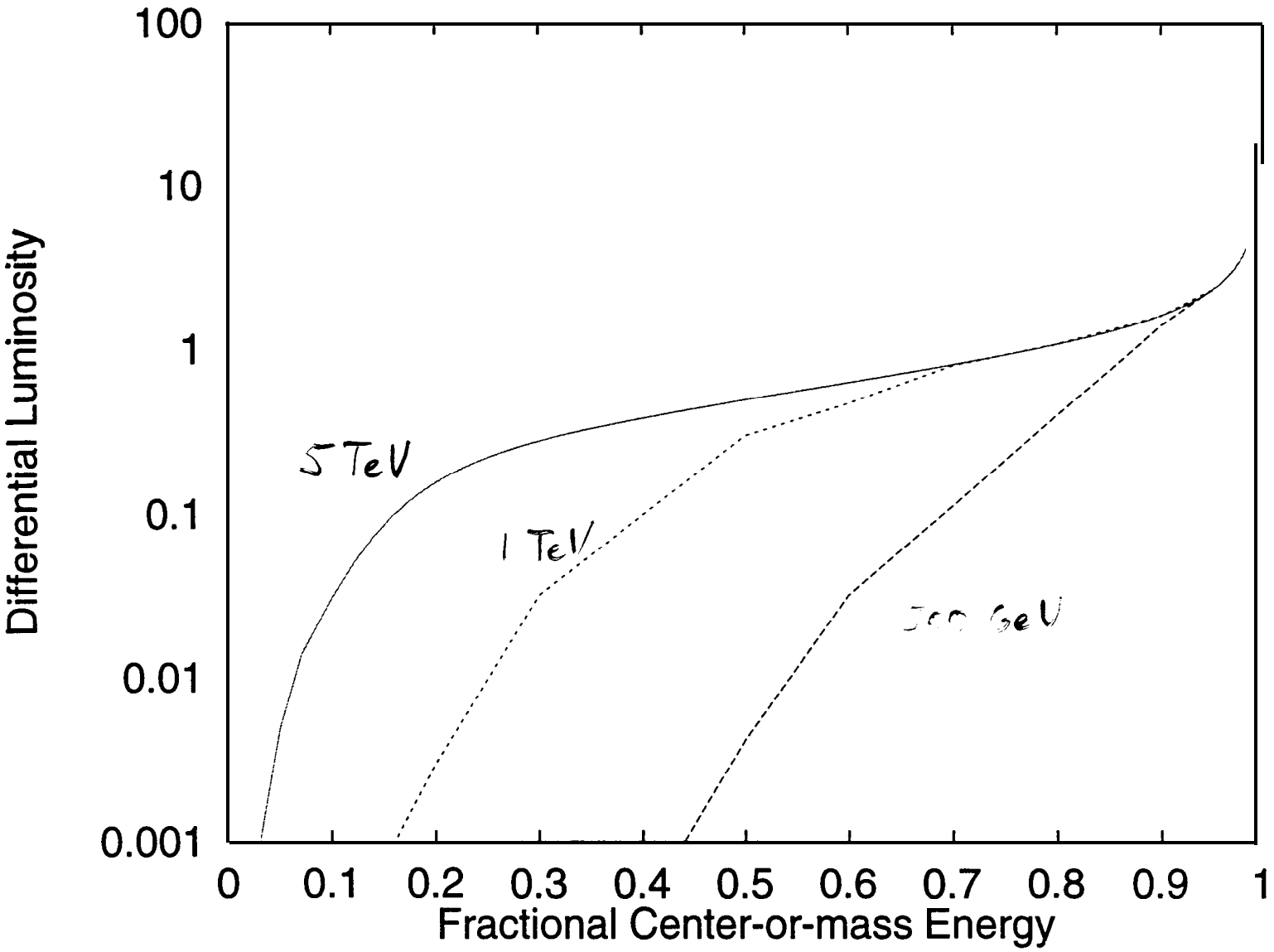
$$L = \frac{P_{ac}\eta_{ac}\eta_{rf}}{4\pi E_{cms}} \frac{N}{\sigma_x} \frac{H_D}{\sigma_y}$$

- where η_{ac} and η_{rf} are the ac→rf and rf →beam efficiencies

- Flat beams are used to reduce the electromagnetic fields at the IP. In this case, the ratio N/σ_x is a measure of the beamstrahlung ($\propto n_\gamma$).

⇒ Luminosity is determined by P,, η_{rf}, σ_y, and n_γ

Luminosity Spectrum



$$\mathcal{L}_{100\%} = \mathcal{L}_0 \frac{(1 - e^{-n_\gamma})^2}{n_\gamma^2}$$

- For clean $\mathcal{L}$ spectrum n_γ is more important than δ_B

RF Efficiency

- To maintain reasonable P_{ac} need high η_{rf} attained with long trains of bunches

$\Rightarrow$ Want power to beam not structures or loads (high beam loading)

- High Q SC structures can be very efficient with low beam current $\Rightarrow$ large bunch spacing

- Normal C traveling wave structures are optimized for $\eta_{rf} \sim 20\%$ – trade between efficiency and operating difficulty

$$\eta_{rf} \sim \frac{k/2}{k+1} \Rightarrow K \equiv \frac{R_s I}{G} \sim 1$$

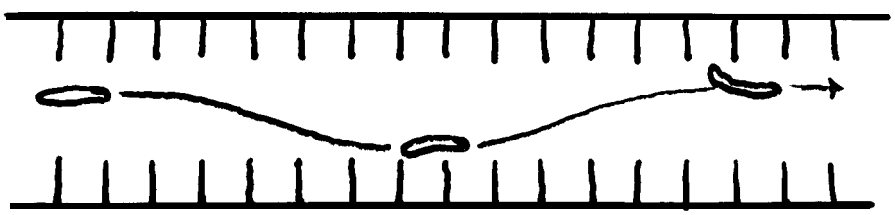
$I \propto N_{bunch} / \Delta t$ $\quad \Delta t$ set by $1-r$ $\omega_\perp \Rightarrow \Delta t \propto 1/\lambda_{rf}$

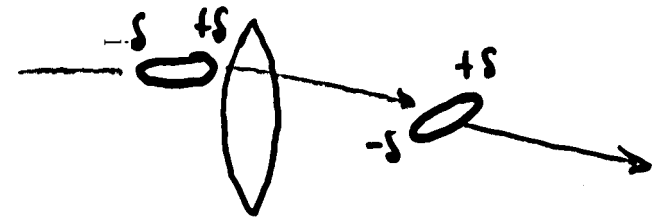
Wakefields

- Longitudinal wakefields:
  - long-range (beam-loading) must be corrected by varying rf system
  - short-range causes correlated energy deviation along the bunch and is corrected by operating off the rf crest
  - w,, $\propto 1 /$ [redacted] λ_{rf}^2
- Transverse wakefields:
  - long-range causes beam-breakup and must by corrected by damping or decohering dipole modes
  - short-range causes tightest alignment tolerances and single bunch BBU and is corrected using BNS damping
  - $W_\perp \propto 1 / \lambda_{rf}^3$ for l-r and $\propto \sigma_z / \lambda_{rf}^4$ for s-r

Short-range Wakes

BNS Damping Compensate $W_\perp$ with focusing chromaticity





$\Rightarrow$ decelerate tail with respect to head

Short-range $W_\parallel$ does this for you

Tolerances

$$y_{tol}^2 \propto \gamma \epsilon_y \left(W_\perp \, rms \, N\right)^2 \frac{\beta \, Lacc}{Grad}$$

(Normal C SC can be looser)

$N \propto \lambda_{rf}$ $\quad \sigma_z \propto \lambda_{rf}$ $\quad W_{\perp rms} \propto \lambda_{rf}^{-2}$

$\beta \propto \lambda_{rf}^{1/2}$ $\quad Grad \propto 1/\lambda_{rf}$ $\quad Lacc \propto \lambda_{rf}^{1/2}$

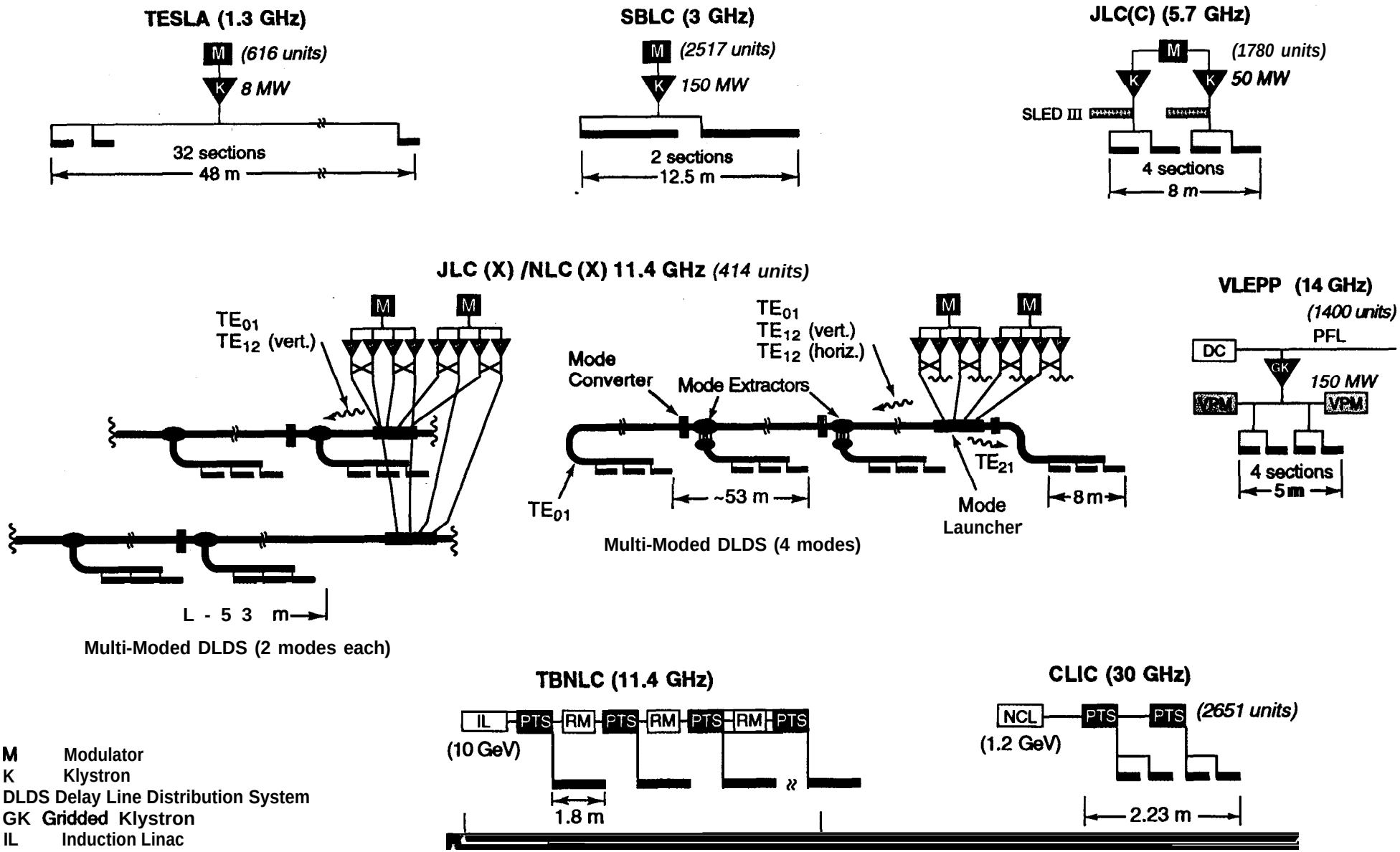
$\Rightarrow y_{tol} \propto \lambda_{rf}$

RF Systems

- Lower frequency (S-band and SC) systems have long pulse lengths (3μs ~ lms) and require lower peak power — sources are available or are relatively easy to develop
- C-band system uses relatively simple (long pulse) klystron and rf pulse compression based on SLED-II concept
- X-band requires high peak power and shorter pulses (350 ns) — not as well suited to klystron / modulator pulses and thus use rf pulse compression
- K-band needs very high peak power (400 MW/m) in shorter pulses (~ 100 ns) — store energy in drive beam and use a two-beam accelerator

Main Linac Power Units for 500 GeV c.m. Energy

(not to scale)



M Modulator
K Klystron
DLDS Delay Line Distribution System
GK Gridded Klystron
IL Induction Linac
PTS Power Transfer Structure
VPM VLEPP Power Multiplier
PFL Pulse Forming tine
NCL Normal Conducting Linac

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TESLA

- Low **frequency super-conducting rf** for **high** efficiency and weak **wakefields** ⇒ relatively ease transverse dynamics
- **Large bunch** separation to allow damping of **HOM — also** allows **intra-pulse** feedback **to ease** jitter tolerances
- Operates **with very** long **bunch** train at low rep. rate
- Difficulties:
  - **attaining** high gradients **(presently at** -30 **MV/m)**
  - **generating long, low emittance, bunch** train in damping ring (15 **km circumference)**
  - **generating** positrons (power density is too high for conventional system)
  - Cost!

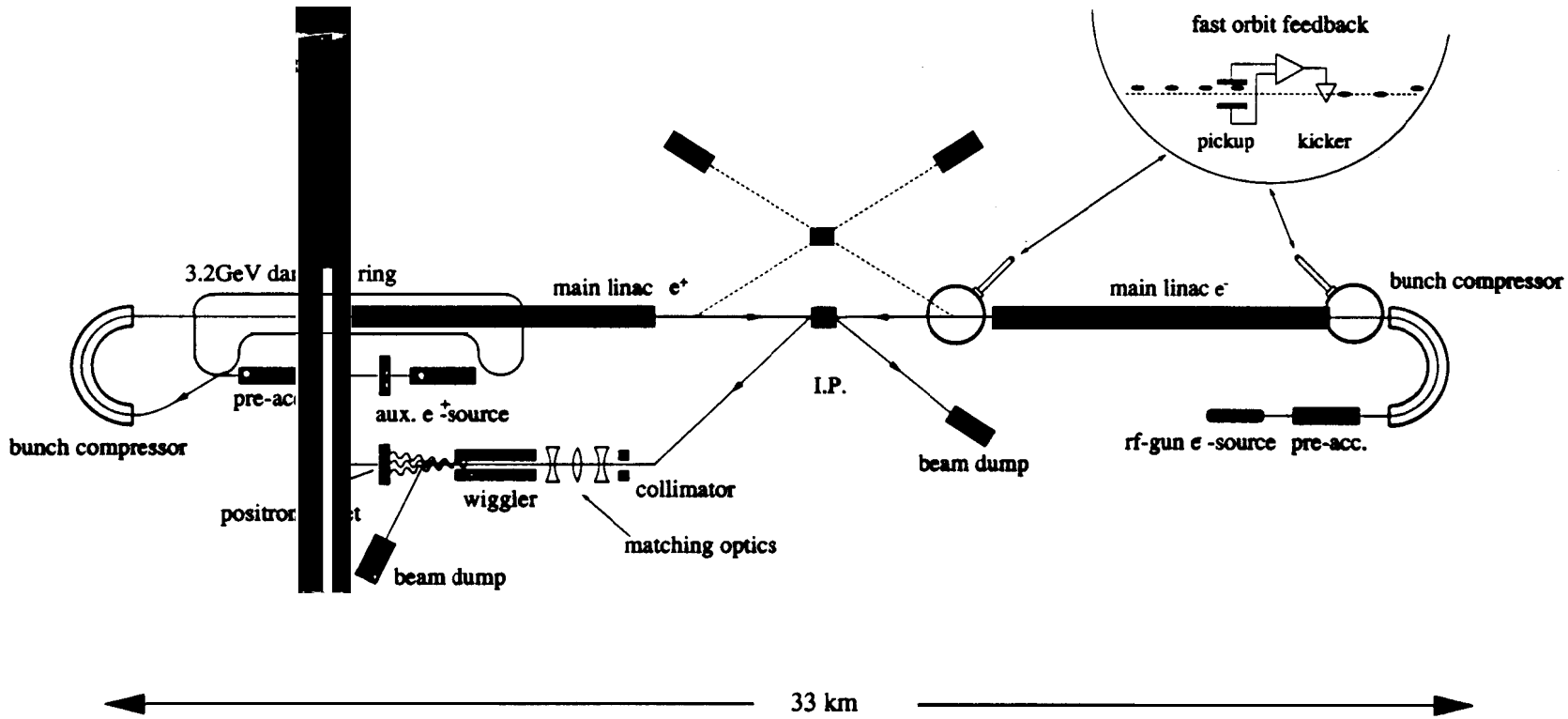
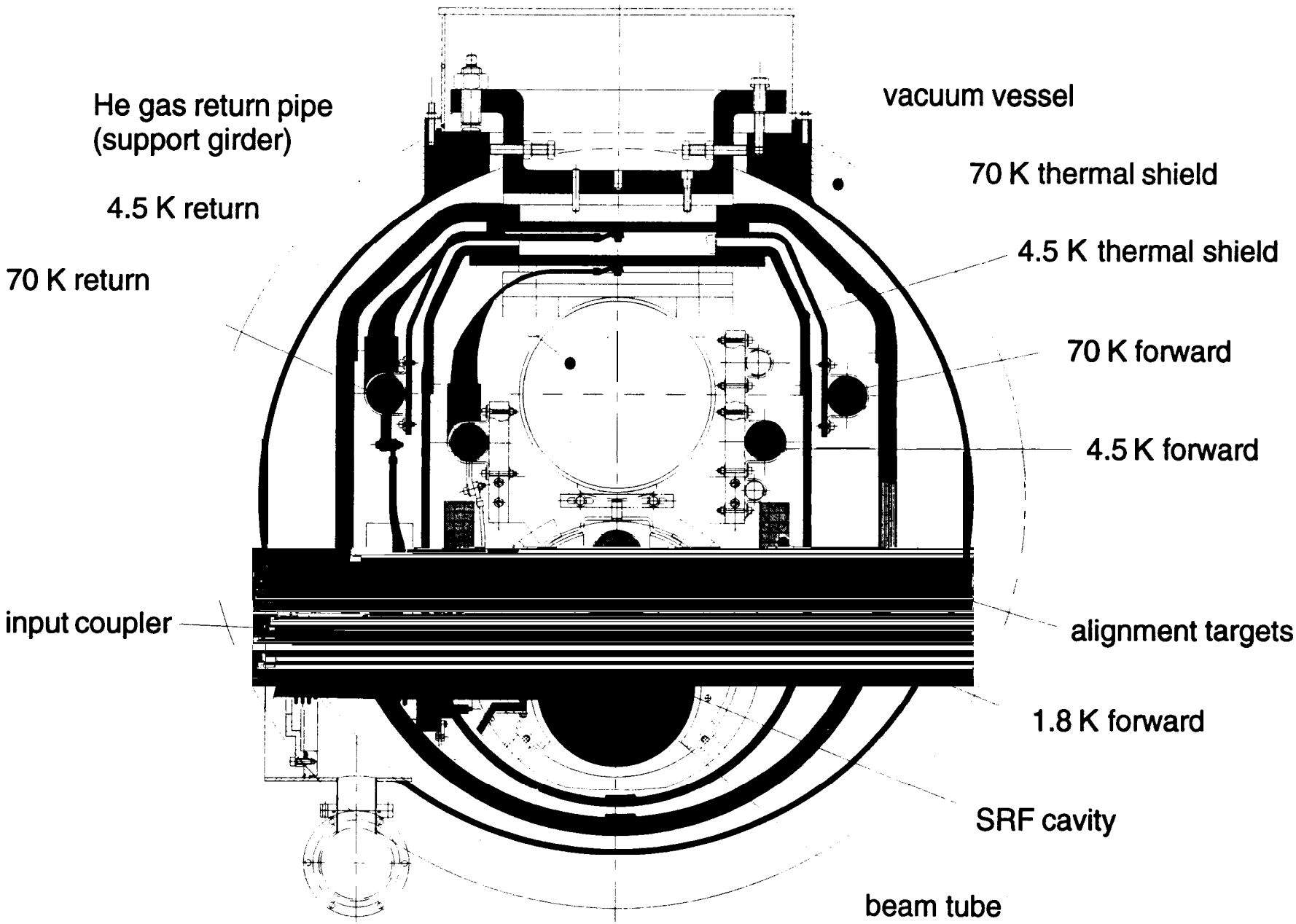


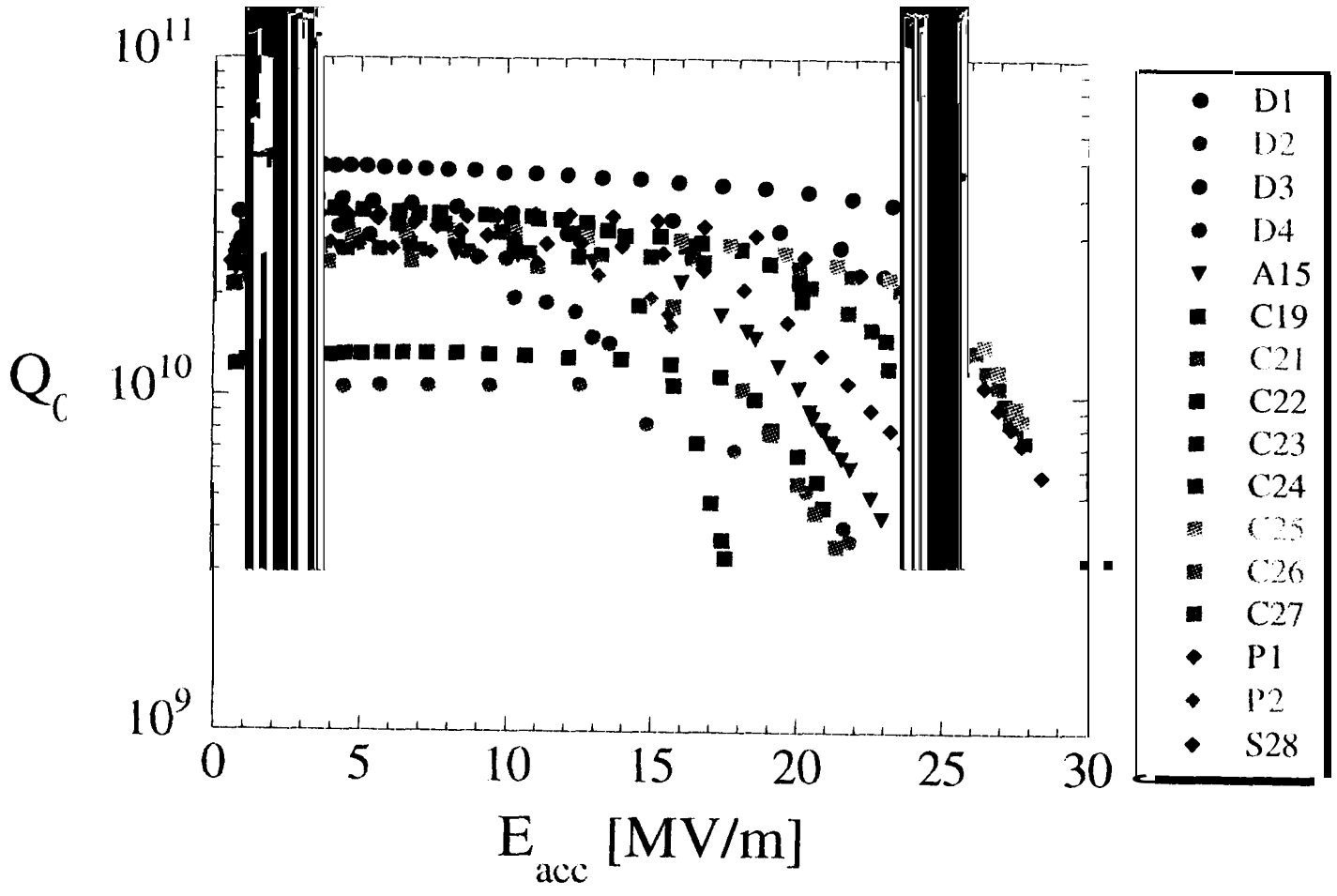
Figure 3.1.4: *Sketch of the overall layout of TESLA.*


He gas return pipe
(support girder)
4.5 K return
70 K return
input coupler
vacuum vessel
70 K thermal shield
4.5 K thermal shield
70 K forward
4.5 K forward
alignment targets
1.8 K forward
SRF cavity
beam tube

