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(N)

DAMPING RINGS AND BUNCH COMPRESSION SUMMARY

by
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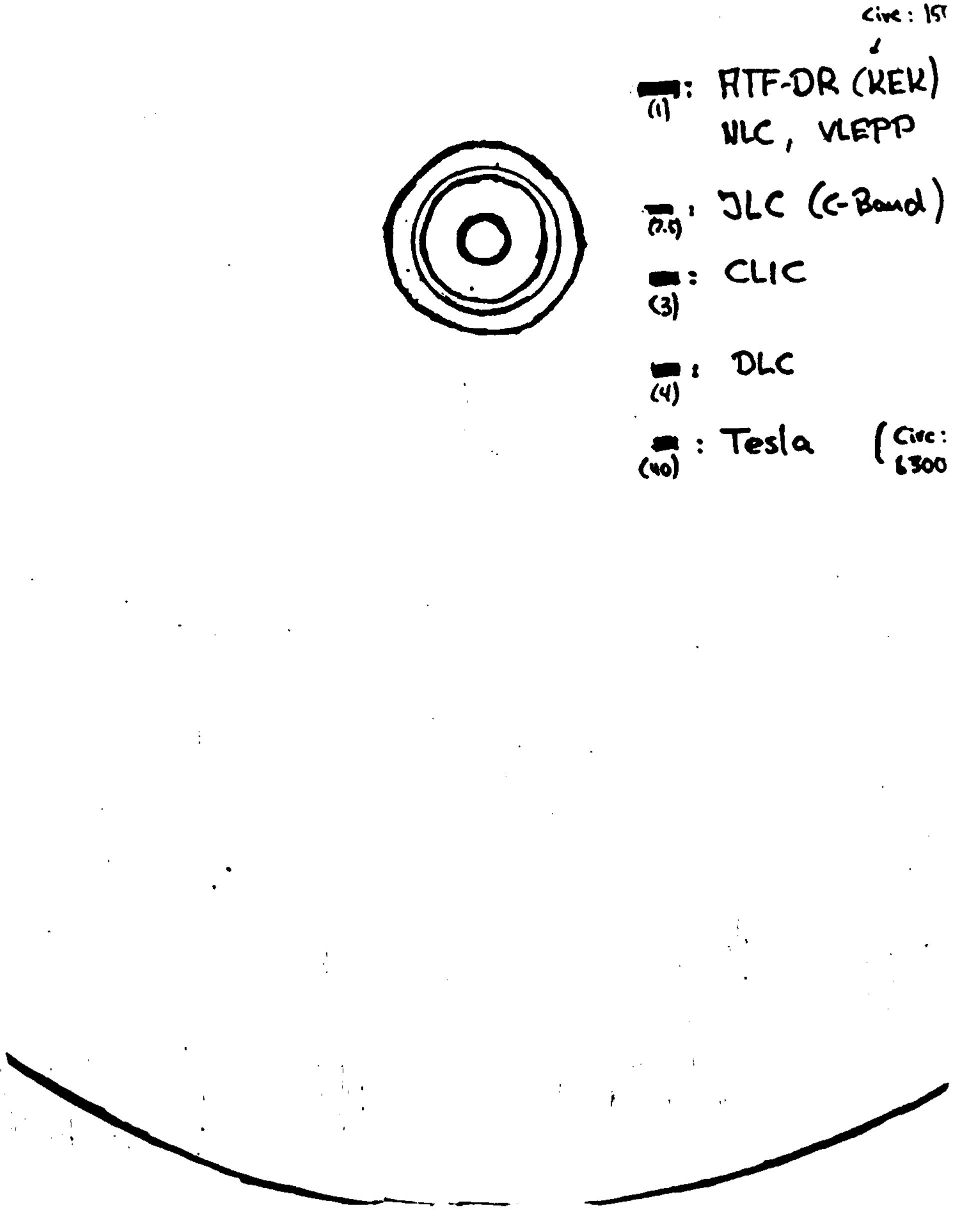
Outline

1) Overview of Linear Collider
   Damping Ring Designs
2) Bunch Compressors
3) Collective Effects

Design Overview



J.-P. [illegible]

CLIC

Specification on vertical emittance was recently tightened by a factor of 10.

That + high rep. rate (1.7 KHz) makes a Pre-Damping-Ring necessary.