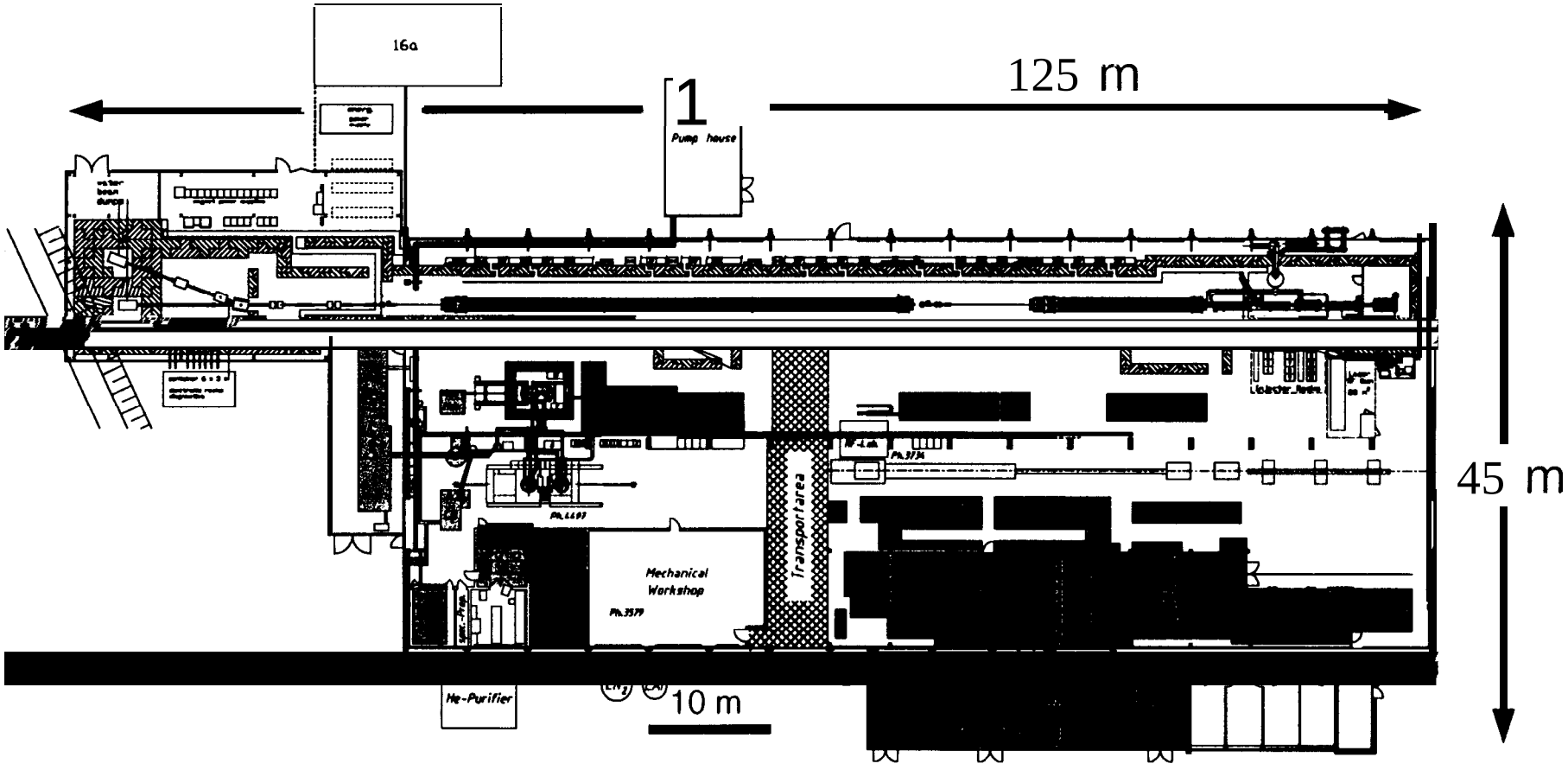
Present

	ref. design	Stage-I	Stage-II	Stage-III
General Parameters				
# of bunches p.p.	1130	1410	2820	4028
pulse length [μs]	800	950	950	950
bunch spacing Δt_b [ns]	708	674	337	236
bunch charge N_e [10^{10}]	3.63	4.0	2.0	1.4
pulse current [mA]	8.2	9.5	9.5	9.5
av. beam power [MW]	8.3	9.5	9.5	9.5
emittance at IP $\varepsilon_{x,y}$ [10^{-6} m]	14, 0.25	14, 0.25	10, 0.03	8, 0.0075
$\beta_{x,y}$ at IP [mm]	25, 0.7	25, 0.7	15, 0.4	12.7, 0.3
spot size at IP $\sigma_{x,y}$ [nm]	845, 19	845, 19	558, 5	459, 2.1
bunch length at IP σ_z [mm]	0.7	0.7	0.4	0.3
beamstrahlung δ_B [%]	2.5	3.0	3.0	3.0
vert. Disruption D_y	18	20	33	50
luminosity [10^{34} cm^{-2} s^{-1}]	0.6	0.9	2.6	5.2
Damping Ring				
energy E_{DR} [GeV]	3.2	3.9	3.9	4.3
circumference C_{DR} [km]	17	8.5	8.5	8.5
arc radius [m]	60	85	85	85
arc FODO cell phase advance Φ_c [deg.]	90	60	75	108
wiggler length [m]	388	350	350	350
wiggler field B_W [T]	1.5	1.06	1.06	1.06
transverse damping time [ms]	33.8	31	31	28
RF voltage [MV]	25	16	16	19
emittance at extraction $\varepsilon_{x,y,DR}$ [10^{-6} m]	12, 0.2	12, 0.2	8, 0.02	6, 0.005
energy spread $\sigma_{E,DR}$ [10^{-3}]	1.0	0.093	0.093	0.097
bunch length $\sigma_{z,DR}$ [mm]	9.5	9	6	6
incoh. space charge ΔQ_{incoh}	0.18	0.07	0.20	0.27
bunch compression ratio	13.3	12.7	15	20
compressor RF voltage [MV] (at 1.3 GHz)	200	220	400	600

Table 4: Proposed modified TESLA-500 parameters for higher luminosity in comparison with the reference design. The values for the beamstrahlung and for the luminosity quoted are scaled numbers, which need to be confirmed by beam-beam simulations (a constant pinch enhancement factor has been assumed for all versions). Some of the damping ring parameters have been obtained from scaling of basic lattice properties. More precise values must be determined from a detailed design study.


10^{11}
10^{10}
10^{9}
Q_0
0
5
10
15
20
25
30
E_{acc} [MV/m]
D1
D2
D3
D4
A15
C19
C21
C22
C23
C24
C25
C26
C27
P1
P2
S28

TESLA TEST FACILITY (HALL 3)

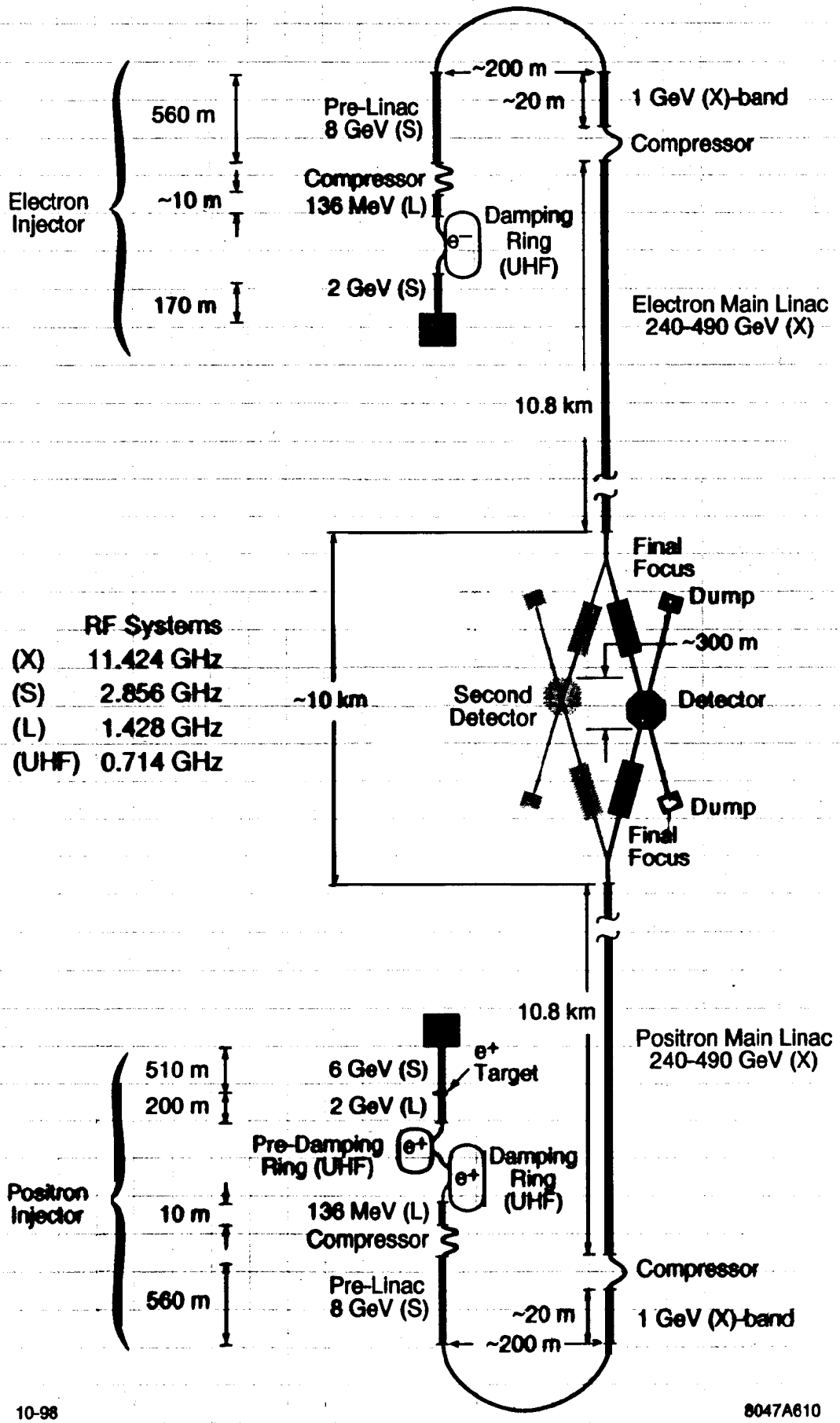


Cavity Treatment and Assembly

Cavity Testing (RF System / He Plant)

NLC / JLC

- Based on X-band technology to allow high gradients (77 MV/m) for expansion to 1.5 TeV
- Damping rings similar to SR sources
- Rf system under development for over 10 years
- Difficulties:
  - stronger wakefields (although less effect on dynamics than in SLC)
  - diffkult to develop high power klystrons because of space charge effects and need complicated (although passive) rf pulse compression system
  - accurate machining and construction of accelerator structures
  - sensitive to component jitter and require very good stability esp. in the final focus
  - Cost!



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IP Parameters for the JLC / NLC (8/8/98)

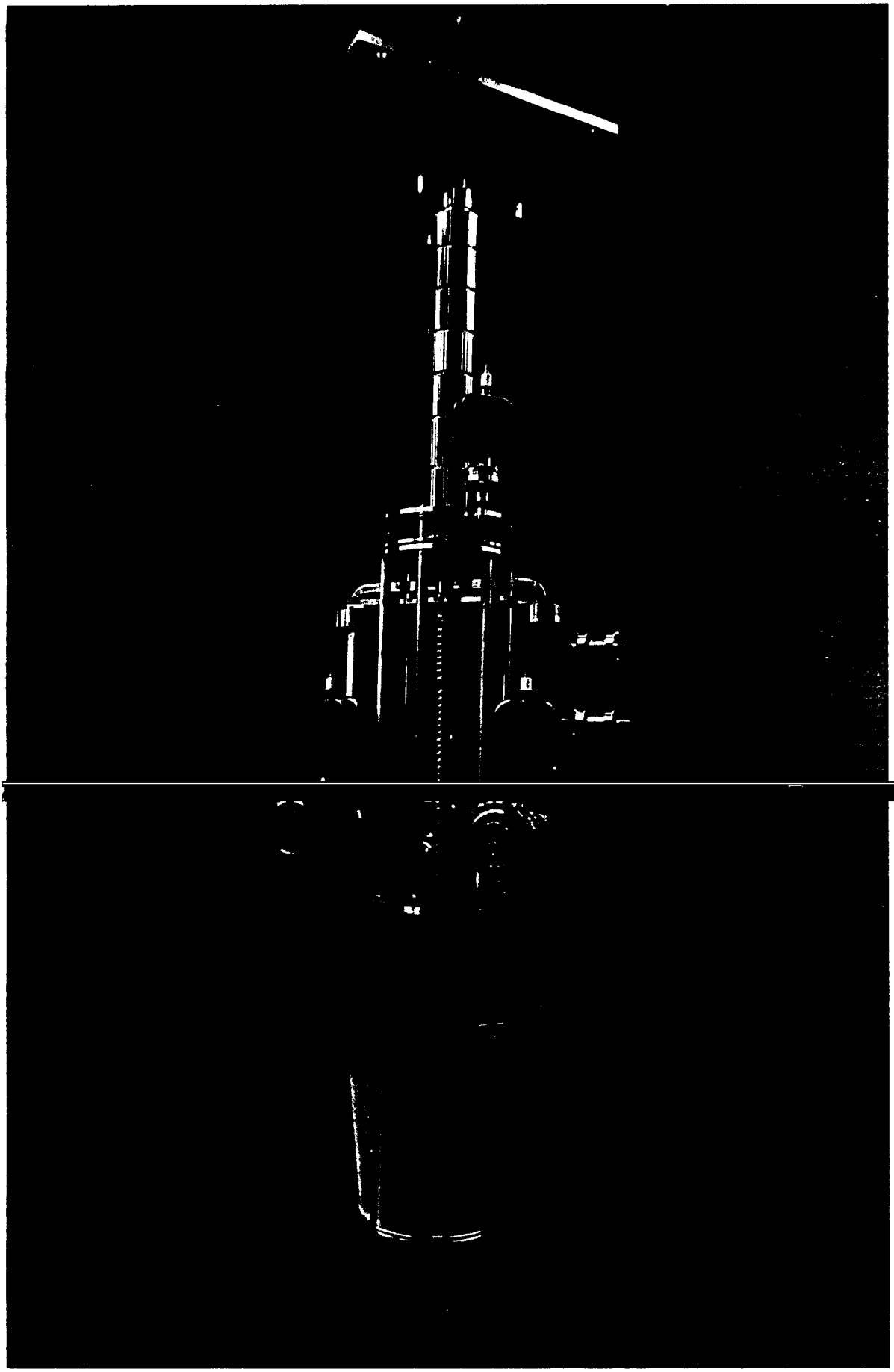
	500 GeV			1 TeV			1.5 TeV	
	A	B	C	A	B	C	A	B
CMS Energy (GeV)	535	515	500	1046	1008	978	1406	1478
Luminosity (10**33)	7.7	7	6	15	13	11.6	14	12.4
Repetition Rate (Hz)	120	120	120	120	120	120	60	90
Bunch Charge (10**10)	0.75	0.95	1.1	0.75	0.95	1.1	1.4	0.95
Bunches/RF Pulse	95	95	95	95	95	95	95	95
Bunch Separation (ns)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Injected γεx/γεy (10**-8)	300/3	300/3	300/3	300/3	300/3	300/3	300/3	300/3
γεx at IP (10**-8)	400	450	500	400	450	500	450	450
γεy at IP (10**-8)	6	10	14	6	10	14	14	10
βx/βy at IP (mm)	10/0.1	12/0.12	13/0.2	10/0.125	12/0.15	13/0.2	15/0.2	13/0.2
σx/σy at IP (nm)	277/3.4	330/4.9	365/7.6	197/2.4	235/3.9	260/5.4	220/4.5	200/3.72
σz at IP (um)	90	120	145	90	120	145	130	150
Yave	0.14	0.11	0.09	0.38	0.3	0.25	0.6	0.42
Pinch Enhancement	1.41	1.36	1.5	1.41	1.46	1.5	1.58	1.52
Beamstrahlung δB (%)	4.5	4	3.6	10.9	10.3	9.7	21.7	14.1
Photons per e+/e-	1	1.1	1.17	1.3	1.43	1.51	2.06	1.61

Linac Parameters for the JLC / NLC (8/8/98)

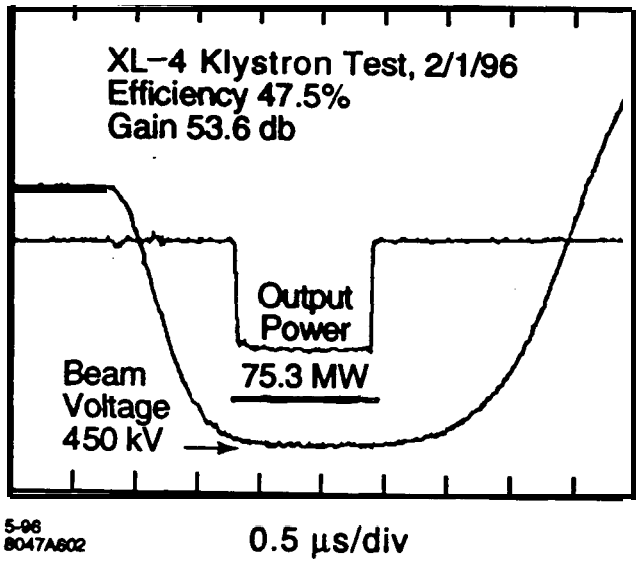
	500 GeV			1 TeV			1.5 TeV	
	A	B	C	A	B	C	A	B
CMS Energy (GeV)	535	515	500	1046	1008	978	1406	1478
Luminosity (10**33)	7.7	7	6	15	13	11.6	14	12.4
Repetition Rate (Hz)	120	120	120	120	120	120	60	90
Bunch Charge (10**10)	0.75	0.95	1.1	0.75	0.95	1.1	1.4	0.95
Bunches/RF Pulse	95	95	95	95	95	95	95	95
Bunch Separation (ns)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Structures								
Structure length (m)		1.8			1.8		1.8	1.8
Structure Iris (a/λ)		0.18			0.18		0.18	0.18
Fill Time (ns)		103			103		103	103
Attenuation		0.475			0.475		0.475	0.475
Eff. Shunt Imped. (Mohm/m)		90.3			90.3		90.3	90.3
Beam Shunt Imped. (Mohm/m		91.2			91.2		91.2	91.2
Rf power per structure (MW)		170			170		340	170
Unloaded Grad. (MV/m)	72.3	72.3	72.3	72.3	72.3	72.3	102.3	72.3
Multibunch loading (MV/m)	7.8	9.9	11.5	7.8	9.9	11.5	14.7	9.9
Single Bunch loading (MV/m)	0.3	0.4	0.5	0.3	0.4	0.5	0.6	0.4
Ave. Rf phase (deg.)	11	11	11	11	11	11	11	11
RF Overhead (%)	8	8	8	8	8	8	8	8
Eff. Gradient (MV/m)	57.1951	54.995149	53.295	57.1951	54.9951	53.2951	77.0886	54.9951
Pulse Comp. Method		DLDS			SLED		SLED	DLDS
Pulse Comp. units per sector		9			9		9	9
Sectors per linac		23			46		46	68
Structures per sector		108			108		108	108

Structures per linac	2484	4968	d968	7344
Active Linac length (km)	4.5	9	8 . 6	13.24
Filling factor	86%	86%	86%	86%
Total Linac length (km)	5.2	10.4	10.4	15.3
Klystrons				
Klystron peak power (MW)	75	75	150	75
Klystron pulse length (ns)	1525	1525	1525	1525
Klystrons per DLDS	8	8	8	8
Klystrons per linac	1656	3312	3312	4896
Pulse Compression				
DLDS feeds	4	4	4	4
Structures per feed	3	3	3	3
DLDS power efficiency	85%	85%	85%	85%
Rf pulse length (ns)	366	366	366	366
Switching time (ns)	15	15	15	15
Rf group velocity in waveguide	0.97c	0.97c	0.97c	0.97c
Distance between feeds (m)	56.3	56.3	56.3	56.3
AC Power				
Rf power in structures (MW)	37.093075	74.1862	74.1 862	82.2499
Modulator efficiency	70%	70%	70%	70%
Klystron efficiency	65%	65%	65%	65%
DLDS power efficiency	85%	85%	85%	8[redacted]%
Rf switching efficiency	96X	96%	96%	[redacted]%
AC power (MW)	99.905934	199.812	199.812[redacted]1	

Main linac ac power



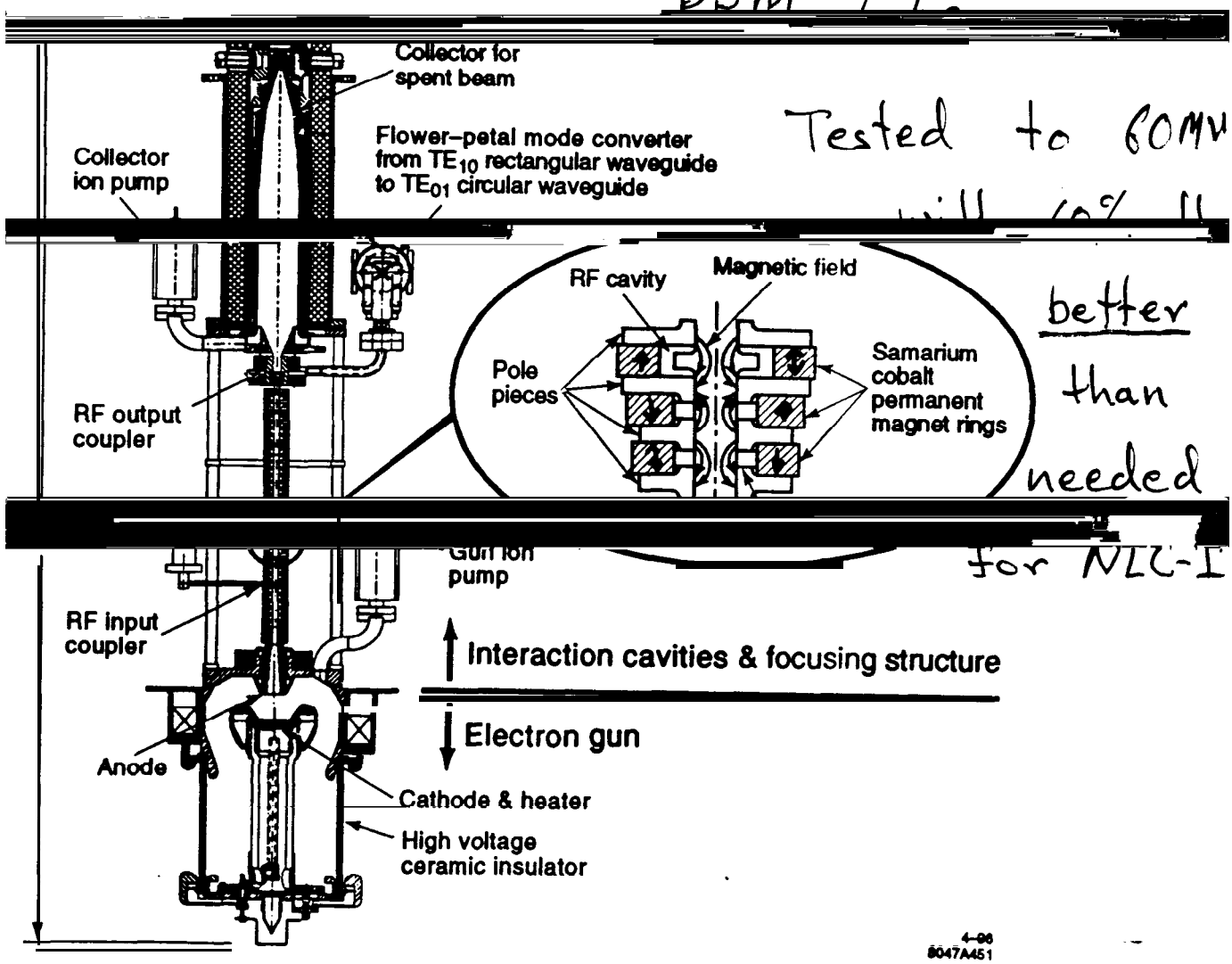
X-band Klystrons



XL4
Solenoid focused

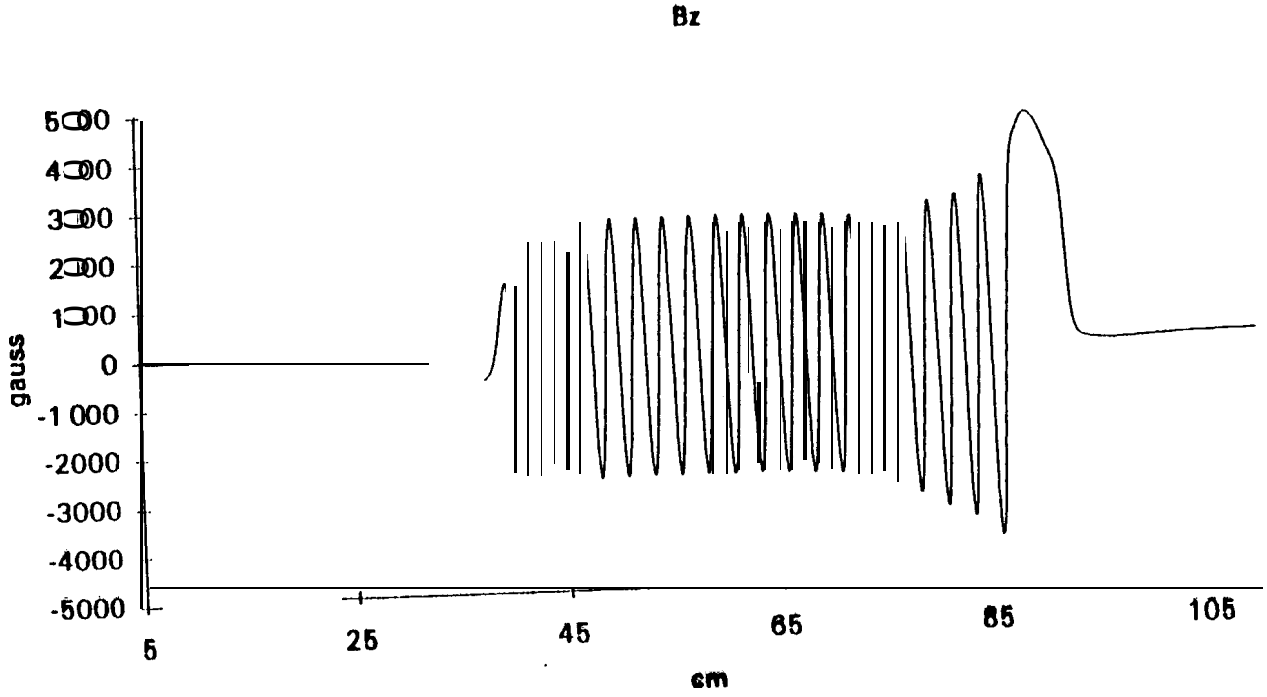
75MW is the power needed for NLC-II

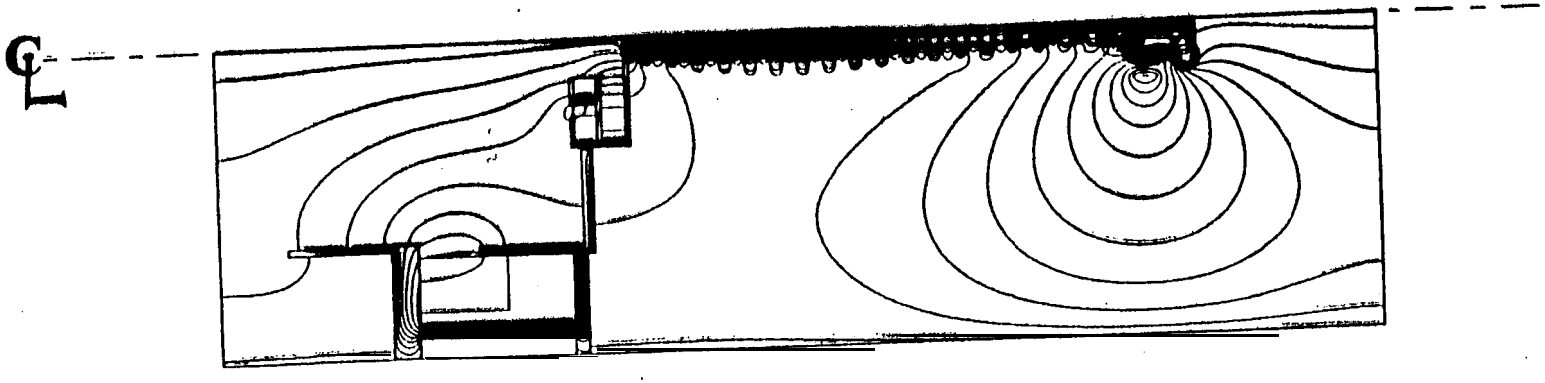
DDM T/



Tested to 60MW
will 60% ll
better than needed for NLC-I

PPM Klystron Magnetic Circuit

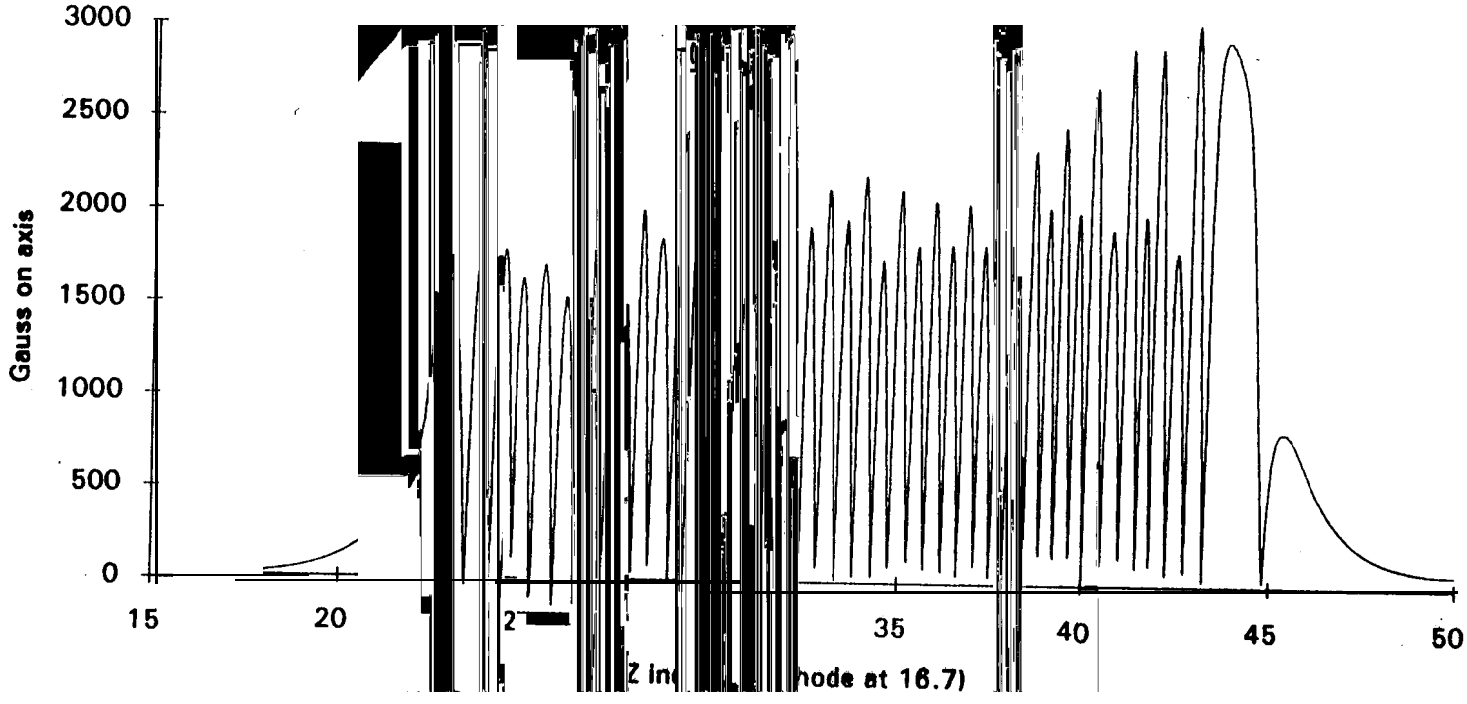




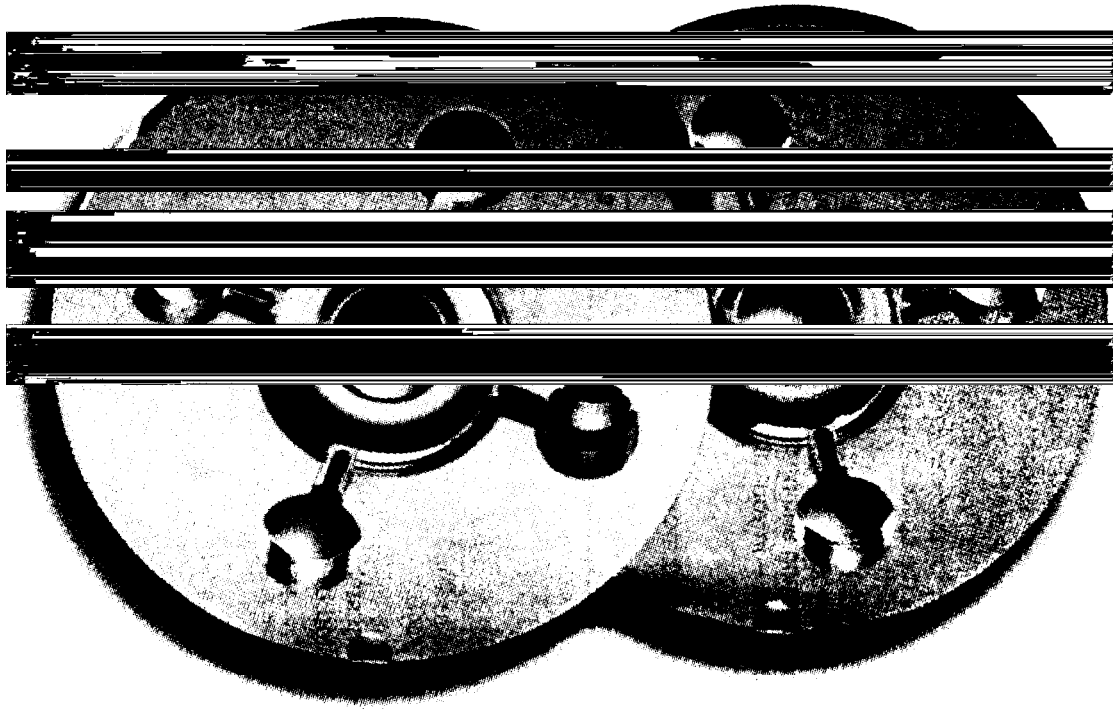
September 12, 1995

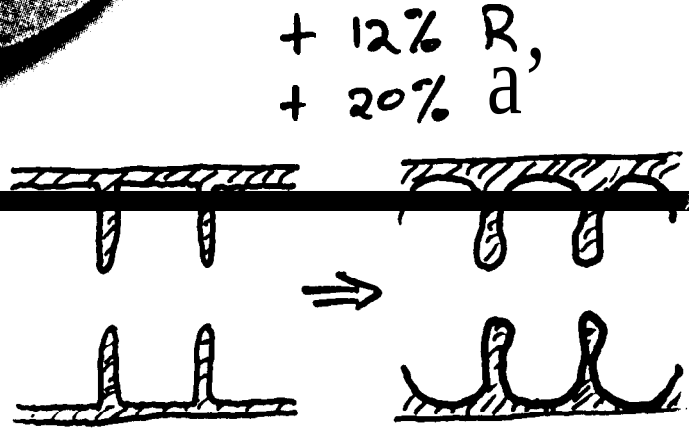
GL

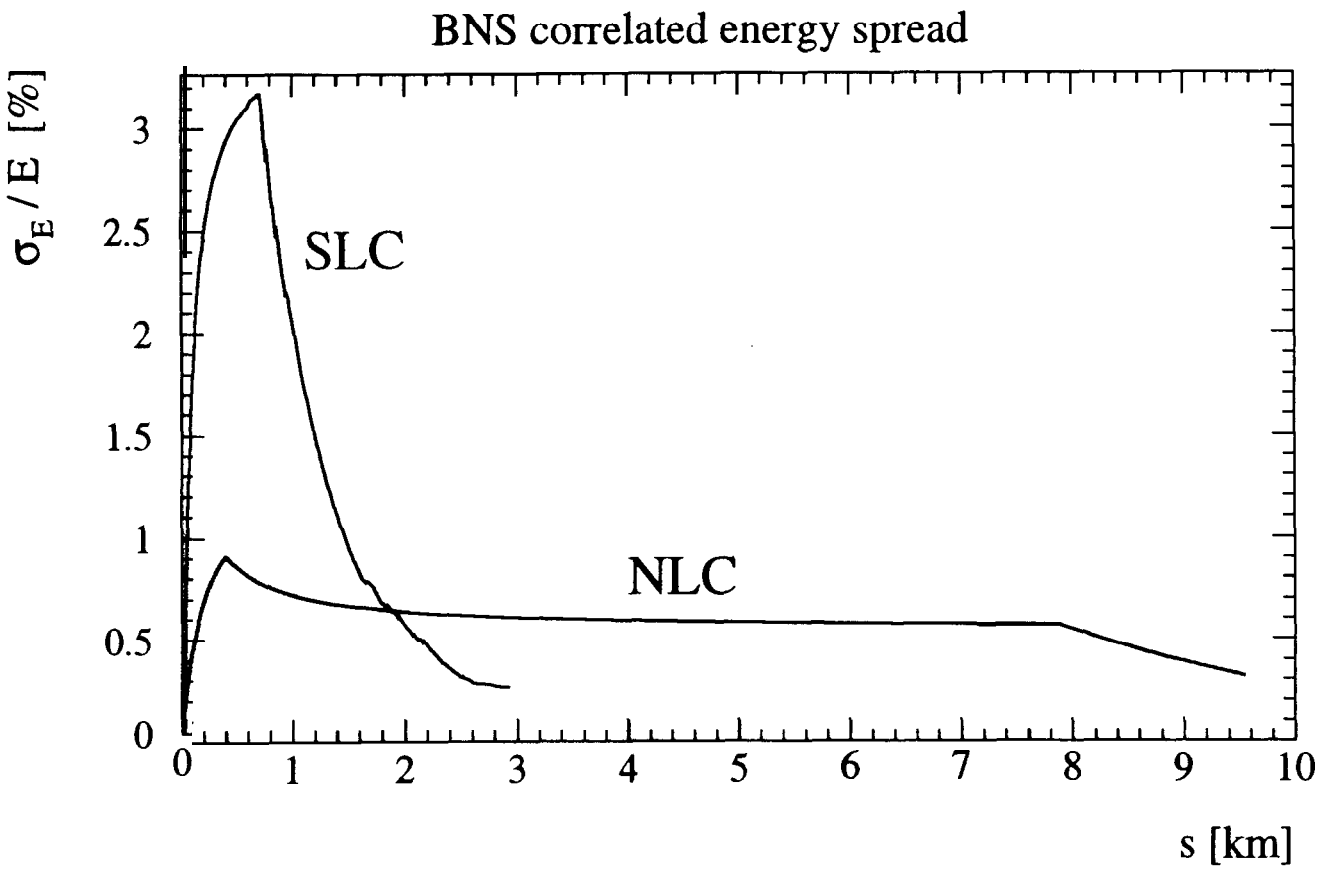
Magnitude of the PPM field used for simulation of the 75 MW klystron (3-27-97)



Rounded DDS Cells





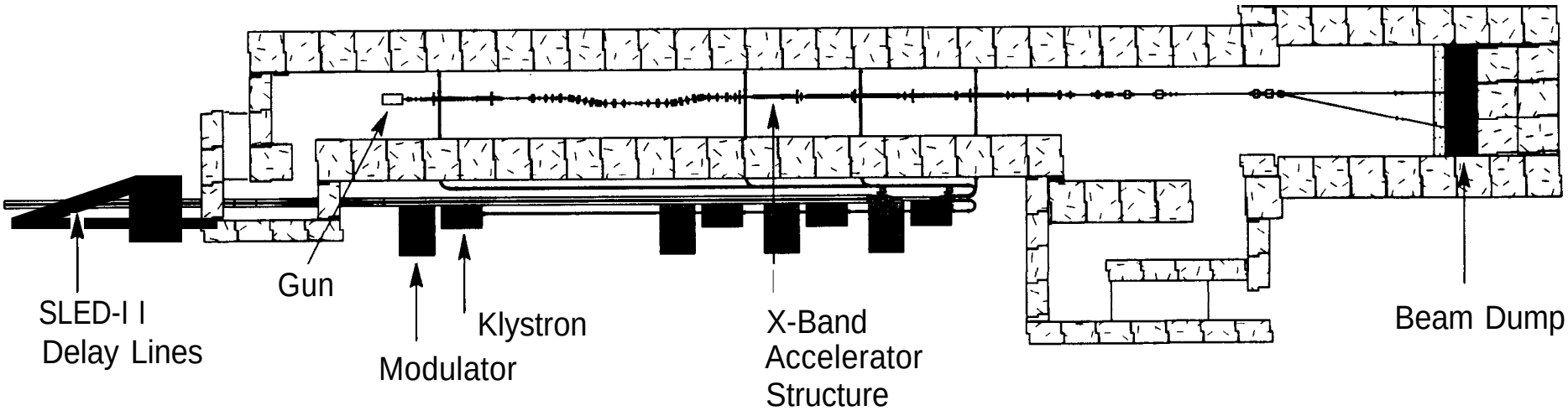

BNS correlated energy spread
σ_E / E [%]
3
2.5
2
1.5
1
0.5
0
SLC
NLC
0
1
2
3
4
5
6
7
8
9
10
s [km]

Next Linear Collider Test Accelerator

GOALS

- *To construct and reliably operate an engineered model of a section of the NLC high-gradient linac.*

- *To test those beam dynamics questions coupled to acceleration.*

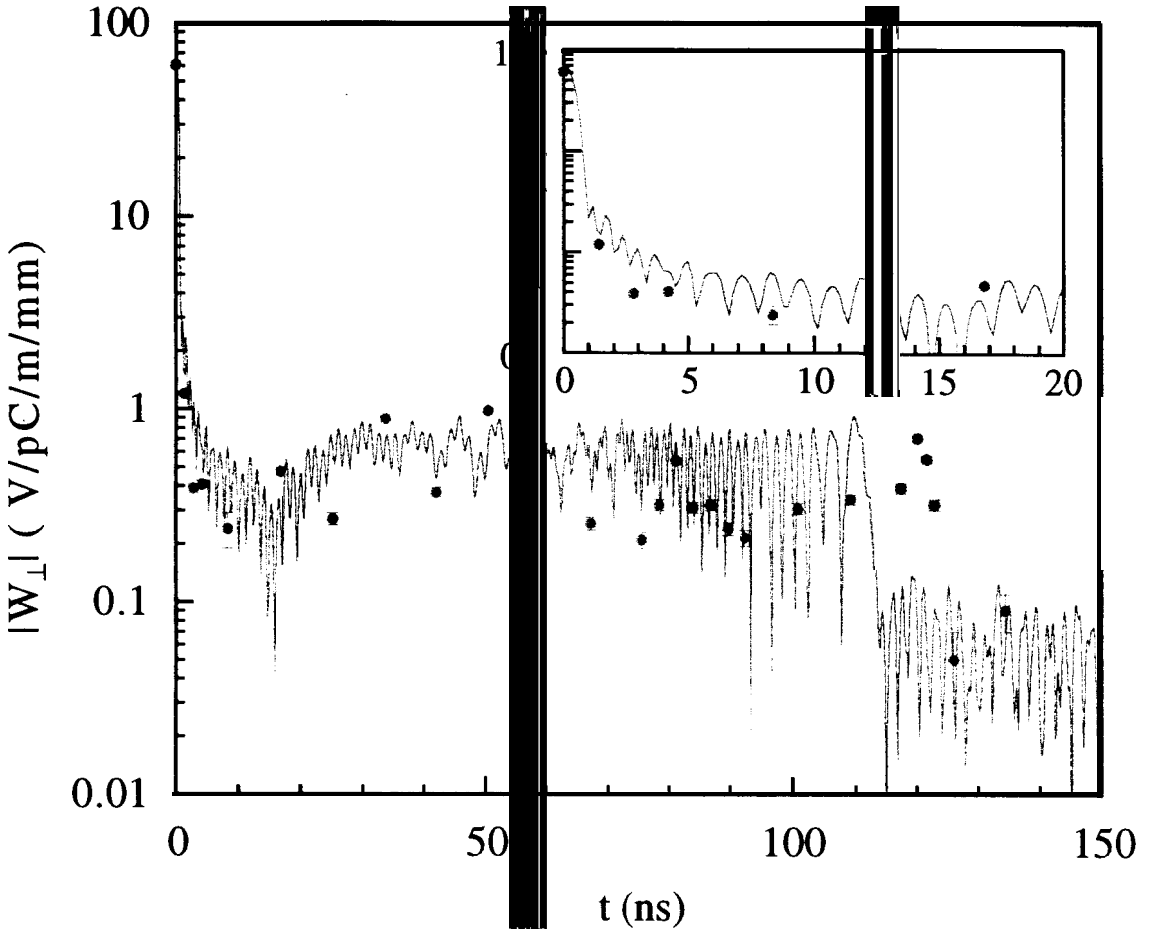


WC0233V-A/2

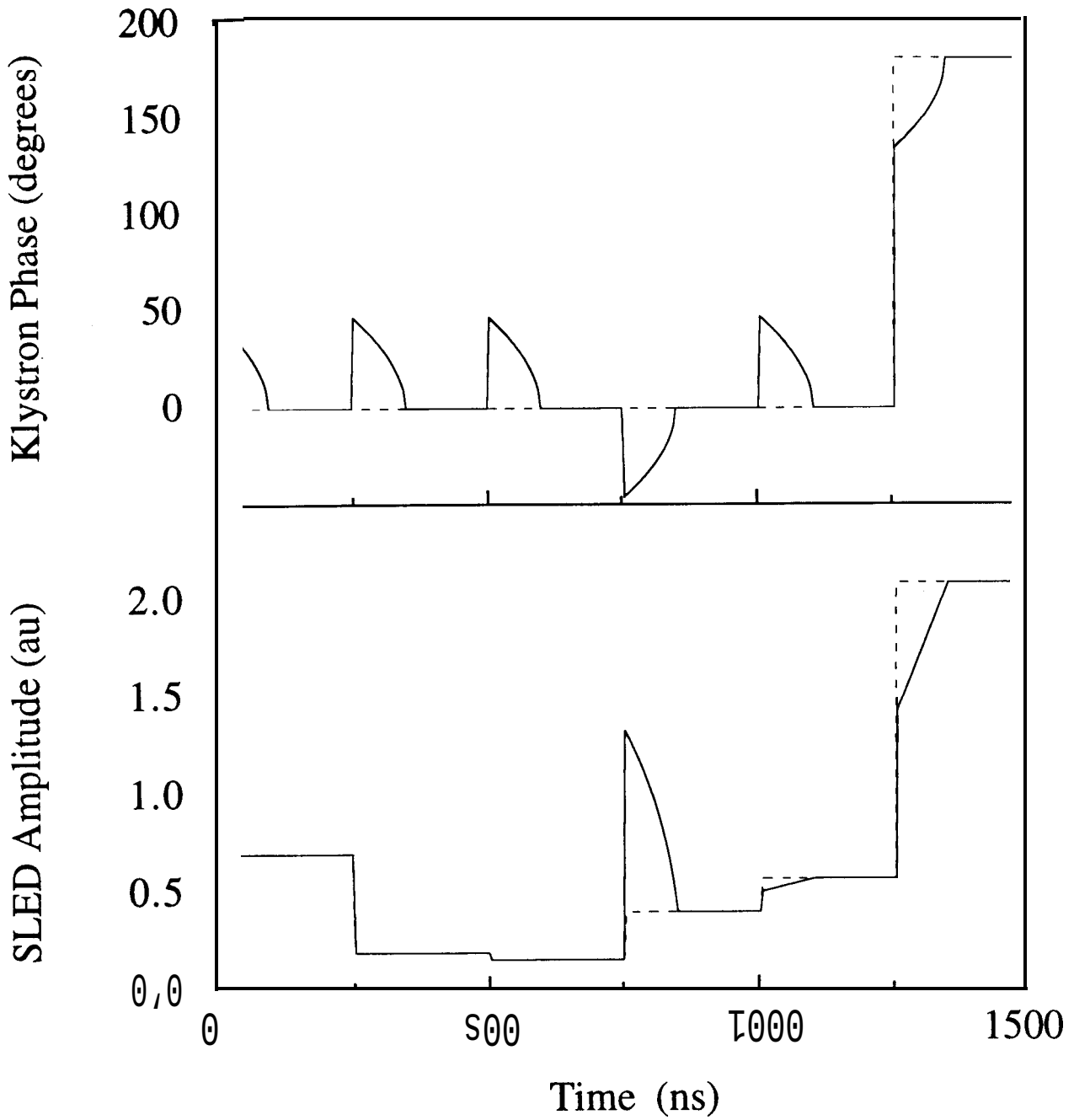
EAST KODAK EAST KODAK EAST KODAK EAST KODAK