Lattice investigation and optimization is under way to improve the dynamic aperture in the presence of errors.*

*R. Brinkmann

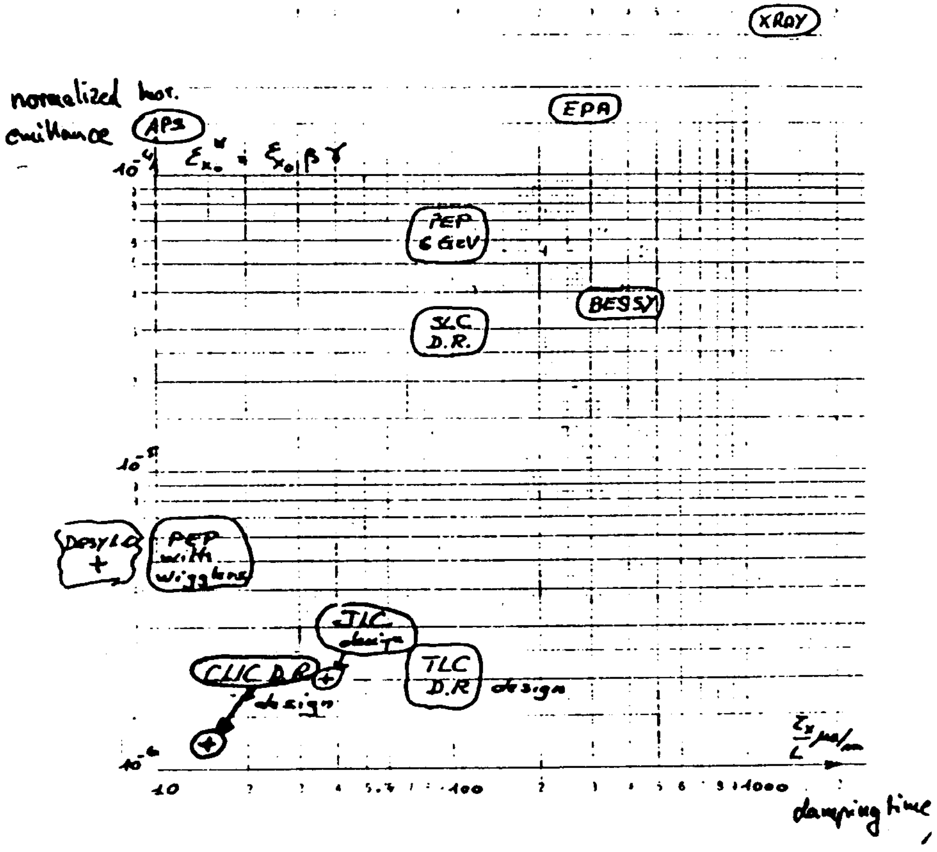


Figure 1
Performences of typical, operational and planned ring terms of normalised equilibrium emittance and dam time.

JLC

(7)

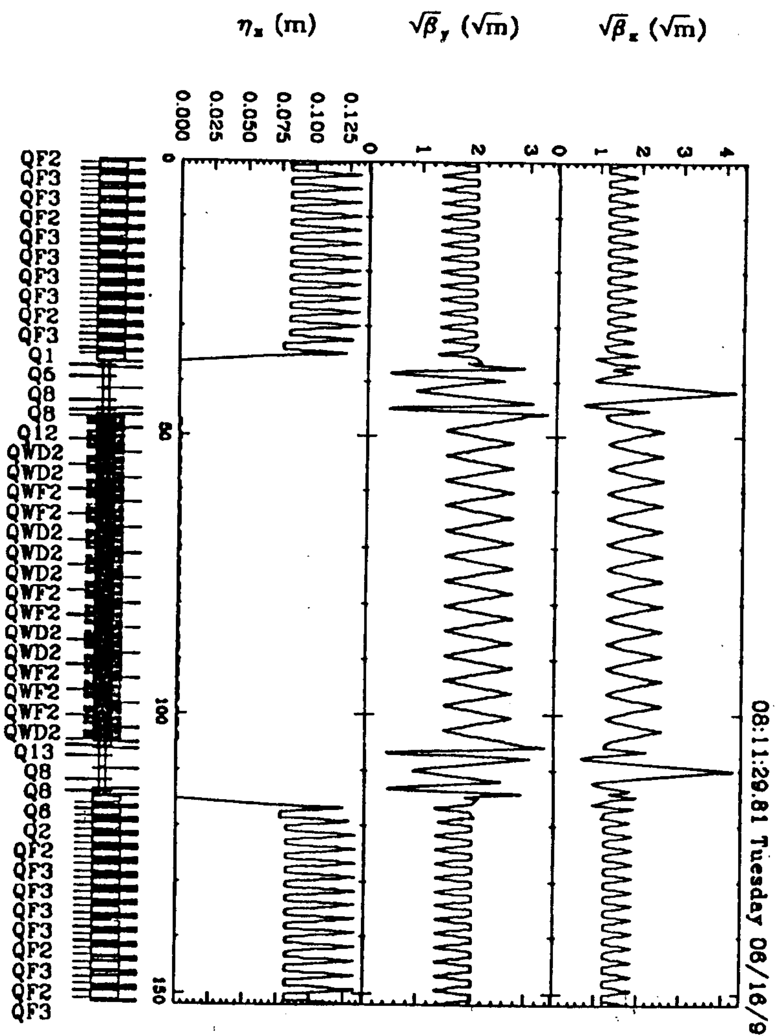
Different RF frequency options for the main Linac leads to a variety of DR designs.