Wakefield Amplitude

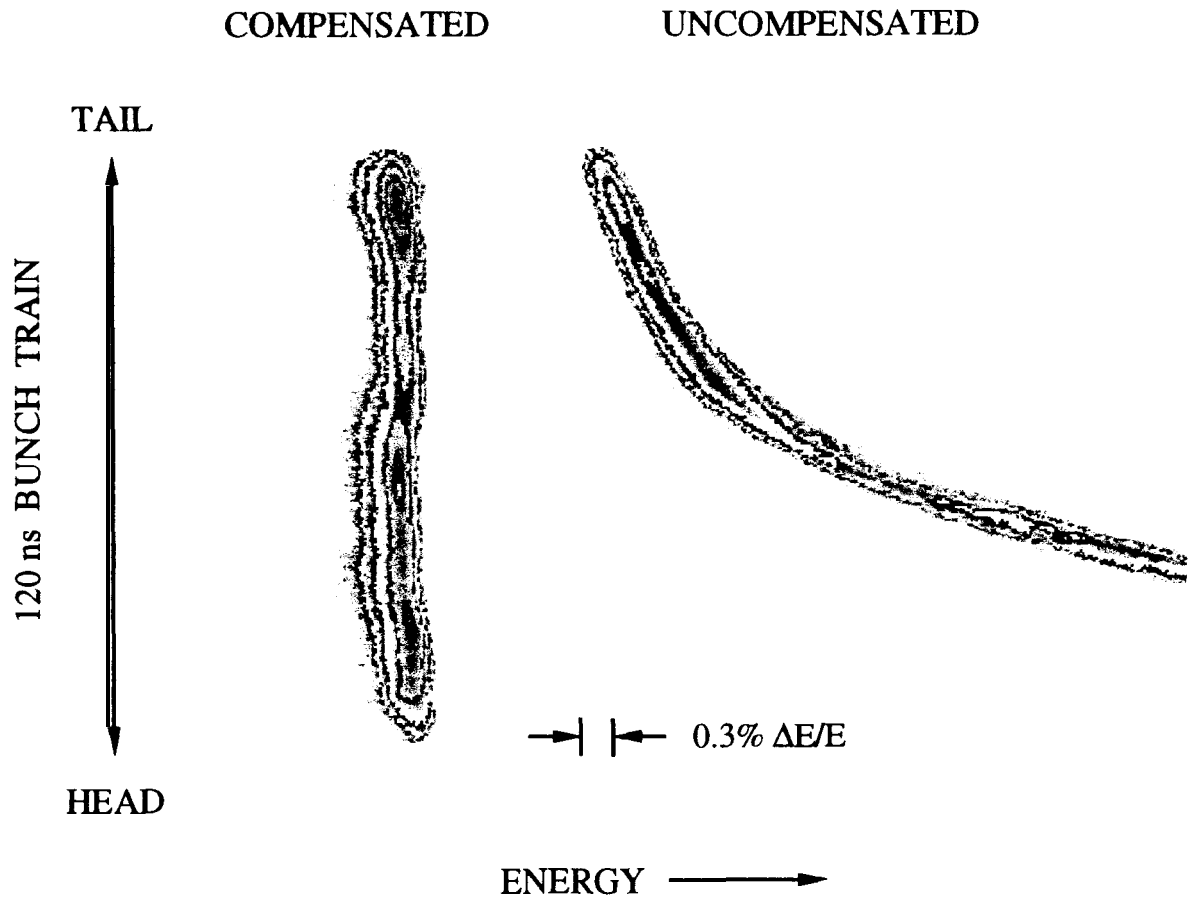
Measurement and Prediction



Klystron Phase Profile and the Corresponding SLED Output Amplitude Required for 13% Beam Loading Compensation (solid) and No Loading (dashed)

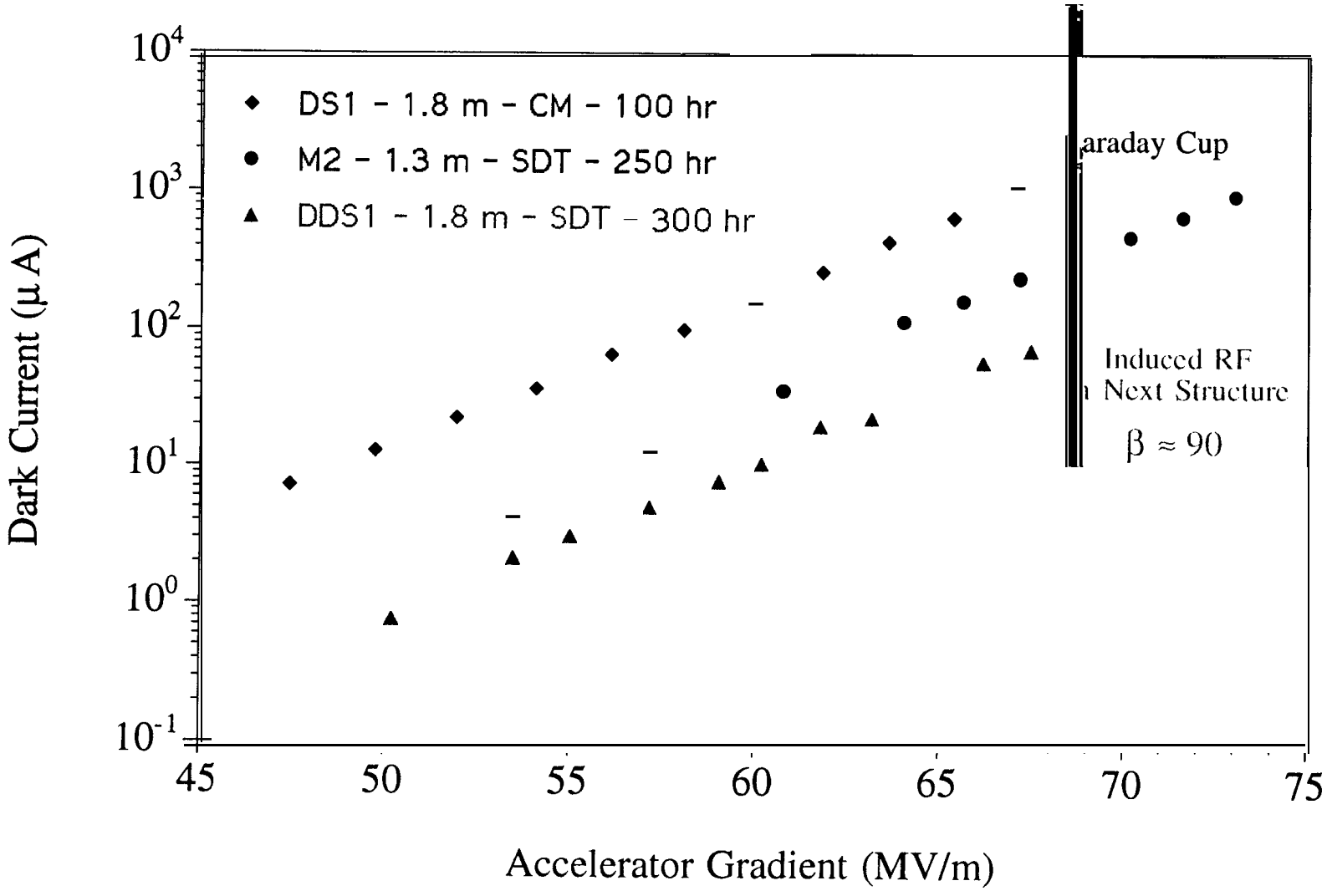


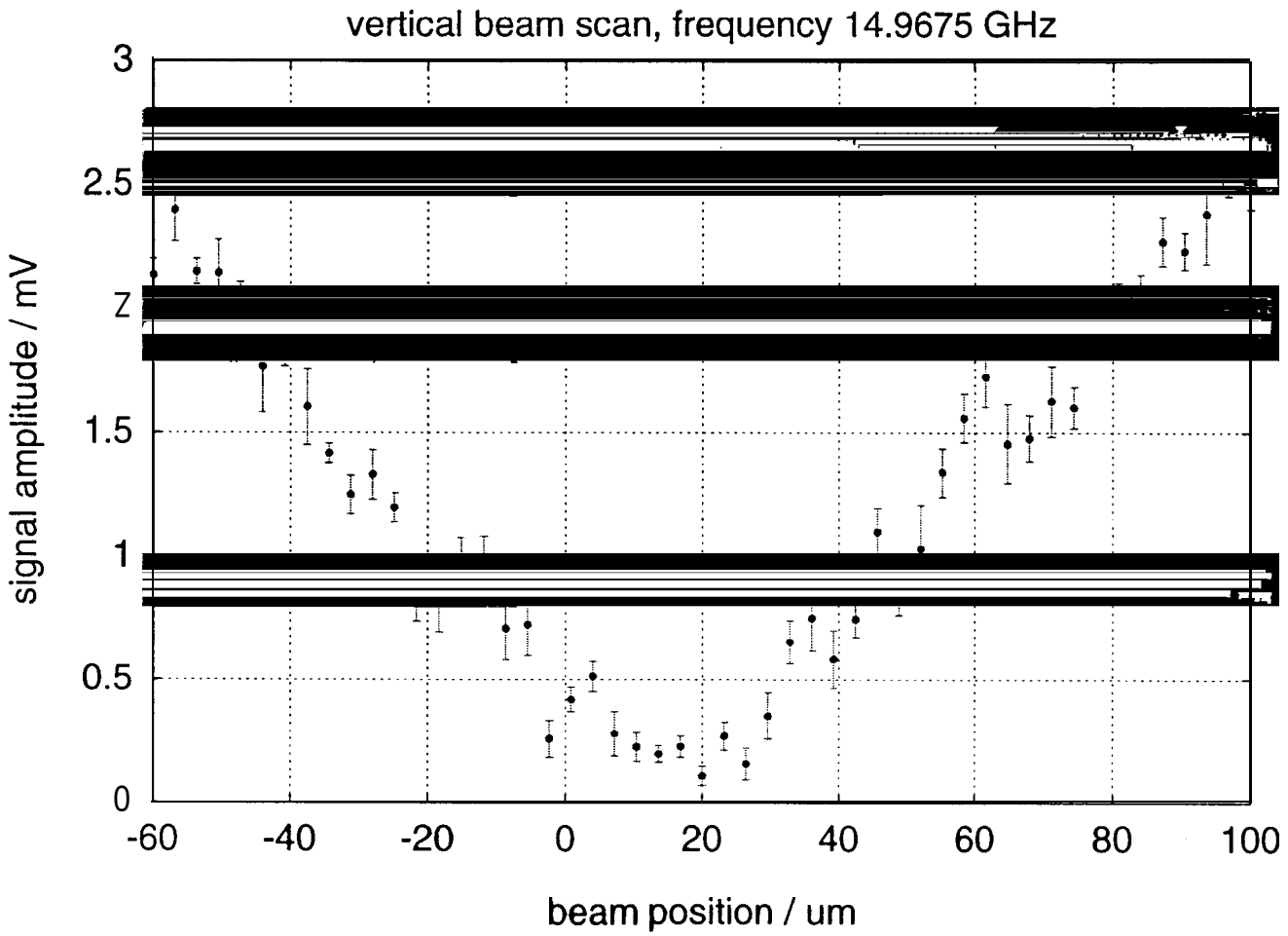
BEAM LOADING COMPENSATION

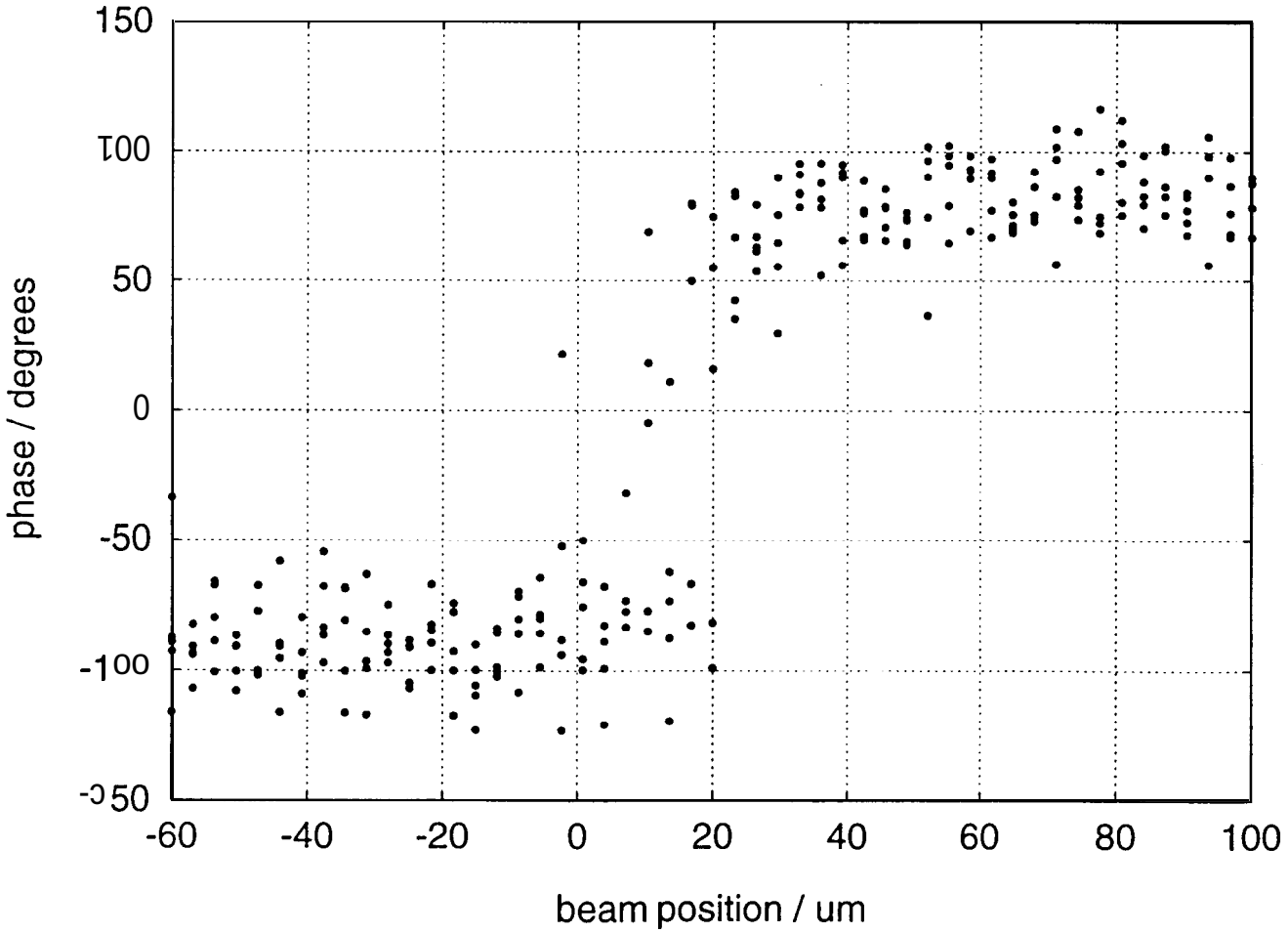


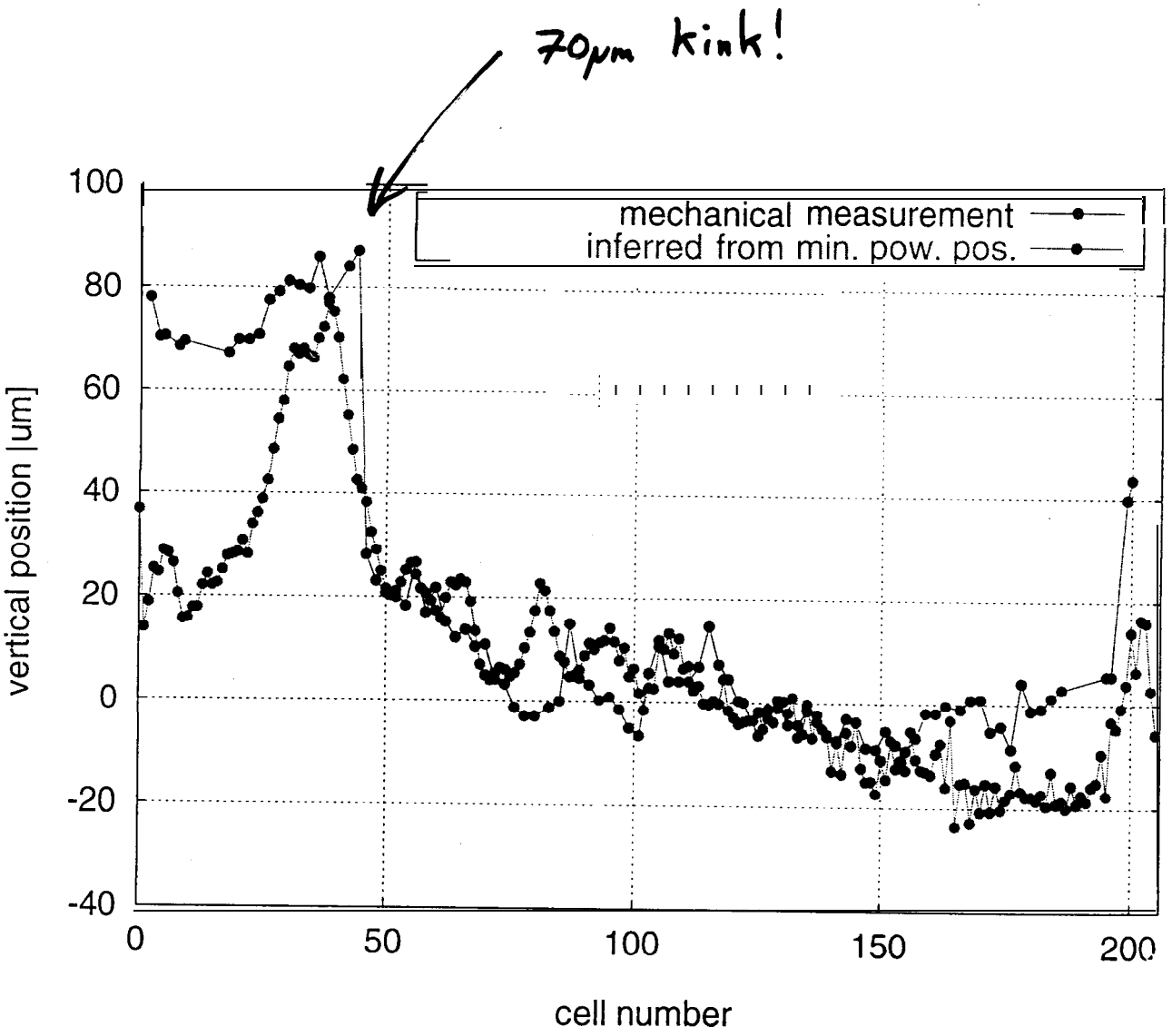
RF Station	Unloaded Gradient (MeV/m)	% Loading
0	47	14
1	44	17
2	37	17

Structure Dark Current Measurements




vertical beam scan, frequency 14.9675 GHz
signal amplitude / mV
beam position / um
3
2.5
2
1.5
1
0.5
0
-60
-40
-20
0
20
40
60
80
100

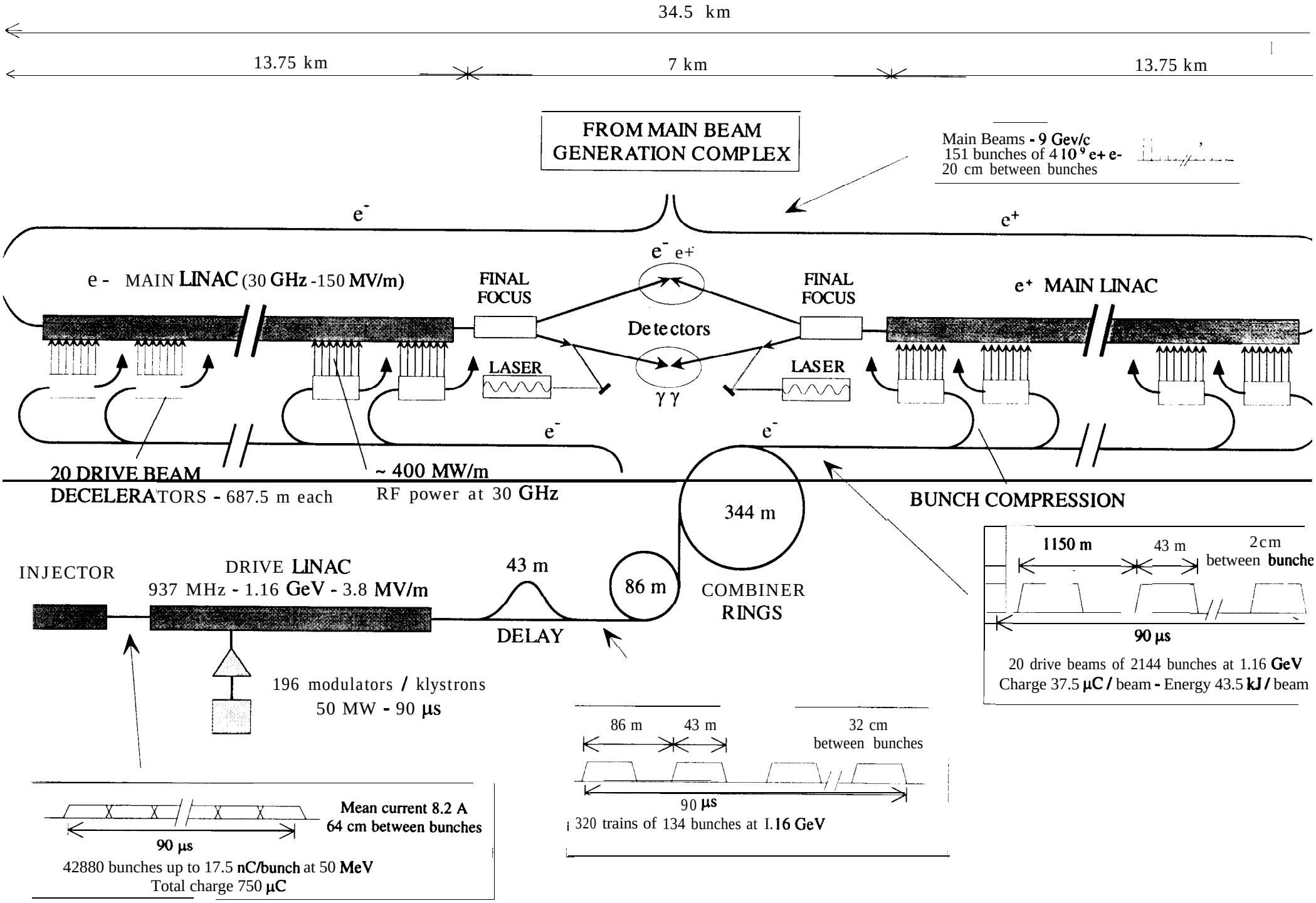

phase / degrees
beam position / um
150
100
50
0
-50
-100
-150
-60
-40
-20
0
20
40
60
80
100

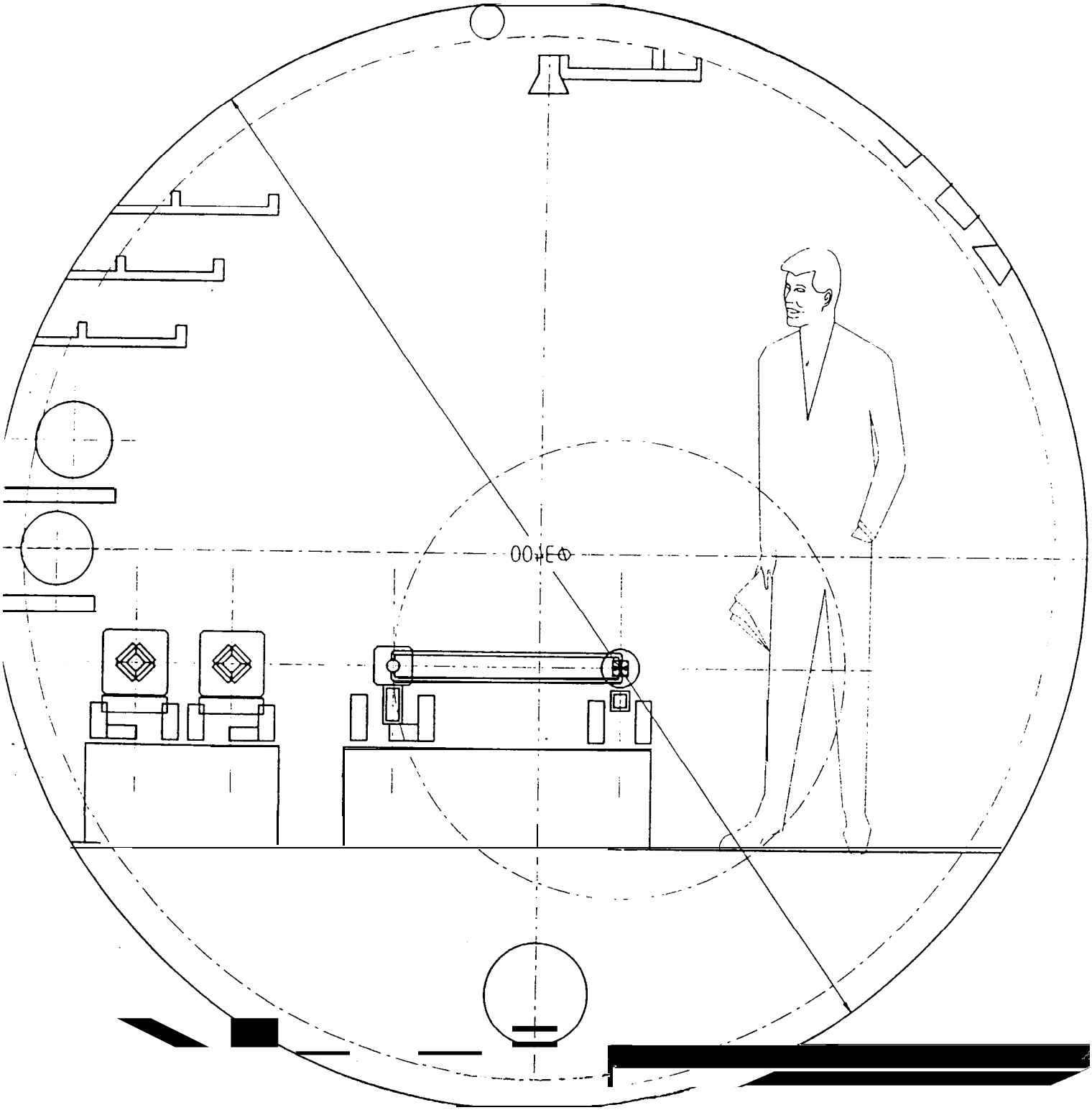


Measure dipole mode power in DDS manifolds

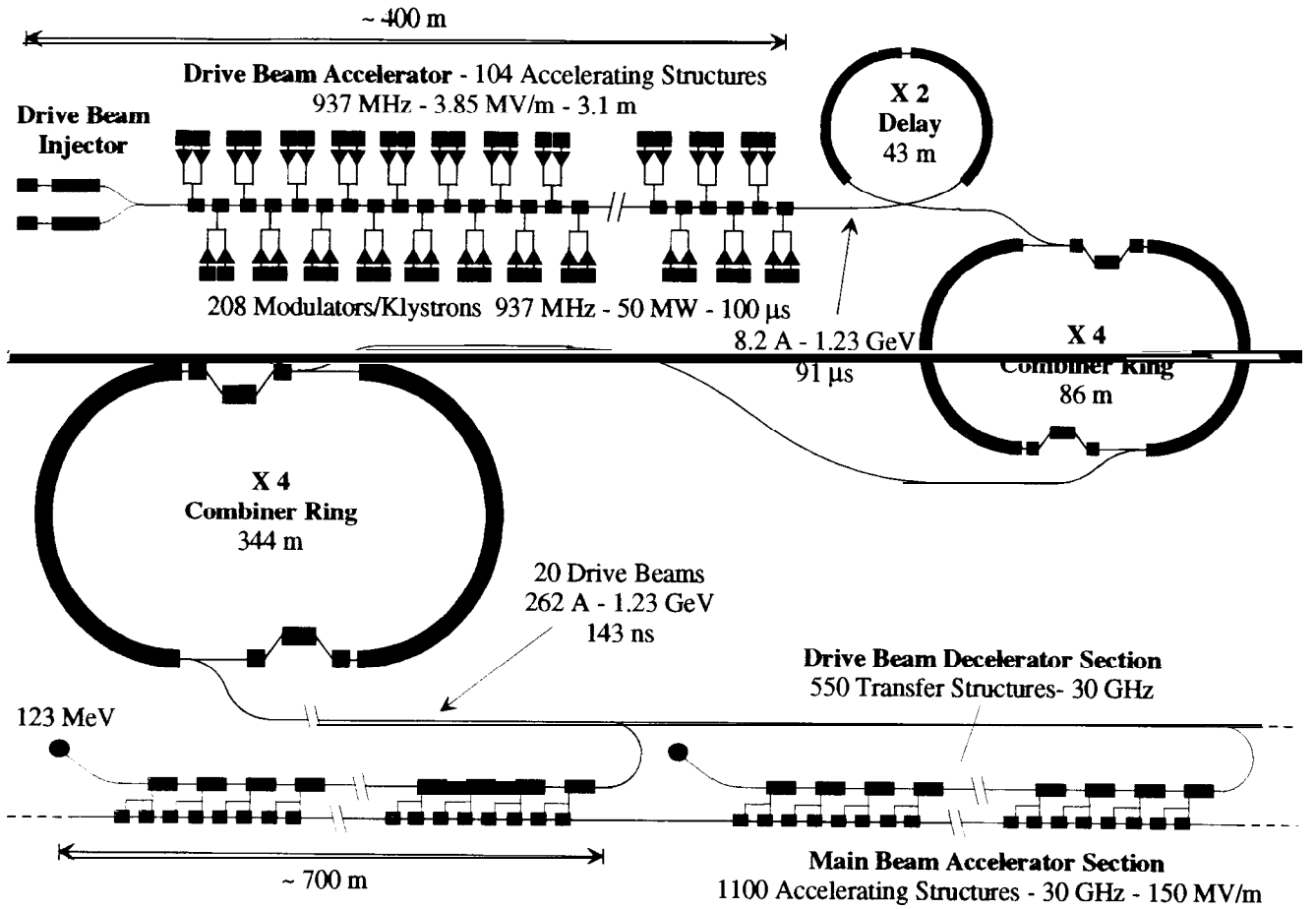
CLIC

- 30 GHz rf frequency for high gradient operation — allows consideration of multi-TeV operation
- Uses TBA which has advantage for very high energies
- Difficulties:
  - two-beam concept is very untested
  - tolerances scale roughly with inverse of rf frequency and are tighter
  - need strong damping of dipole modes in acc. structures
  - require very small emittances at higher energies
  - final focus and beam collimation are quite diffkult at high energy and probably require new concepts


34.5 km
13.75 km
7 km
13.75 km
FROM MAIN BEAM GENERATION COMPLEX
Main Beams - 9 Gev/c
151 bunches of 4 10 9 e+ e-
20 cm between bunches
e-
e+
e - MAIN LINAC (30 GHz -150 MV/m)
FINAL FOCUS
e- e+
Detectors
γ γ
FINAL FOCUS
e+ MAIN LINAC
LASER
LASER
e-
e-
20 DRIVE BEAM DECELERATORS - 687.5 m each
~ 400 MW/m
RF power at 30 GHz
344 m
BUNCH COMPRESSION
1150 m
43 m
2cm between bunche
90 µs
20 drive beams of 2144 bunches at 1.16 GeV
Charge 37.5 µC / beam - Energy 43.5 kJ / beam
INJECTOR
DRIVE LINAC
937 MHz - 1.16 GeV - 3.8 MV/m
43 m
86 m
COMBINER RINGS
DELAY
196 modulators / klystrons
50 MW - 90 µs
86 m
43 m
32 cm between bunches
90 µs
320 trains of 134 bunches at I.16 GeV
Mean current 8.2 A
64 cm between bunches
90 µs
42880 bunches up to 17.5 nC/bunch at 50 MeV
Total charge 750 µC



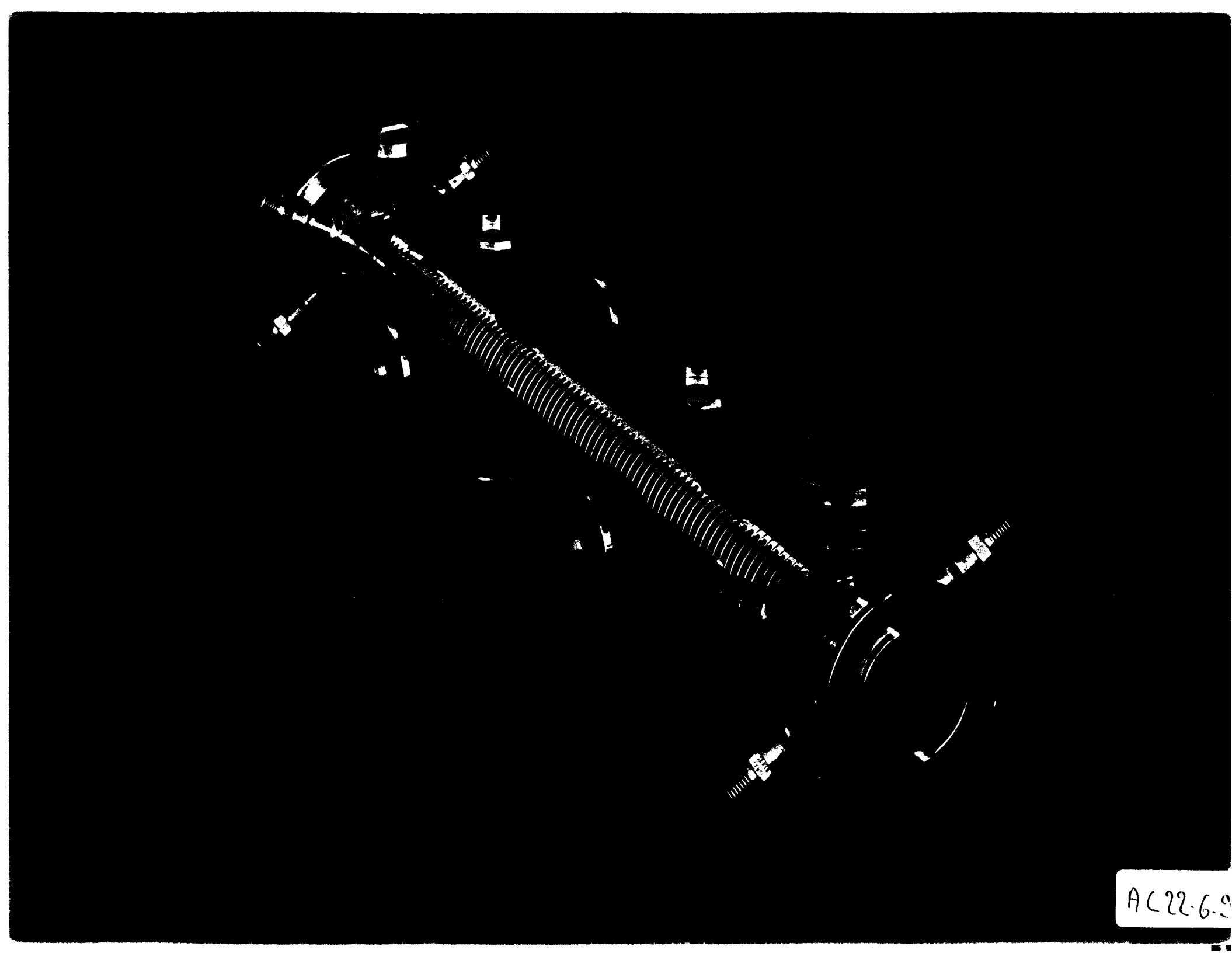
An Overview of the CLIC Two Beam Accelerator



- Bunches (trains) fill even or odd buckets from alternating injectors
- Inter leave bunches using rf deflector and delay line or ring
- Compress long pulse by 32

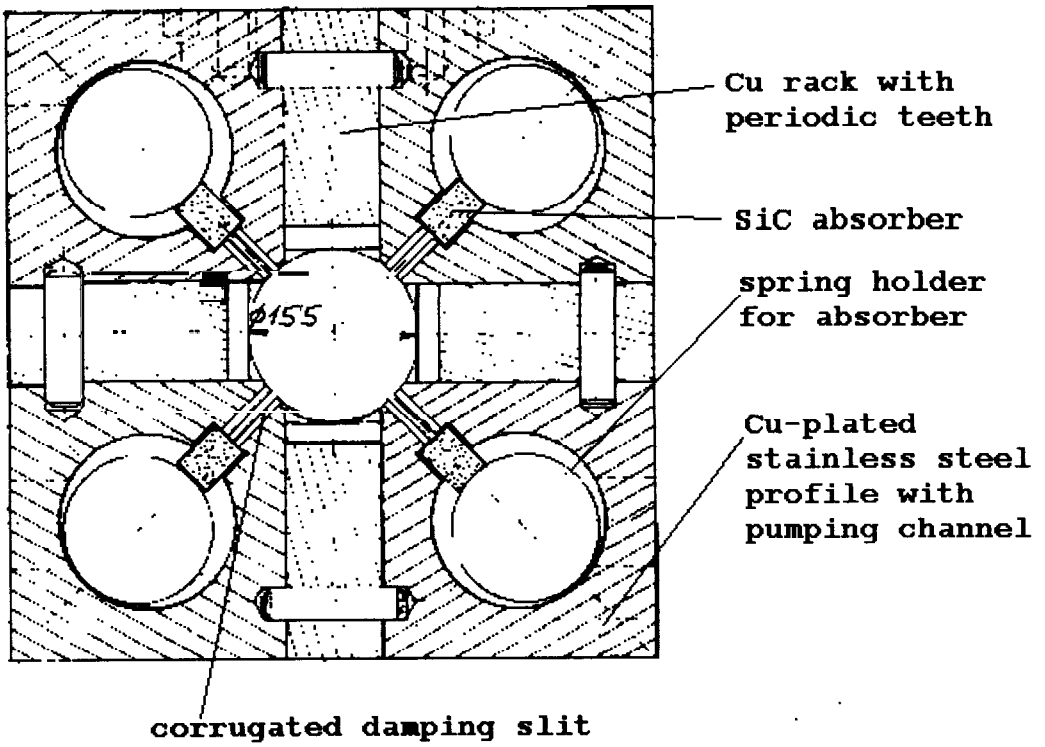
New CLIC Parameters

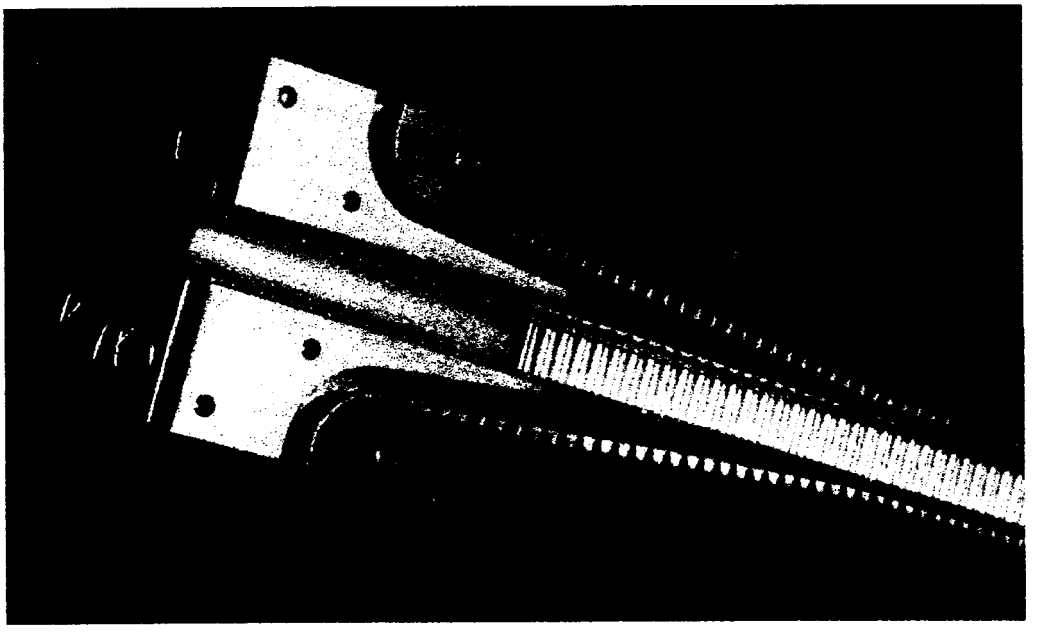
Centre of mass energy	**[TeV]**	**2 E_b**	**1**	**3**	**5**
Beam parameters at IP					
Luminosity (with pinch)	[10^{33}cm^{-2}sec^{-1}]	L	12.93	112.5	152
Effect lumin. (with dilution)	[10^{33}cm^{-2}sec^{-1}]	L	10.34	90	121.5
Beamstrahlung mom. spread	[%]	δ_s	10	40	50
Beamsthralung parameter	[-]	Y	0.54	8.33	25.3
Number of photons/electron	[-]	n_γ	1.03	1.81	2.00
Linac repetition rate	[Hz]	f_r	150	75	50
Number of particles/bunch	[$10^9 e^\pm$]	N_e	4.0	4.0	4.0
Number of bunches/pulse	[-]	n_b	150	150	150
Bunch spacing	[nsec]	Δ_b	0.67	0.67	0.67
Transverse emittances	[10^{-8} radm]	$\gamma\varepsilon_{x/y}$	148/7	60/1	58/1
Beta functions	[mm]	$\beta_{x/y}$	10/0.10	8/0.10	6/0.10
RMS beam width (FF diluted)	[nm]	$\sigma^*_{x/y}$	129/3.2	42.5/0.70	28.0/0.54
Bunch length	[μm]	σ_z	50	30	25
Enhancement factor	[-]	H_D	1.45	1.87	1.93
Beam power per beam	[MW]	P_b	7.24	10.81	12.02
Main Linac					
RF frequency of main linac	[GHz]	$\omega/2\pi$	30	30	30
Accelerating field (loaded)	[MV/m]	G	100	150	200
Total two linac length	[km]	l_T	14.0	27.5	35
RF power at section input	[MWatts]	P_s	116	231	386
RF pulse length	[μsec]	Δ_K	0.121	0.121	0.121
Drive Beam Segments	[-]	N_D	24	48	60
Frequency Multiplication			32	32	32
# of modulators/klystrons	[-]	N_K	180	360	360
Klystron power (drive beam)	[MWatts]	P_K	50	50	90
AC to RF efficiency	[%]	η_{RF}	40	40	40
RF to beam efficiency	[%]	η_{RF-B}	35.45	26.64	19.38
AC to beam efficiency	[%]	η_{AC-B}	14.18	10.65	7.75
AC power for RF generation	[MW]	P_{AC}	102.1	206	310



AC22.6.9

Construction of an Power Extraction Structure



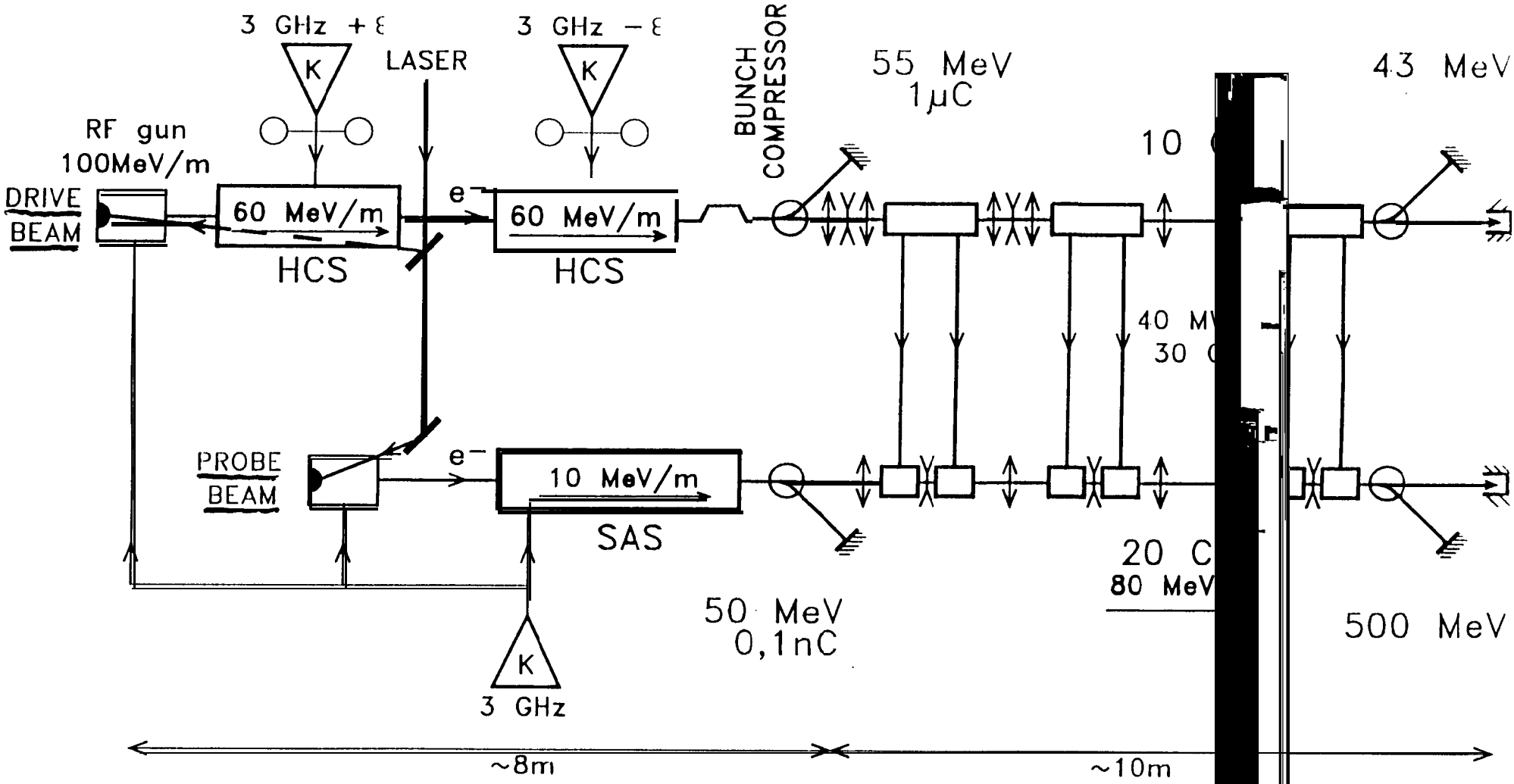


A Damped and Detuned Structure for the Drive Beam Accelerator

G. Carron, A. Millich, L Thorndahl

- Change iris cell-to-cell so they don't ring in unison
- Damp higher modes in each Cell using four waveguides