It was nevertheless possible to keep the 3 designs very similar.

Similar to CLIC: problems with dynamic aperture

Pre-damping-ring needed (e^+)

(8)



ENDUP

J. Urakawa

(1)

Items	S-band	C-band	X-band
Synchrotron Radiation per turn	0.873MeV	1.10MeV	0.71MeV
Harmonic Number	723	808	660
Total Current	380mA	453mA	546mA
Circumference	303.6m	339.3m	277.1m
Number of Trains	3	4	5
Number of Bunches per Train	50	80	90
Number of Particles per Bunch	1.6E10	1.0E10	0.7E10
Longitudinal Impedance Threshold	0.221Ω	0.385Ω	0.585Ω
Repetition Rate	100Hz	150Hz	150Hz
Momentum Compaction	0.00126	0.00139	0.00147
Natural Emittance	0.569nradm	0.606nradm	0.640nradm
Horizontal Damping Time	3.74msec	3.33msec	3.99msec
Vertical Damping Time	4.60msec	4.08msec	5.20msec
Bunch Length	4.83mm (4.96mm)	4.84mm (4.91mm)	4.93mm (4.99mm)
RF Voltage (0.714GHz)	2.0MV	2.5MV	2.0MV
Energy Spread	0.091%(0.0934%)	0.092%(0.0933%)	0.0917%(0.0928%)
Touschek Lifetime	50sec	80sec	126sec
Emittance with Intra-beam	6.74E-10	6.69E-10	6.92E-10
Horizontal Phase Advance per Cell	92degree	84degree	90degree
K2 values of SF and SD	25.8,-33.5	24.1,-30.6	25.6,-32.6
Necessary Total Power	8MVA	10MVA	7MVA

J. Urakawa

Tesla

(10) 1

Crude estimate for s.c. lin. Coll. damping ring:

$N_e = 5\times10^{10}$, $n_b = 800$, $T_{Pulse} \cong 1ms$

$f_{rep.} = 10 s^{-1}$, $\gamma\epsilon_x = 2\times10^{-5} m$, $\sigma_z = 2mm$

→ take HERA-e ring

$L = 6.3 km \rightarrow \boxed{\Delta t_b \cong 25 ms}$

- problem #1: need fast kicker operating at ≈ 1 MHz rep. rate to extract single bunches every 1μs

Operate @ E = 14 GeV, install ≅ 40 m Wiggler with $\hat{B} \cong 1.6 T$, 90°/FODO cell in arcs

$\longrightarrow \gamma\epsilon_x \cong 2\times10^{-5}, \gamma\epsilon_y \cong 1\times10^{-6}, \tau_{x,y} \cong 20 ms$ ~ok

needs $U_{rf} \cong 50 MV$ (1/3 of installed rf)

- problem #2: need 40 MHz-bandwidth multibunch feedback system

present instability threshold: ≈ 3 mA

want to store 330 mA!

(have 10 MHz feedback system for $I \rightarrow 60 mA$)

Damping Rings Parameters Design Values Present Status

	Symbol	Unit	ATF-DR /KEK	CLIC / CERN	DLC / DESY-Da	JLC / KEK	NLC / SLAC	TESLA	VLEPP
Beam Parameters									
Energy	E	Gev	1.54	3.00	3.15	1.98	1.8	14	3.0
Normalized Horizontal emittance including IBS	ε_0	10**-6 rad*m	4.8	1.56	4.1	3.0	2.7	20	45.5
Particles per bunch	N	10**10	3	1	2	1	2	5	20
Number of bunches /trains	K_b / K_t	-	20 / 5	60 / 4	172	80 / 4	10 / 10	800	1
Bunches / Trains spacing in the Damping Ring		ns	1.4/60	0.3/25	13			25	
Emittances ratio	$\varepsilon_y/\varepsilon_x$	%	1.0	3.3	1.0to 10.0	1.0	1.0	5.0	0.01
Bunch Length	σ_L	mm	5.0	1.46	3.7	5.0	5.0	7.0	9.8
Momentum Spread	σ_E/E	10**-4	8.0	15.0	11.5	9.0	10.0		16.0
Longitudinal Impedance Threshold	(Z/n)	Ω	0.1	0.08	0.04	0.4	0.2		0.2
Ring Parameters									
Circumference	C	m	138.6	451	650	339	155	6336	160
Basic Lattice			FOBDO	FOBDO	Ch. Gr	FOBO	FOBDO	FODO	FOBDO
Wigglers		Y/N	Y	N	Y	Y	Y	Y	N
Number of cells			36	200	240		66		50
Dipole Field	B_0	T	0.9	1.4					
Quad. Field in Bend or Max quad field	B_g'	T/m	56	150	60	-31	-30		-18.5
Wiggler Peak Field	B_w	T	1.88	--	2.0	1.88	2.40		--
Length of wiggler	L_w	m	24	--	84	100	22	40	--
Wiggler Period	λ_w	cm	40	--	20	40	20		--

(11)
3

Assume:

$A_{dyn.} \cong 4$ mrad x mm

can be reached for $\phi_c \approx 90°$ (per arc FODO cell)

⇒ normalized acceptance for injected e^+-beam

$\gamma A_{inj} \cong 0.1$ m

(SLC-DR has ≈ 0.012 m)

Very good for accumulating high e^+-Intensities!

Bunch Length:

$\sigma_z \cong \overset{7}{\cancel{10}}$ mm ($\sigma_p \approx 1‰$)

⇒ need compression by factor 3.5 (or 7)

difficult at 14 GeV (!)

(although somewhat relaxed due to larger $\gamma\varepsilon_x$)

	Symbol	Unit	ATF-DR / KEK	CLIC / CERN	DLC / DESY-Da	JLC / KEK	NLC / SLAC	TESLA	VLEPP
RF Parameters									
Energy Loss per Turn	U_0	keV	119	1000	3600	1100	468	30000	1000
RF Voltage	V_{RF}	kV	1000	6000	5000	2500	900	50000	1500
RF Frequency	f_{RF}	Mhz	714	3000	500	714	1428	500	700
Tranverse Tunes	ν_x / ν_y	-	15.8 / 9.4	50.21 / 50.16	43.18 / 27.29		24.4 / 11.3		15.74 / 15.68
Natural Chromaticities	ξ_x / ξ_y	-		-53 / -54	-54 / -48		-28 / -22		-54 / -54
Momentum compaction	α_p	10**-4	22	2.4	1.7	14	12		17
Damping Times	τ_x / τ_y	msec	5.7/7.5	4.1/9.0	3.83	3.3/4.1	2.5/4.0	20/20	1.8/2.9
Bunch Circulating time	T_0	msec	200	36	20	26.5	28	800	10
Incoming Beam Parameters									
Predamping required			N	Y	N	Y	N	N	N
Normalized Transverse Acceptance	$A(1\sigma)$	10**-3 rad*m	6.0	0.02	3	30(PDR 0.3(DR	15		3
Acceptance of Momentum Spread	$\delta P / P$	%	±1	±0.5	±1	±1	±1.7		±1

Remarks

Different problems for different designs:

- dynamic aperture problems with the extreme lattices used

  possible solution: pre-damping ring [CLIC needs it
  (amnesia device!)