A DEMONSTRATION OF THE TWO BEAM ACCELERATION SCHEME IN THE CLIC TEST FACILITY



SAS: STANDARD ACCELERATING STRUCTURE
HCS: HIGH CHARGE SECTION

CTS: 30GHz CLIC TRANSFER STRUCTUR
CAS: 30GHz CLIC ACCELERATING STRU

The First Test Facility: CTF3a

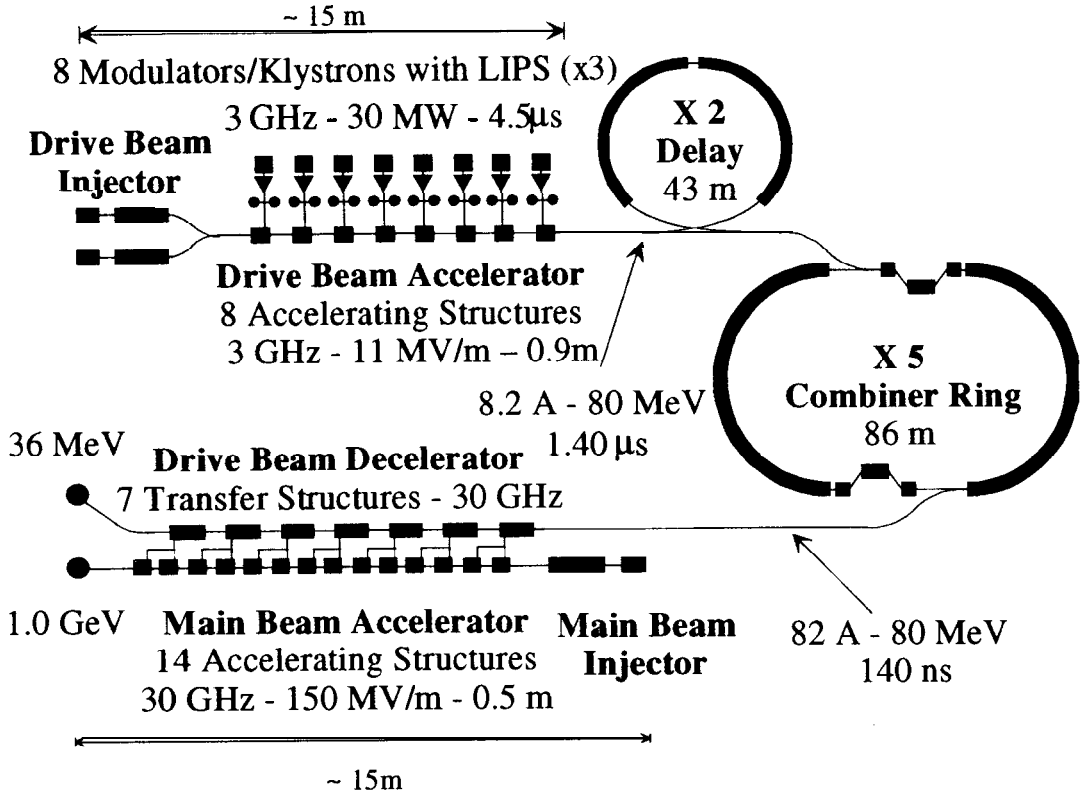
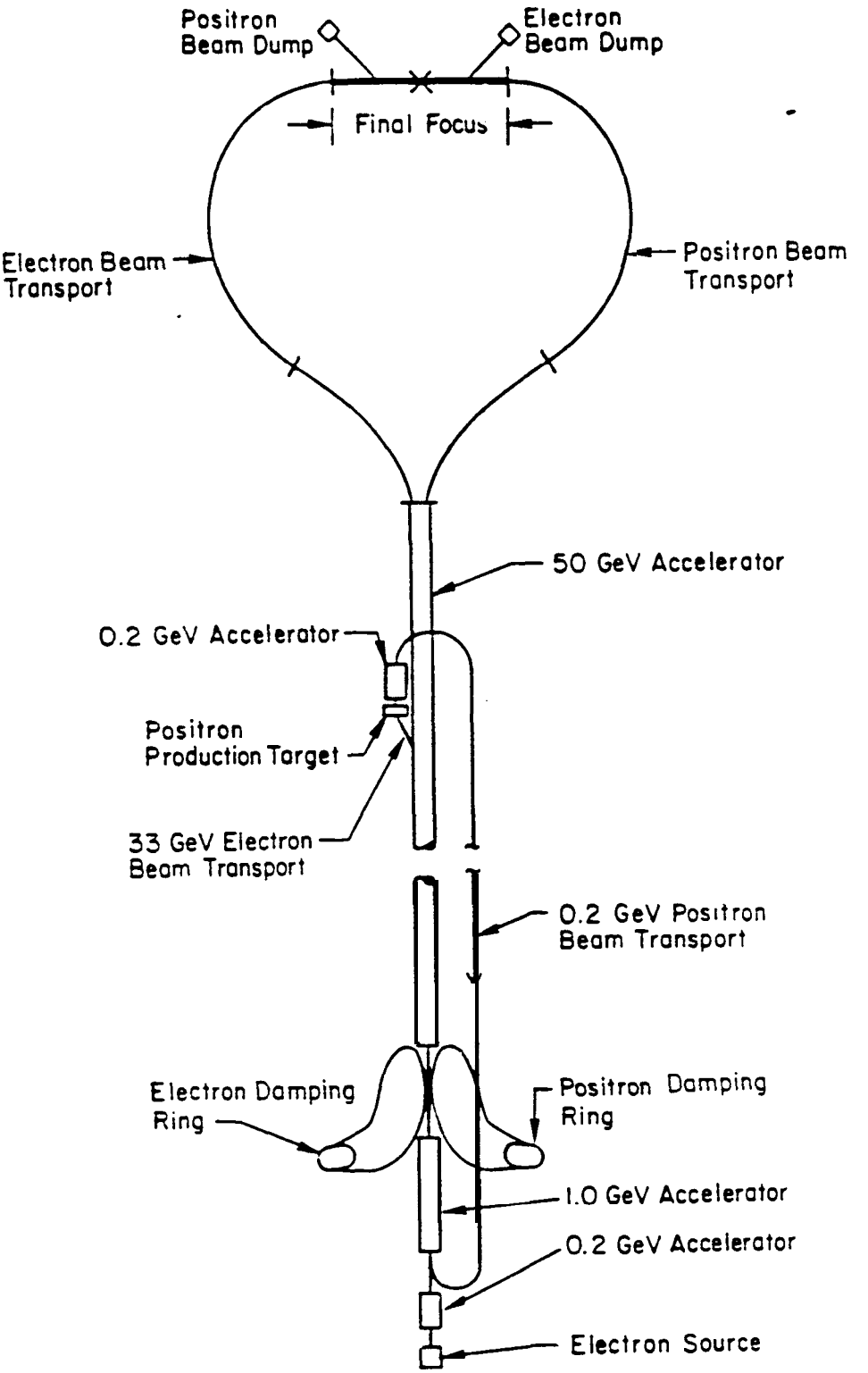


Table1 -Comparison of CTF3 and CLIC 1 parameters for one drive beam

	CTF3	CLIC
[redacted]	3 GHz	937 MHz
	10 Hz	75 Hz
	8.2 A	28 A
Drive beam pulse length	1.4 µs	26 µs
Drive beam energy	80 MeV	1160 MeV
43 m Delay combiner (x 2)	Yes	Yes
86 m Combiner ring (x 4)	X 5	Yes
344 m Combiner ring (x 4)	No	Yes
RF pulse length	140 ns	140 ns
Frequency of RF power generated	30 GHz	30 GHz
Number of transfer structures	7	550
Number of accelerating structures	14	1100
Main linac accelerating gradient	150 MV/m	150 MV/m
Drive beam energy on beam dump	36 MeV	150 MeV

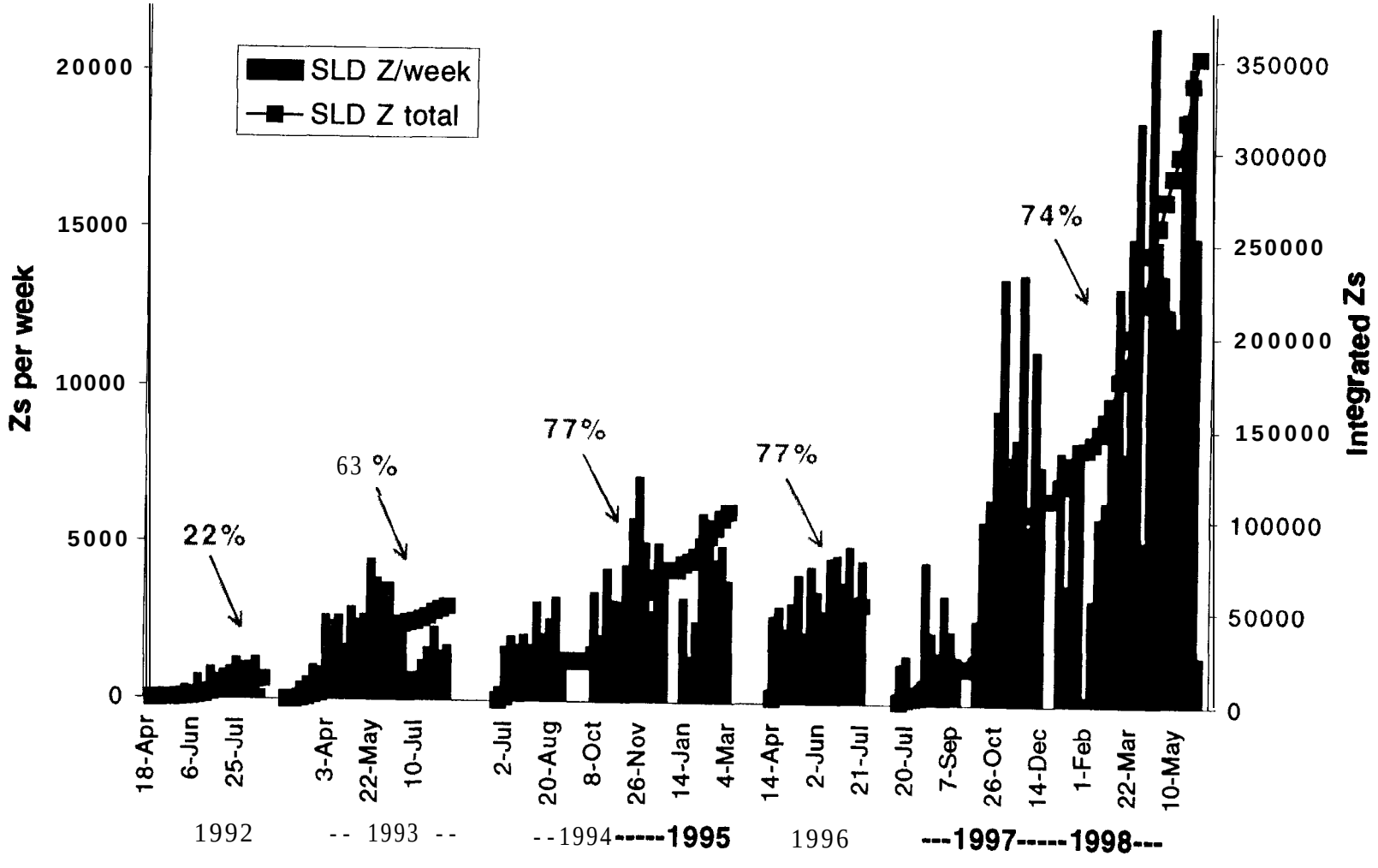
SLC

- 1st linear collider
- Learned about:
  - Wakefields, BNS damping, emittance bumps
  - Polarized electron sources
  - Beam-based feedbacks and final focus tuning
  - IP backgrounds
  - Operational stability (and damping ring difficulties)
- Close to design luminosity
- Physics results comparable to LEP with order-of-magnitude fewer Z_0's due to polarization

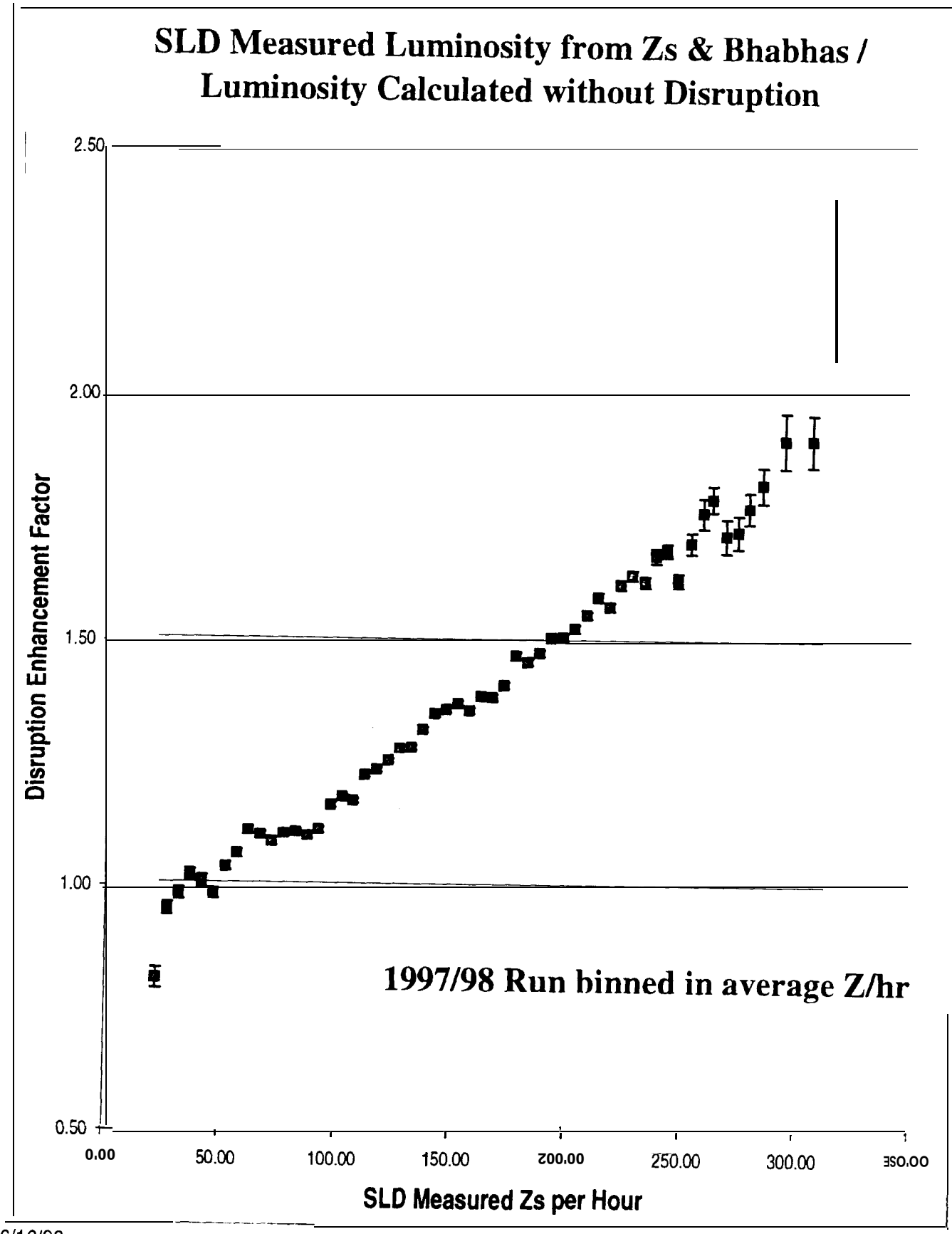


3-87 OVERALL SLC LAYOUT 5722A7

1992 - 1998 SLD Luminosity



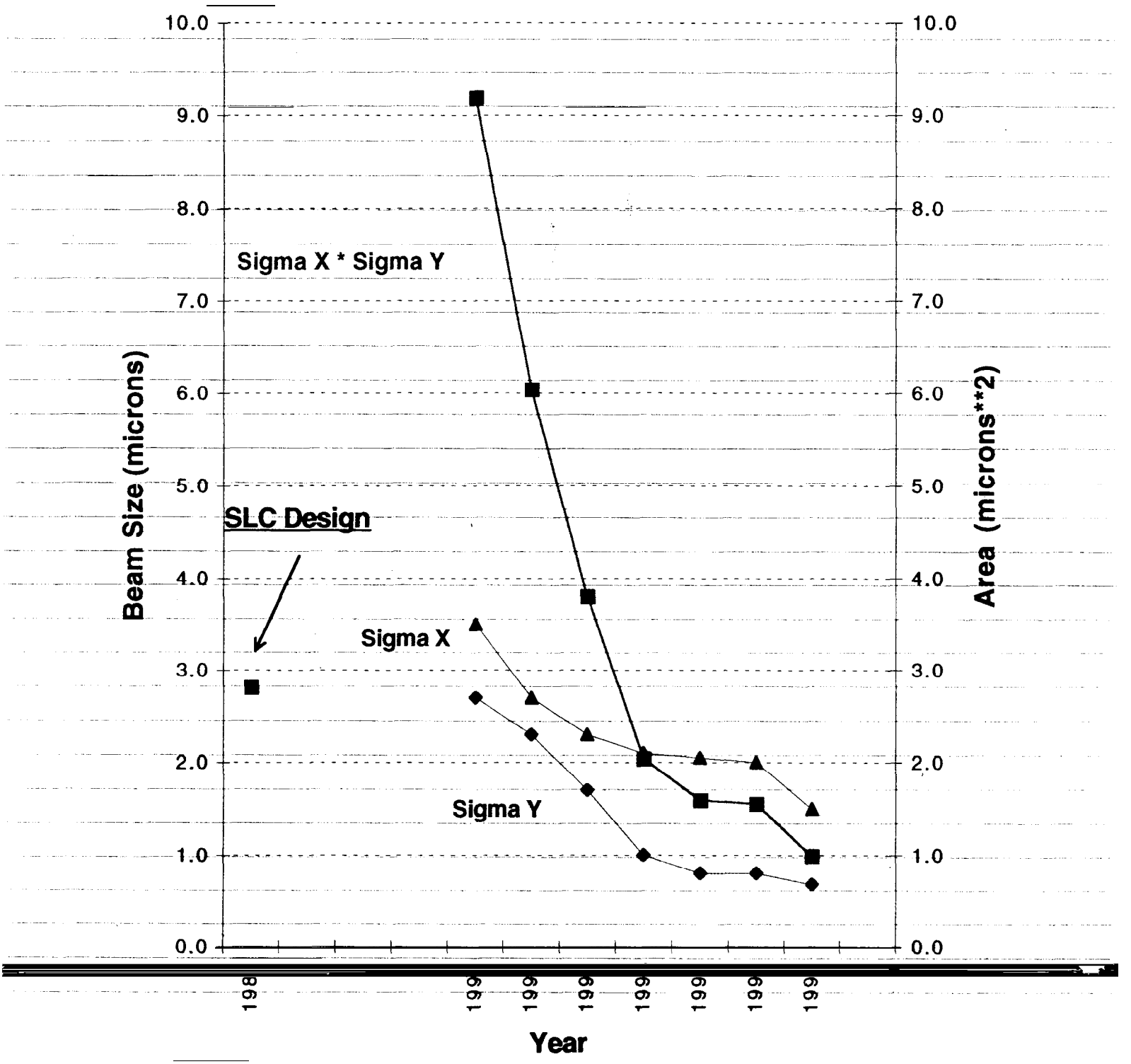
N. Phinney 9/3/98



6/16/98

T. Markiewicz

IP Beam Size vs Time



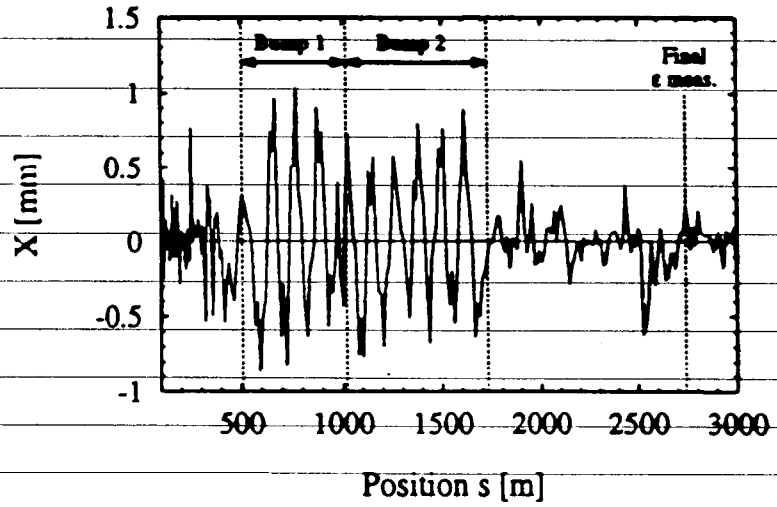
N. Phinney 6/17/98

150

Emittance Bumps

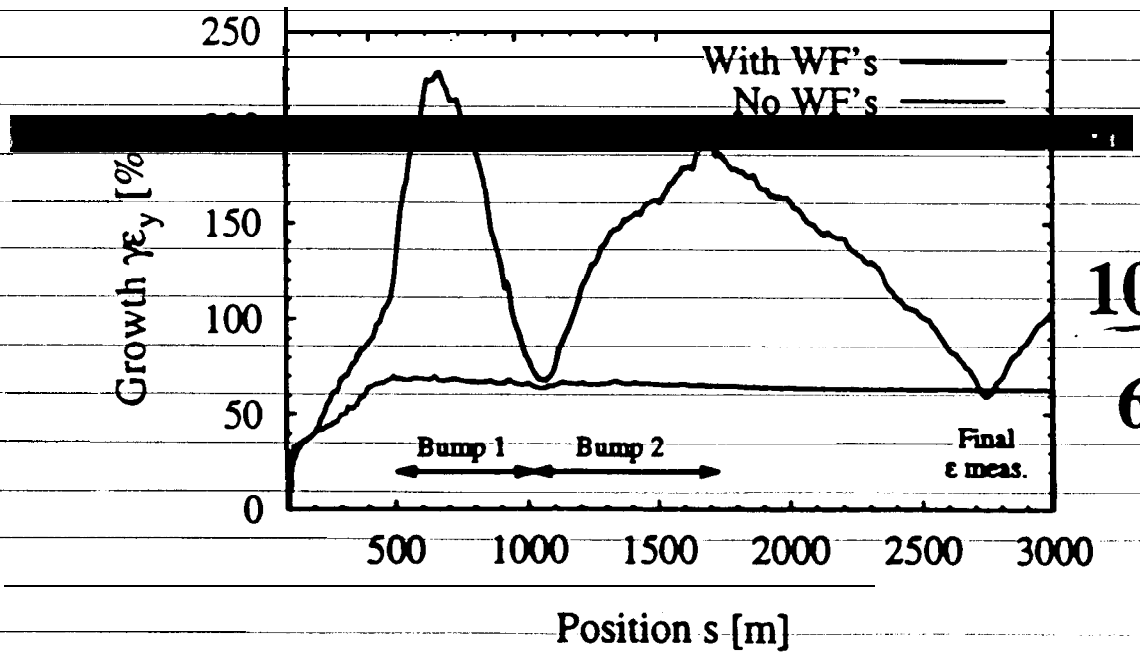
(J. Seeman et al 1991)