  Details need to be worked out, might have its own problems

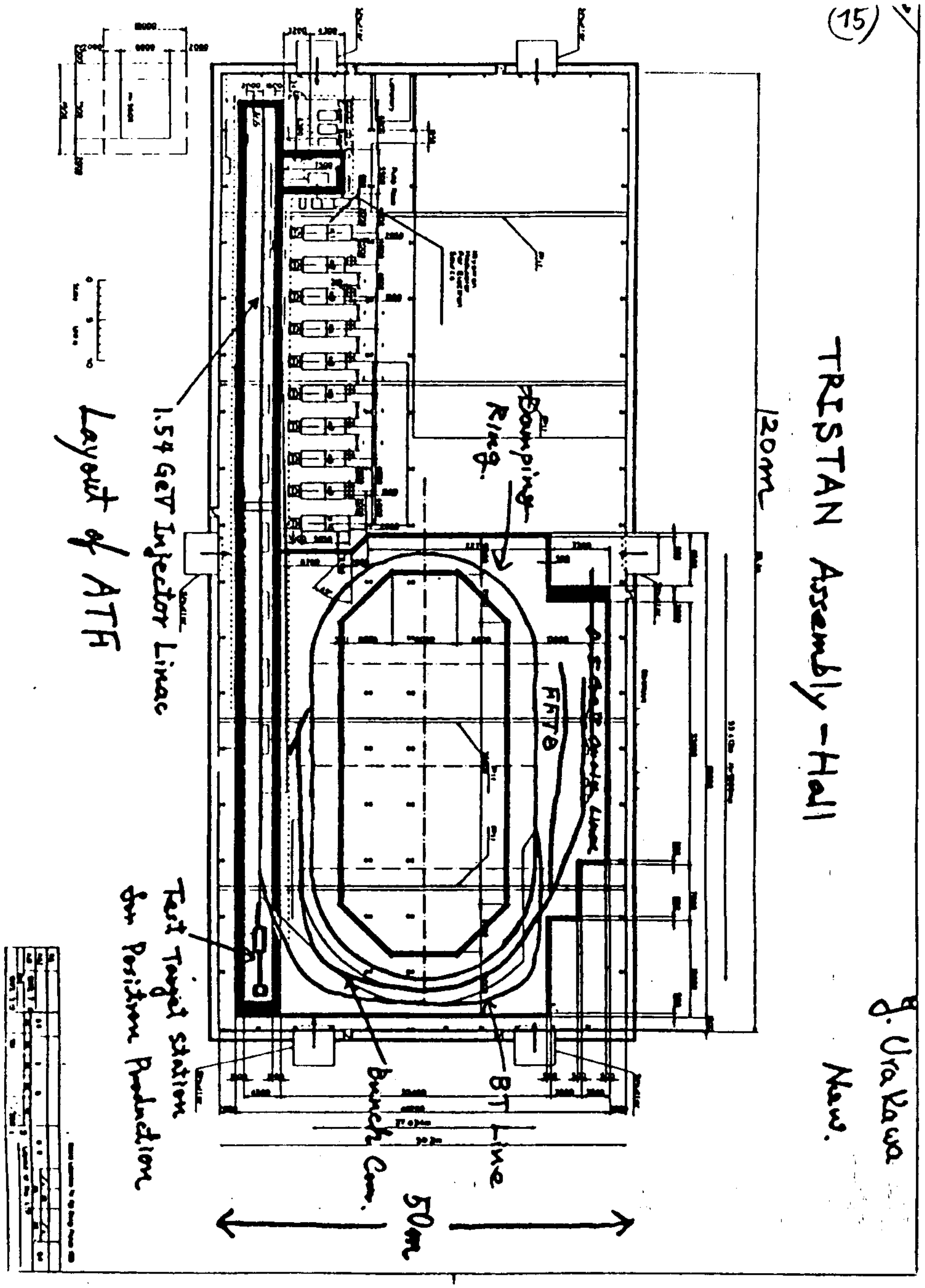
- tolerances get very tight if very small vertical emittance is required.

  Third generation synchrotron light source come close and ESRF seems to work.

- wigglers, Kickers ... No principal problem, but lots of parameters pushed -> R&D

General: A DR should have high safety margins for every parameter since you need <u>reliable</u> and stable operation to commission the LC.

If designs without DR's are considered: be sure to make very thorough jitter analysis



Layout of ATF

1992.10 Test Magnet System for Damping Ring will be ordered.

1992.11 Test Support Table with movers for Damping Ring will be made.

1993.6 1.0GeV S-band Injector Linac will be almost completed.

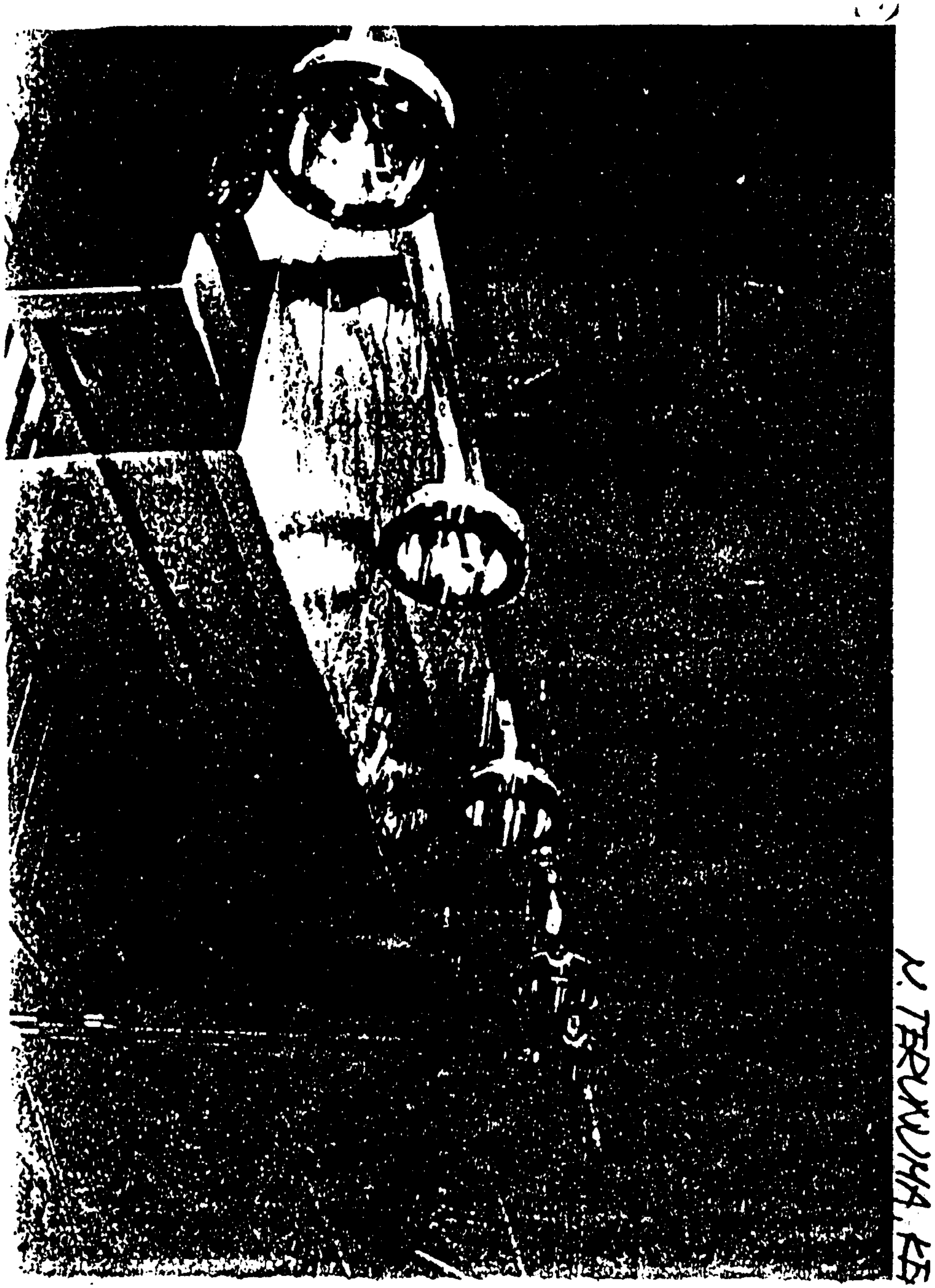
1993.6 Construction of Damping Ring including the reconstruction of the floor will be started.