Induce betatron oscillations → Generate wakefield tails that compensate structure errors



during record luminosity 21-JUN-1996

TYPICAL BUMPS USED IN 1996

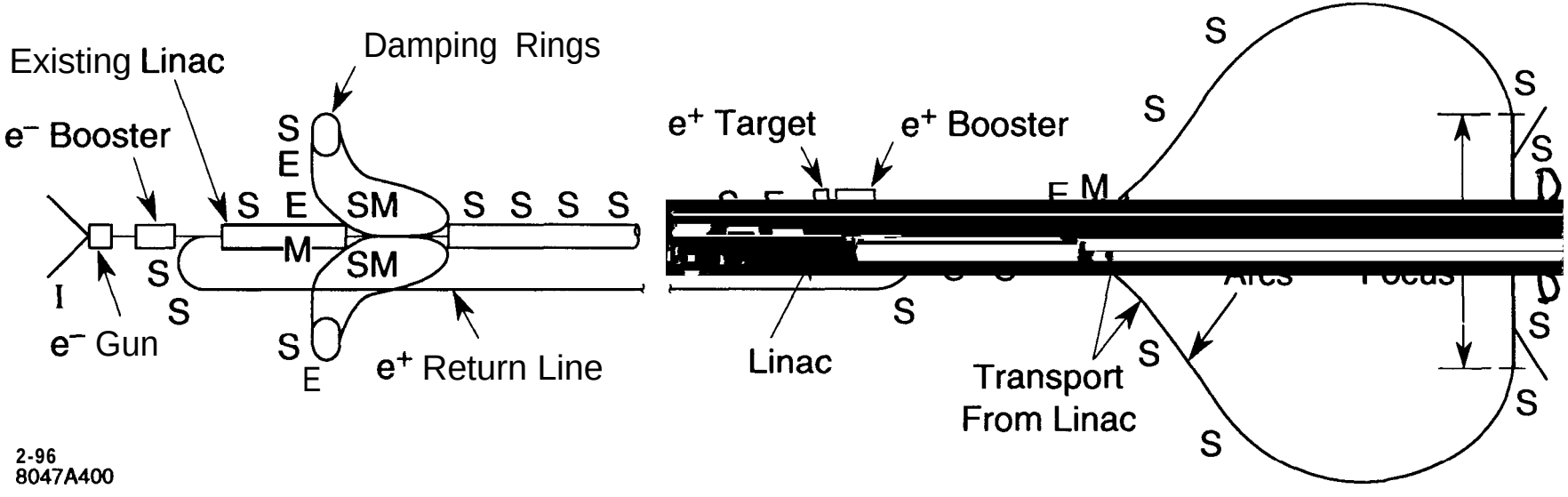


EMITTANCE GROWTH AFTER LAST MEASUREM

100 %

62 %

R. ASSMANN



S - position feedback

E - energy

I - intensity

C - auto collide

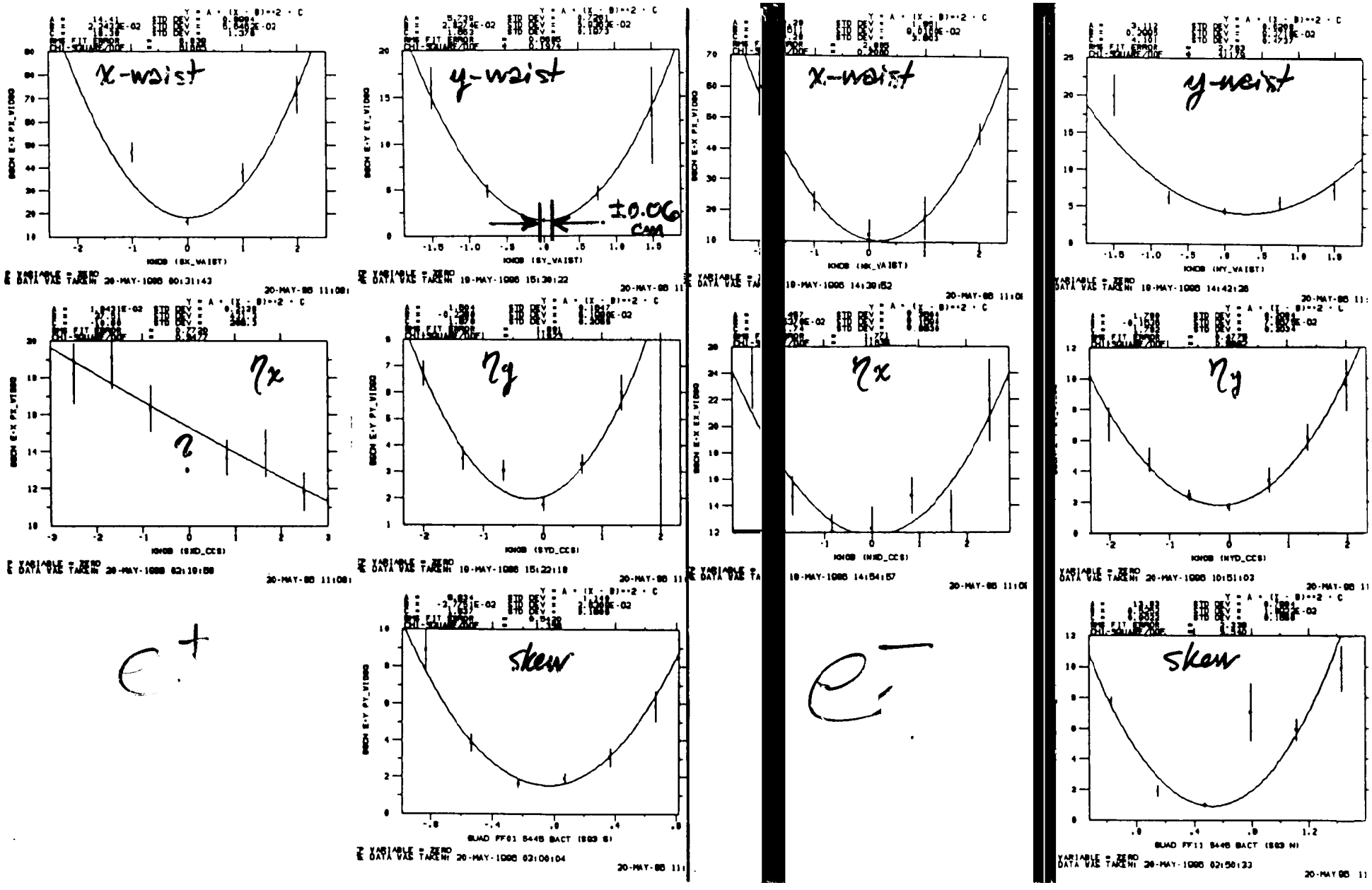
M - matching

D - dither feedback

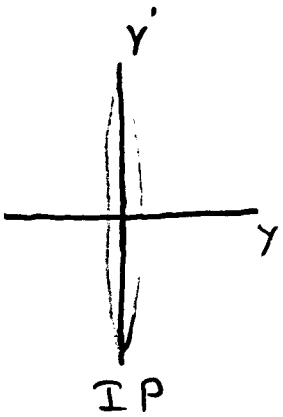
P. Emma

IP TUNING PRECISION

SLC measured



Final Focus System



$\sigma_y = \sqrt{\epsilon \beta^*}$

$\sigma_y' = \sqrt{\epsilon / \beta^*}$

- To attain luminosity, $\sigma_x/\sigma_y \sim 1 \times 0.5\mu$m in SLC and $\sim 0.3 \times 0.004\mu$m in NLC

- To focus beams to very small spot sizes, use final telescope with quadrupole doublet (for flat beams) or quadrupole triplet (for round beams) to demagnify spots $\sigma = \sqrt{\epsilon\beta}$

Small Spot at IP

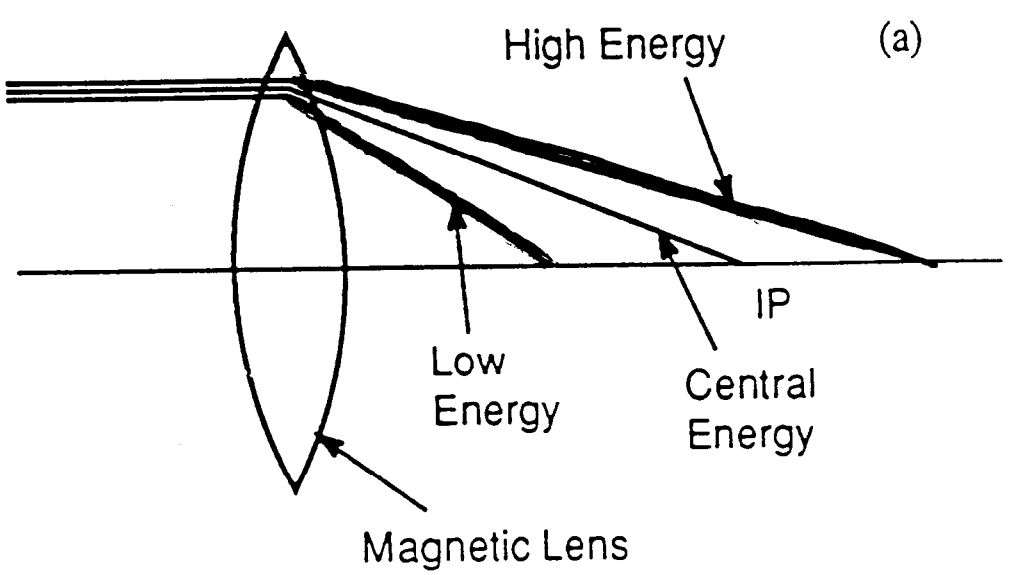
$\Rightarrow$ large σ_y'

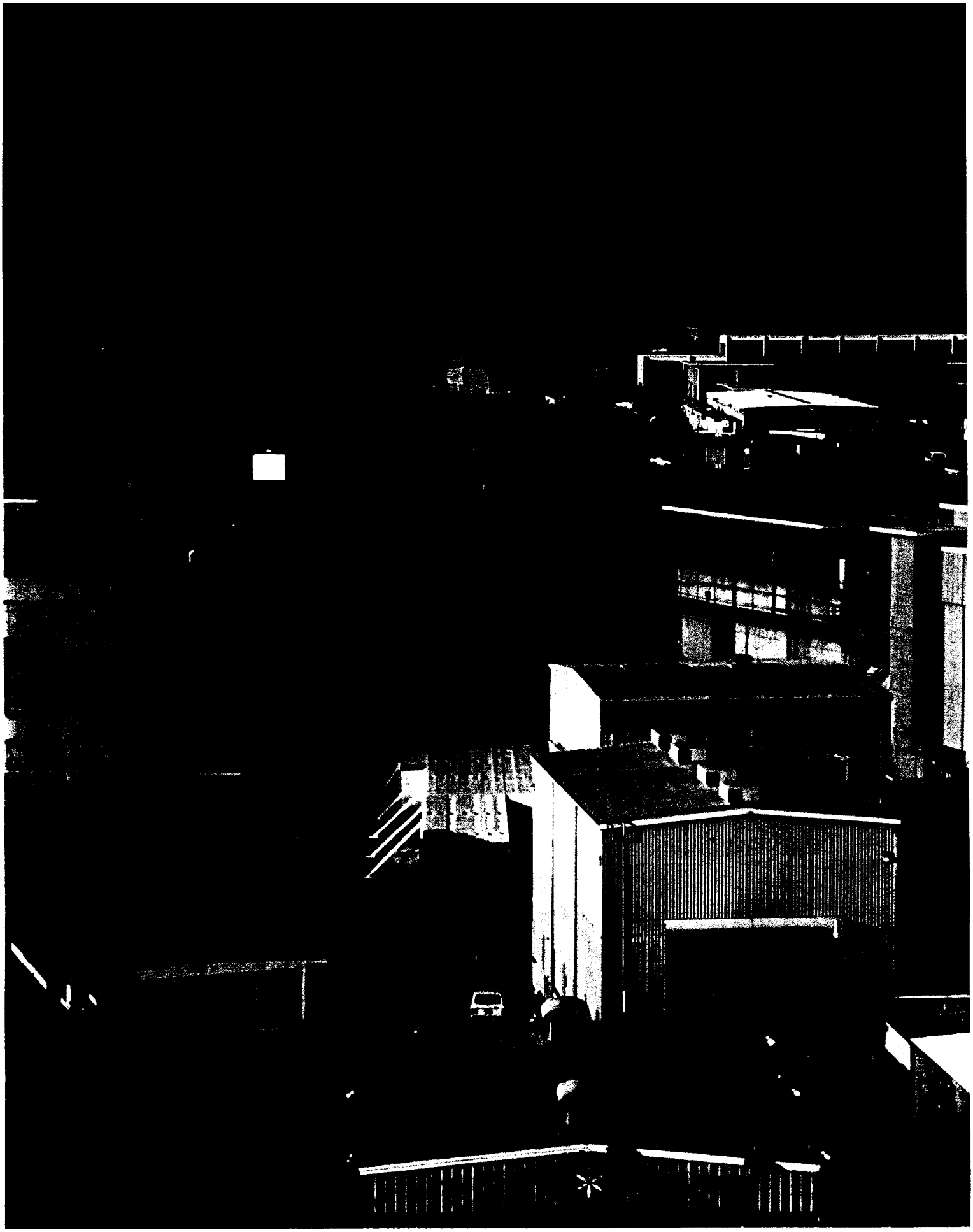
large σ_y in final lens

- The problem is the chromaticity (energy dependence of focal point) which depends on demagnification and distance to IP

$$\frac{\Delta\sigma_y}{\sigma_y} = \psi_y \sigma_{\Delta E/E} \qquad \psi_y \sim \frac{L^\star}{\beta^\star}$$

- $\psi_y \sim 6000$ in SLC and $\psi_y \sim 25,000$ in NLC which requires energy spreads less than $10^{-5} \sim 10^{-6}$ without chromatic correction





FFTB Collaborating Institutions

BINP (Novosibirsk/Protvino)

DESY

Fermilab

IBM

Kawasaki

KEK

LAL(Orsay)

MPI(Munich)

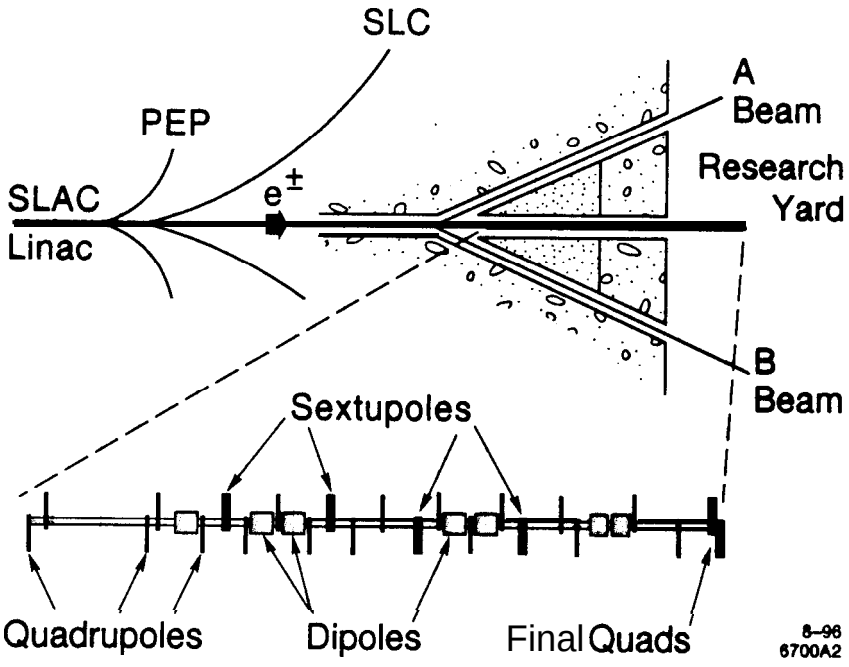
Rochester

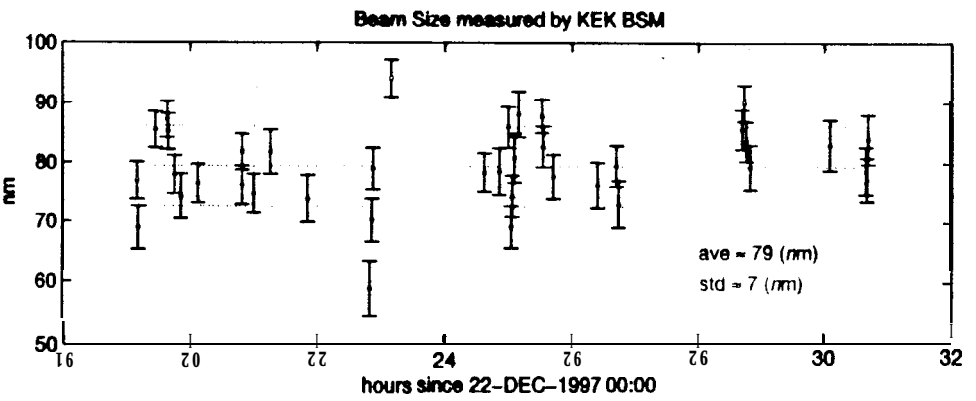
SLAC

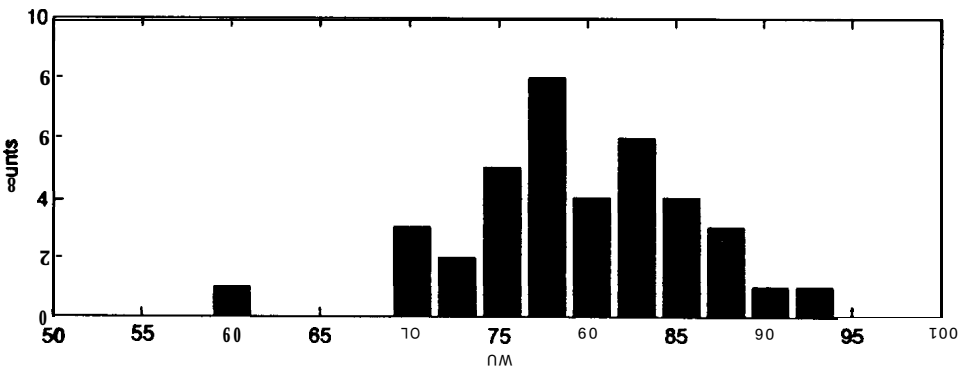
Final Focus Test Beam

- Prototype of NLC final focus system
- Has demagnification of roughly 300 while NLC needs demagnification of about 200
- Uncorrected geometric spot size is roughly 40 times nominal while uncorrected chromatic effect is about 25 times the nominal spot size

Comparable to NLC







A 12 hour period of quiet running were the main goal was to produce a small spot.

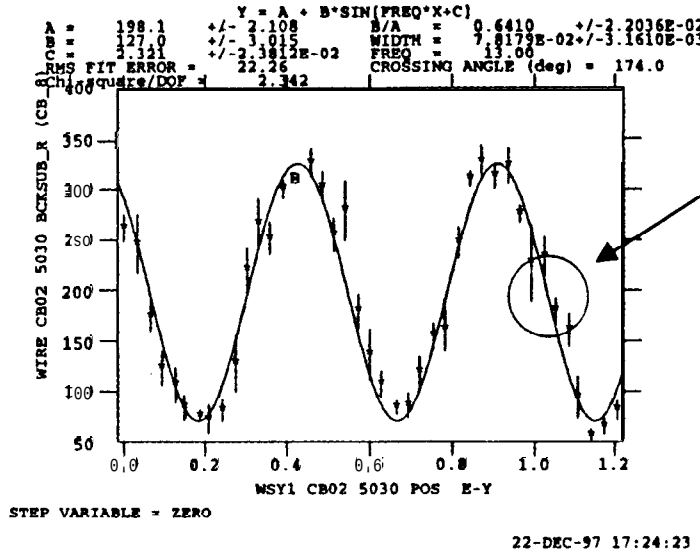
$$\sigma_{real}^2 = \frac{\sigma_{measured}^2 - \sigma_{noise}^2}{1+\delta(\sigma_{real})^2}$$

- Beam jitter
- Laser hourglass effect
- Laser power imbalance effect
- Beam line aberrations

- Structural/Mechanical vibrations
- Beam line aberrations
- Tuning resolutions

A summary of PT's spot size analysis from the last FFTB run:

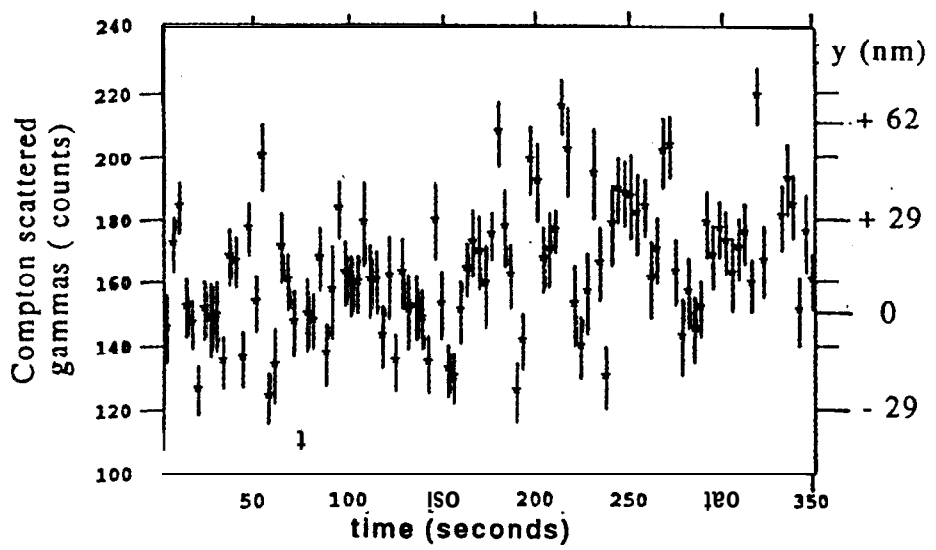
- $\varepsilon = 0.2 \times 10^{-11}$ m.
- $\beta^* = 120 \pm 24$ um.
- $\sigma_{expected} = 58 \pm 8$ nm with synchrotron radiation, aberrations, and 38 nm of beam jitter
- $\sigma_{measured} = 70 \pm 7$ nm after hourglass and power imbalance corrections.

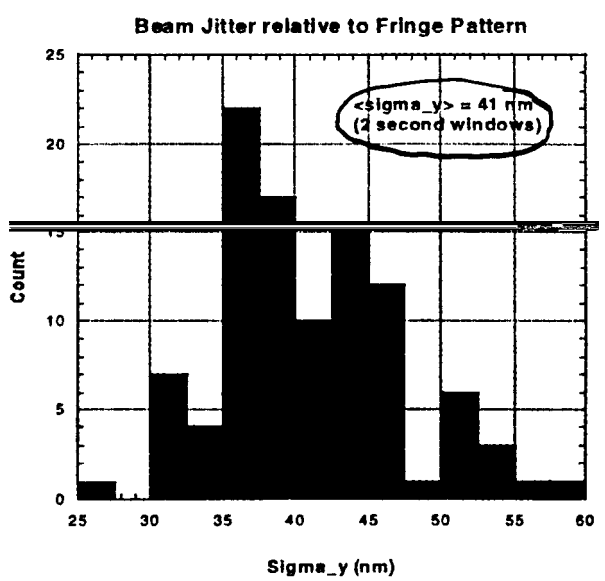


Inflection point

Beam jitter at the IP can be measured by placing the beam at an inflection point on the KEK BSM fringe pattern.

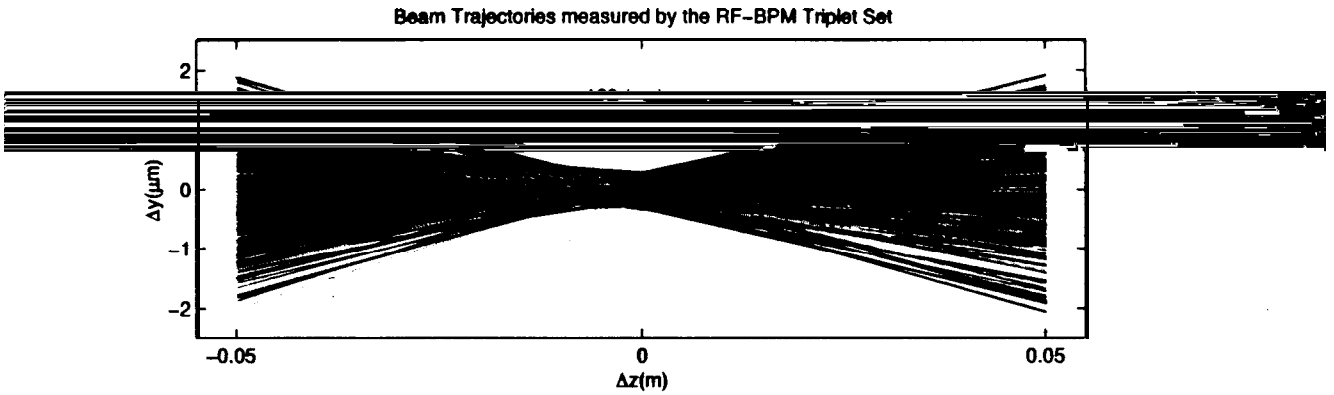
Each point is for 20 laser on pulses or 2 seconds of data. The error bars are a measurement of the beam's rms motion during the 2 second period.