1993.6 Orders for Damping Ring will be started.

1993.6 Expansion of S-band Injector from 1.0GeV to 1.54GeV will be started.

1994.12 ATF Damping Ring will be completed.

1995.1(?) Beam Operation of ATF Damping Ring will be started.



N. TERUNUMA, KEK

4.Operation Plan

Main Study Plan

A. To investigate the achievable emittance.
We must establish the correction techniques of some errors.

B. To investigate the effect of Intra-beam scattering by changing the intensity of bunch.
$1.0\times10^{10} \sim 5.0\times10^{10}$ electrons/bunch

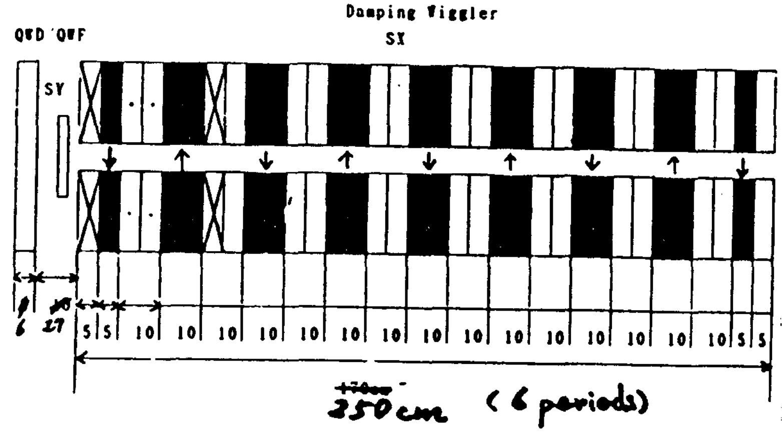
C. To investigate the performance of damping wiggler.

D. To investigate the acceptance of the damping ring by changing the horizontal phase advance.

E. To investigate the jitter of extracted beam.

F. To establish the method to overcome the multi-bunch instability.

+ experiences with single bunch instability thresholds [illegible] wiggler magnet [illegible] measure the field and to investigate the alignment method. (19)

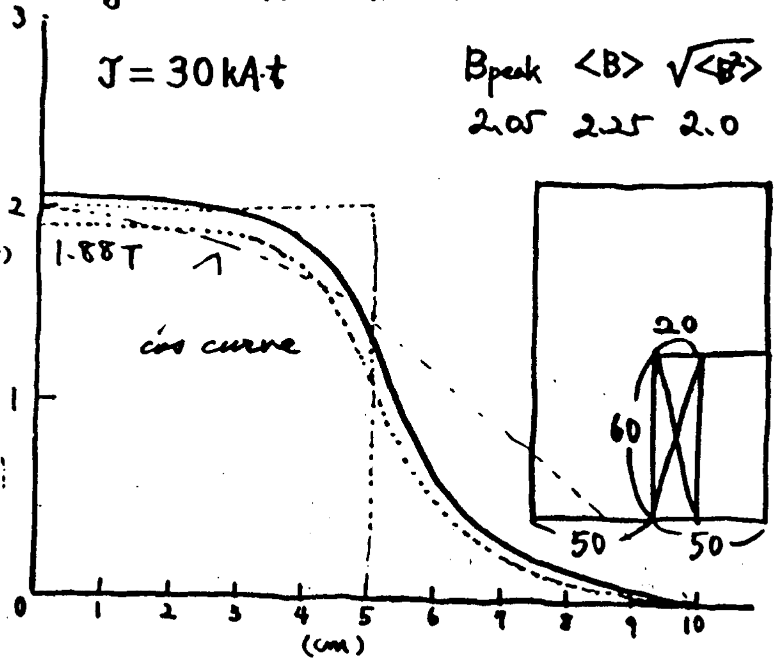


Effective Field $\sqrt{\langle B^2\rangle} = \sqrt{\int B^2 dl / l_{pole}}$ where $l_{pole} = 10$ cm

$\sqrt{\langle B^2\rangle} = 2.0$ T at gap = 2 cm

$\sqrt{\langle B^2\rangle} = 1.88$ T

Magnetic Field Distribution



Bunch Compression (Optics)

Experience with SLC RTL is intimidating. All sorts of high order dispersion — use octupoles to fix 3rd order η.

Furthermore with flat beams the sextupole tolerances are tight.