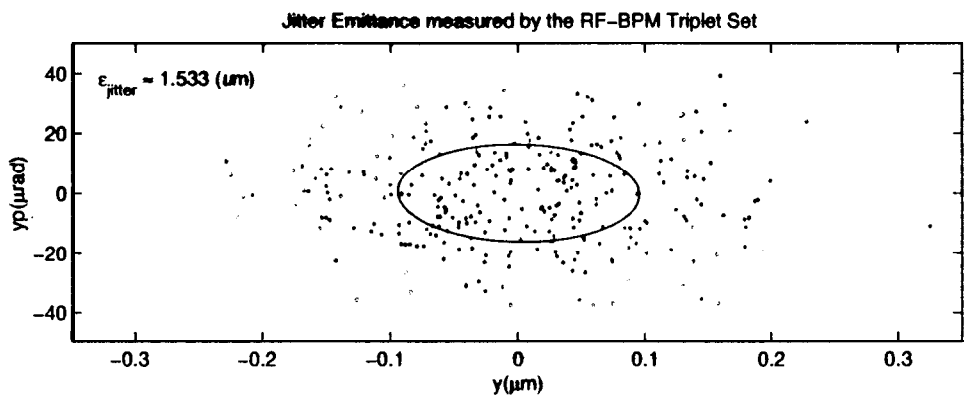




The histogram of the above error bars shows beam jitter relative to the fringe pattern of 41 nm. This is about a factor of 2 larger then what is expected for the 30% beam jitter to beam sigma ratio.

to end of FD table



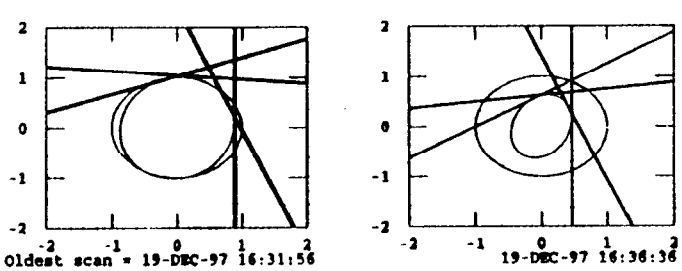


3 rf BPMs

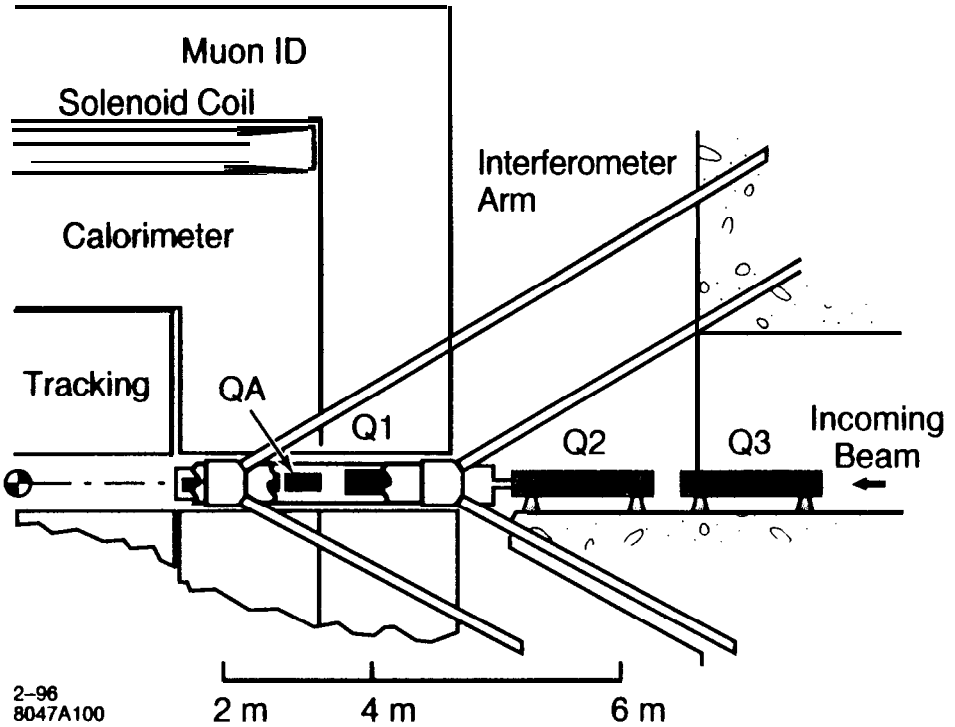
With their close spacing (5 cm) and high resolution (30 nm) the RF-BPMs can be used to measure the beam's jitter emittance at [redacted] emittance at the RF-BPMs is about 1/10th of the beam emittance measured in sector 28. This is consistent with the 30% beam jitter to beam sigma ratio.

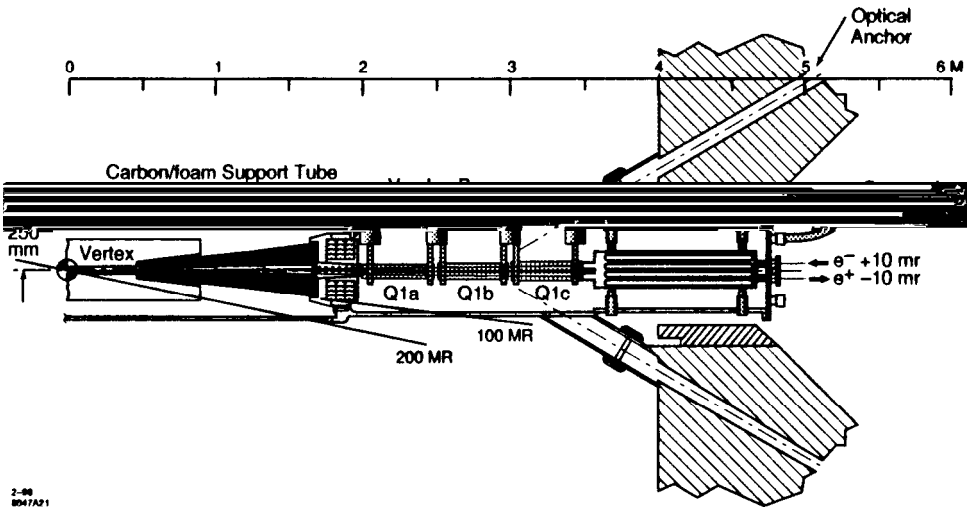
SLC 2-DIMENSIONAL PHASE SPACE ANALYSIS

LI28 X-PLANE ELEC				LI28 Y-PLANE ELEC	
3.201+- 0.069	(3.600)	EMITTANCE(mE-5)		0.141+- 0.003	(0.500)
3.245+- 0.065	(3.600)	BMAG*EMIT(mE-5)		0.151+- 0.003	(0.500)
1.014+- 0.007	(1.000)	BMAG		1.072+- 0.018	(1.000)
-0.151+- 0.017	(0.000)	BMAG_COS		-0.297+- 0.028	(0.000)
-0.067+- 0.047	(0.000)	BMAG_SIN		-0.205+- 0.040	(0.000)
18.705+- 0.485	(21.719)	BETA (m)		41.071+- 1.058	(54.481)
-0.709+- 0.044	(-0.745)	ALPHA		1.089+- 0.065	(1.736)
84.862+- 1.697	(95.557)	SIG(44)	(um)	26.143+- 0.523	[illegible]
135.212+- 2.704	(149.186)	SIG(144)	(um)	18.816+- 0.376	
97.379+- 1.948	(93.383)	SIG(444)	(um)	30.403+- 0.608	
129.651+- 2.593	(133.889)	SIG(544)	(um)	17.982+- 0.360	
0.638+- 0.055		INTENSITY		0.619+- 0.061	
2.712416		CHISQ/DOF		.4800980	
-0.051+- 0.071		ASYM(44)		0.030+- 0.106	
0.040+- 0.025		ASYM(144)		0.315+- 0.046	
0.093+- 0.115		ASYM(444)		-0.130+- 0.119	
-0.008+- 0.042		ASYM(544)		-0.885+- 0.024	

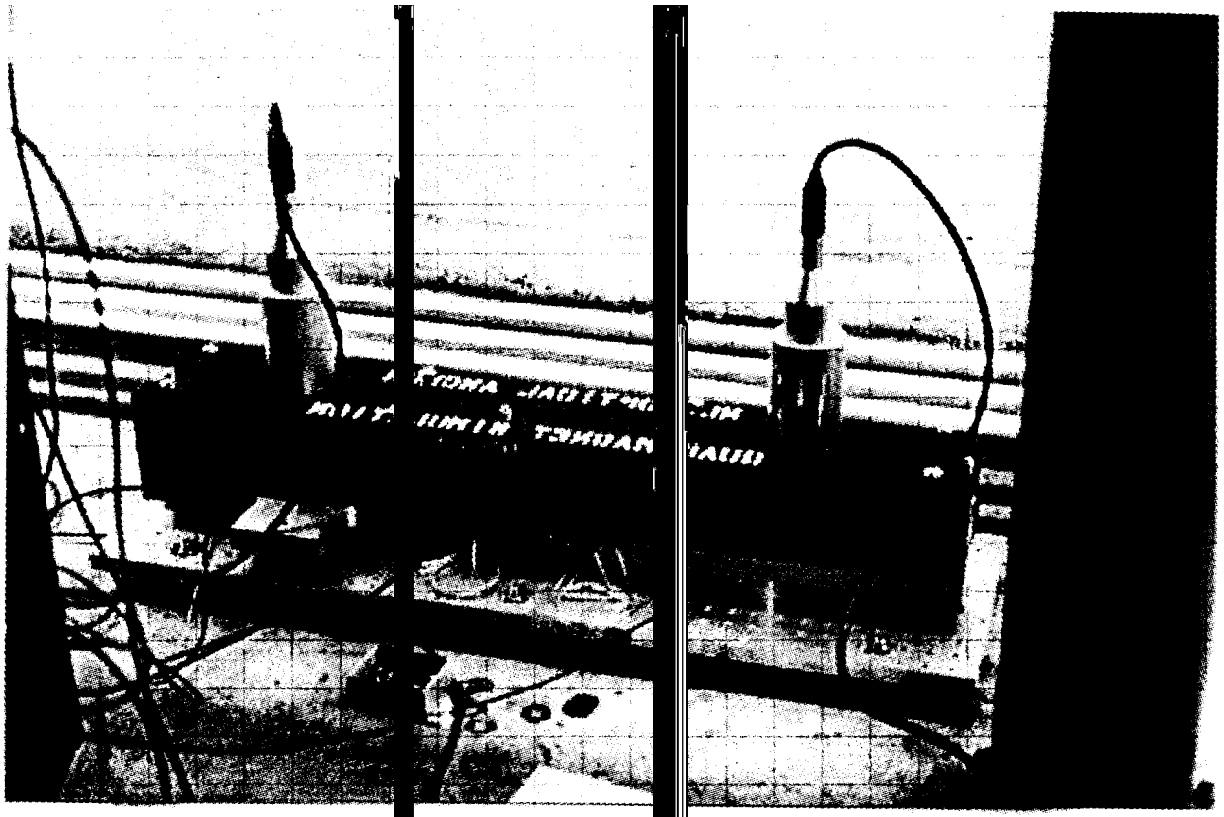


Final Magnet Supports

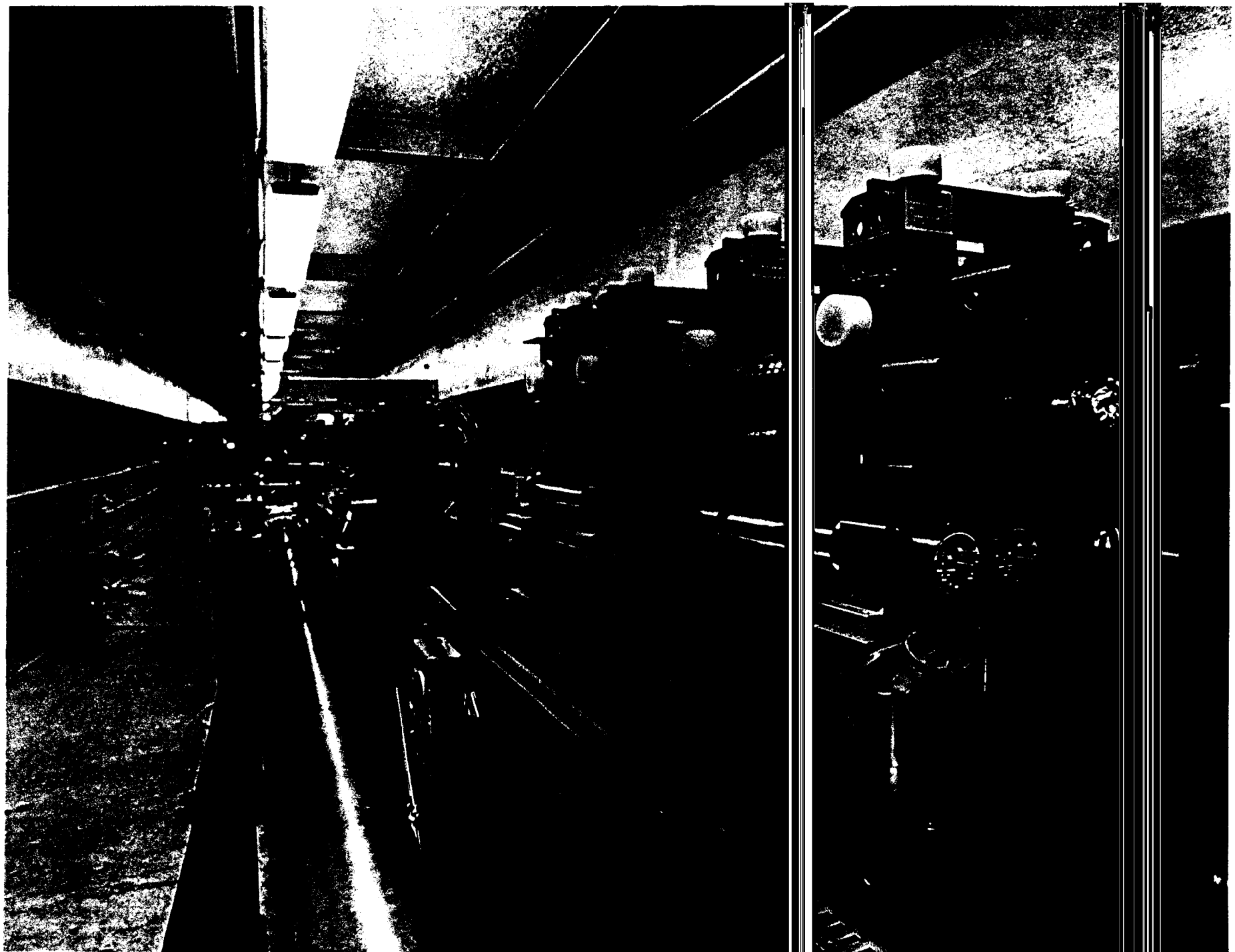




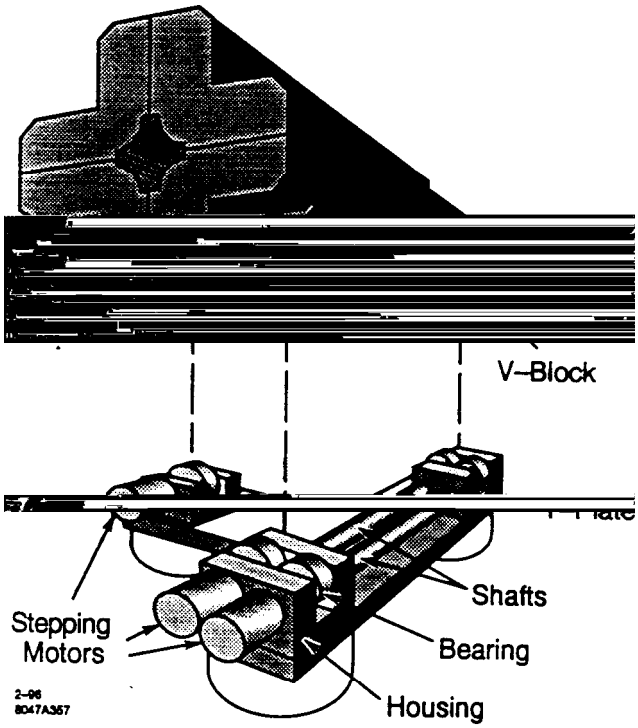
Optical Anchor to stabilize final doublet to ~ 1nm

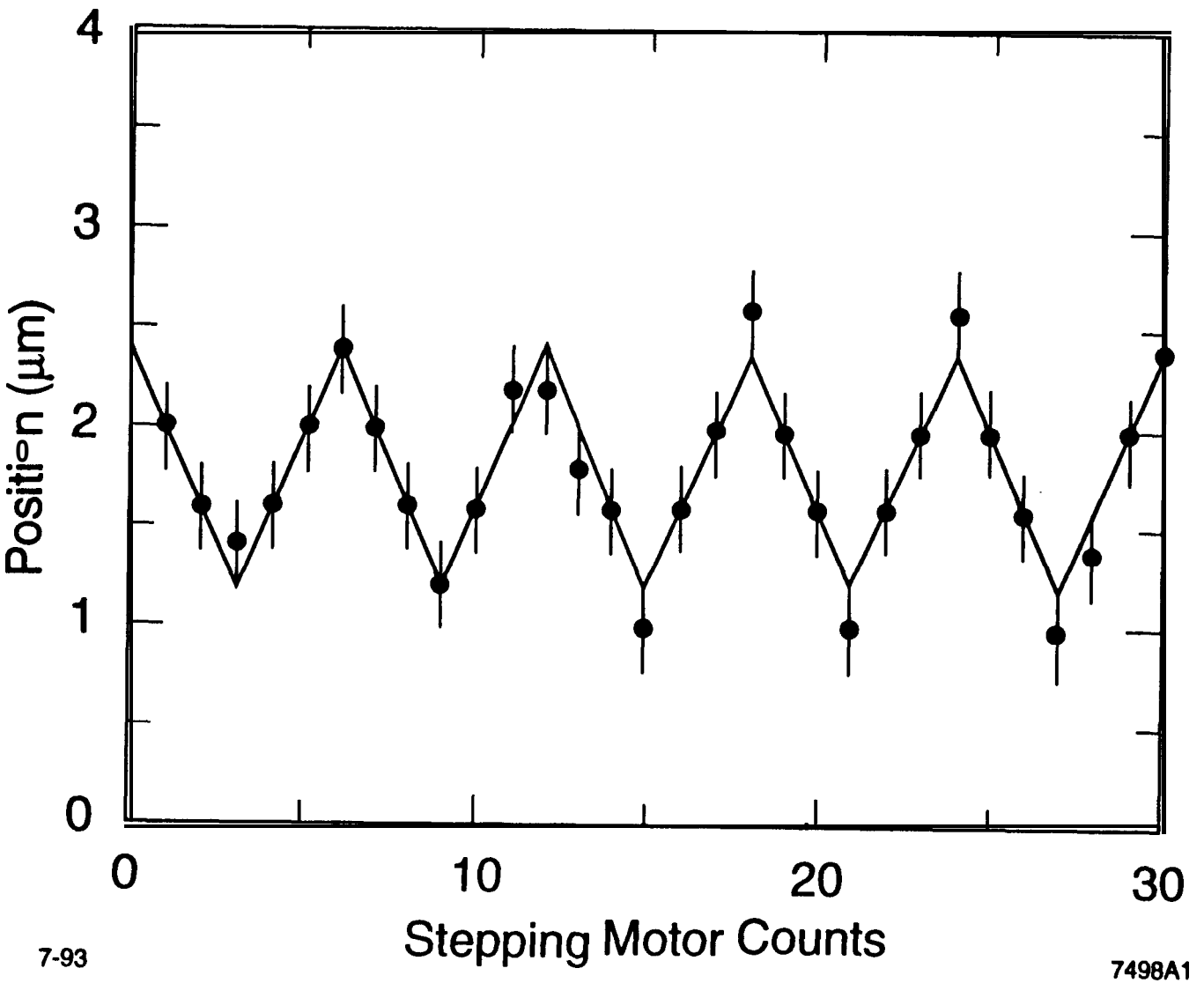


Interferometers to measure motion relative to bedrock and then move quads

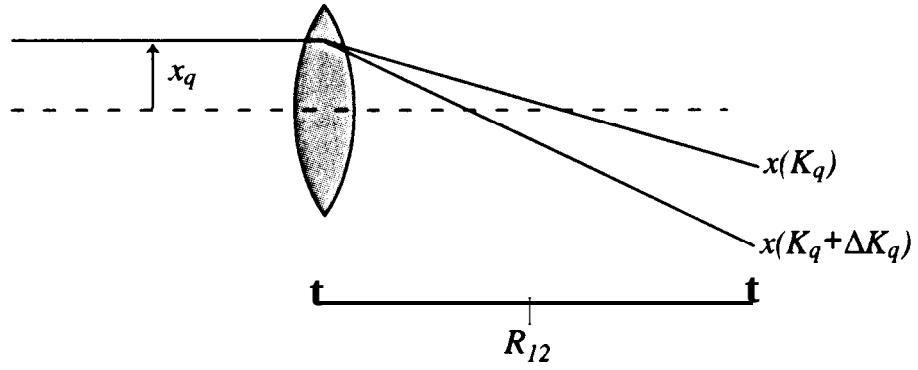


0449-10

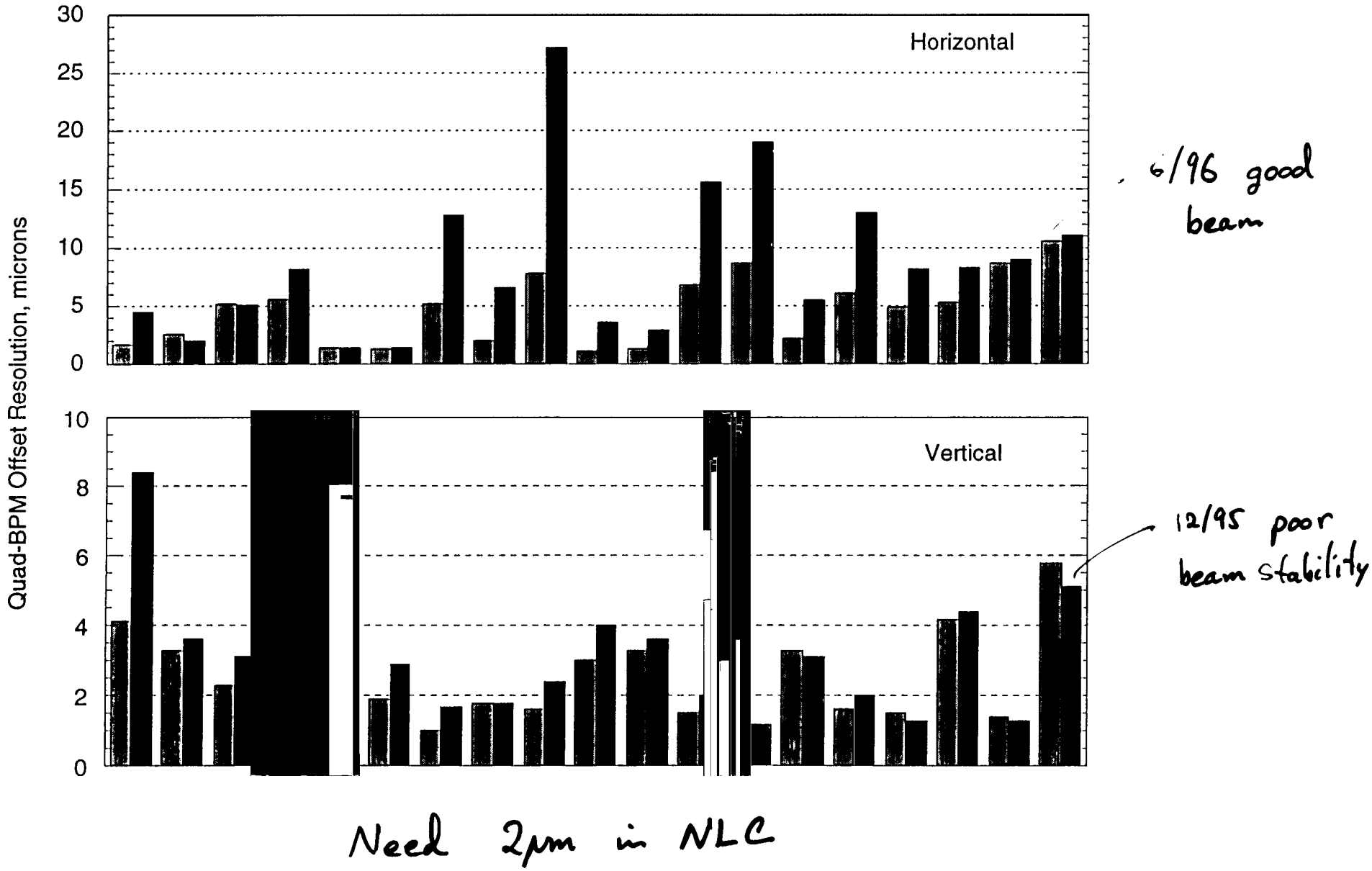

V–Block
Shafts
Stepping
Motors
Bearing
Housing
2–96
8047A357


4
3
2
1
0
Position (µm)
0
10
20
30
Stepping Motor Counts
7-93
7498A1

Beam-Based Alignment in FFTB



- Quad shunting technique used in FFTB
- Two problems:
  - short alignment sections with few up- and downstream BPMs
  - synchrotron radiation from horizontal bending reduces BPM sensitivity
- Expected resolution in NLC is better than 1 μm with 10 downstream and 10 upstream BPMs for fitting
- Questions on the magnetic field stability during shunting


Quad-BPM Offset Resolution, microns
Horizontal
Vertical
30
25
20
15
10
5
0
10
8
6
4
2
0
6/96 good beam
12/95 poor beam stability
Need 2μm in NLC

Summary

- Presently four or five active designs: TESLA, SBLC, JLC(C), NLC / JLC, and CLIC
- CLIC is probably a next-next generation design with higher cms energy (~ 3 TeV)
- SBLC and C-band have more limited energy reach but use more straight-forward rf systems
- TELSA and JLC / NLC are being pursued most actively at present: both are working towards engineered cost estimates and have established most of the essential components although both still have many difficult unsolved problems