Sextupoles are needed for chromatic correction of the dispersion NOT the β-chromaticity.

$$\eta_0'' + k_1 \eta_0 = G$$
$$\eta_1'' + k_1 \eta_1 = G + k_1 \eta_0 + k_2 \eta_0^2/2$$

⇒ Remove quads and sextupoles from regions with $\eta_0 \neq 0$.

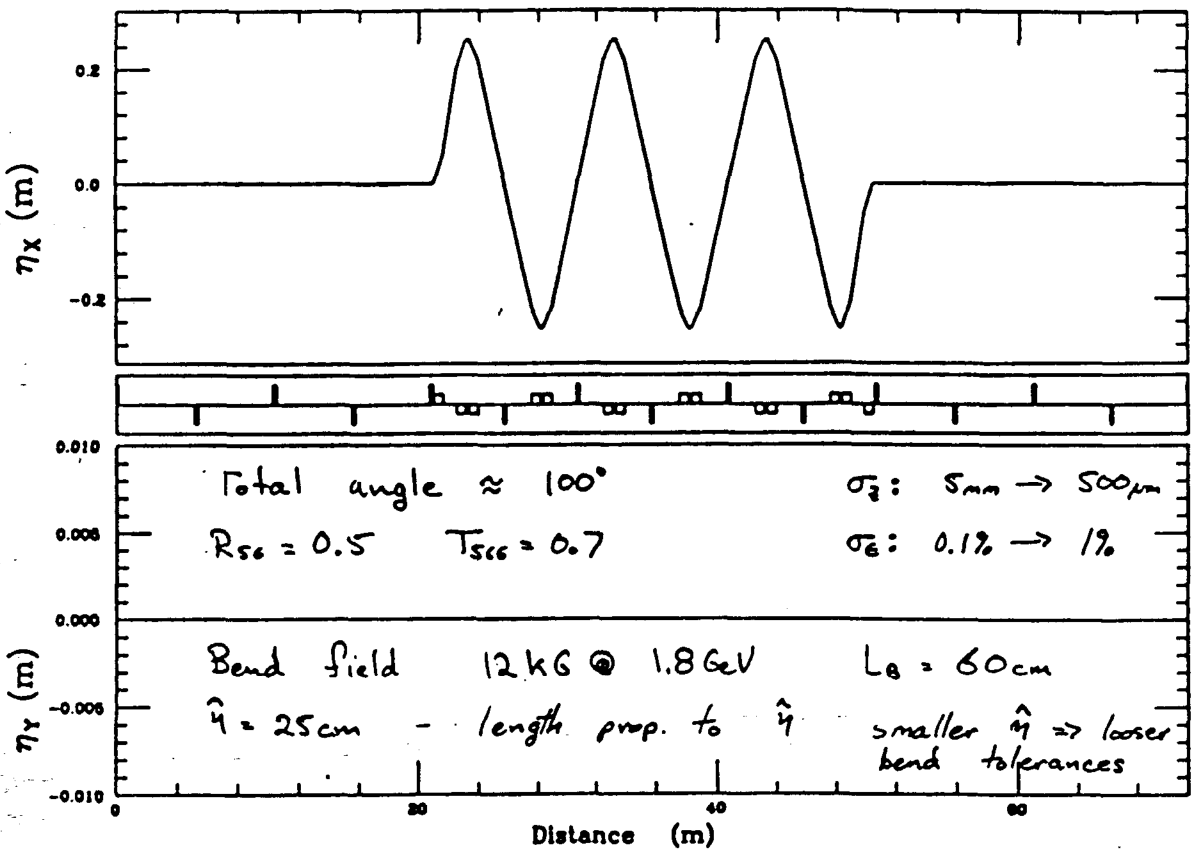
$$\sigma_{z\,\text{final}} = R_{56}\, \sigma_{\varepsilon\,\text{initial}}$$
$$\sigma_{\varepsilon\,\text{initial}} = R_{56}\, \sigma_{z\,\text{final}}$$
$$R_{56} = \in \cdot \eta$$

(full compression)

Low energy 1.8 GeV

NLCCOMP3

$R_{56} = 0.5$



Total angle ≈ 100°

$R_{56} = 0.5$ $T_{566} = 0.7$

σ_z: 5mm → 500μm

σ_ϵ: 0.1% → 1%

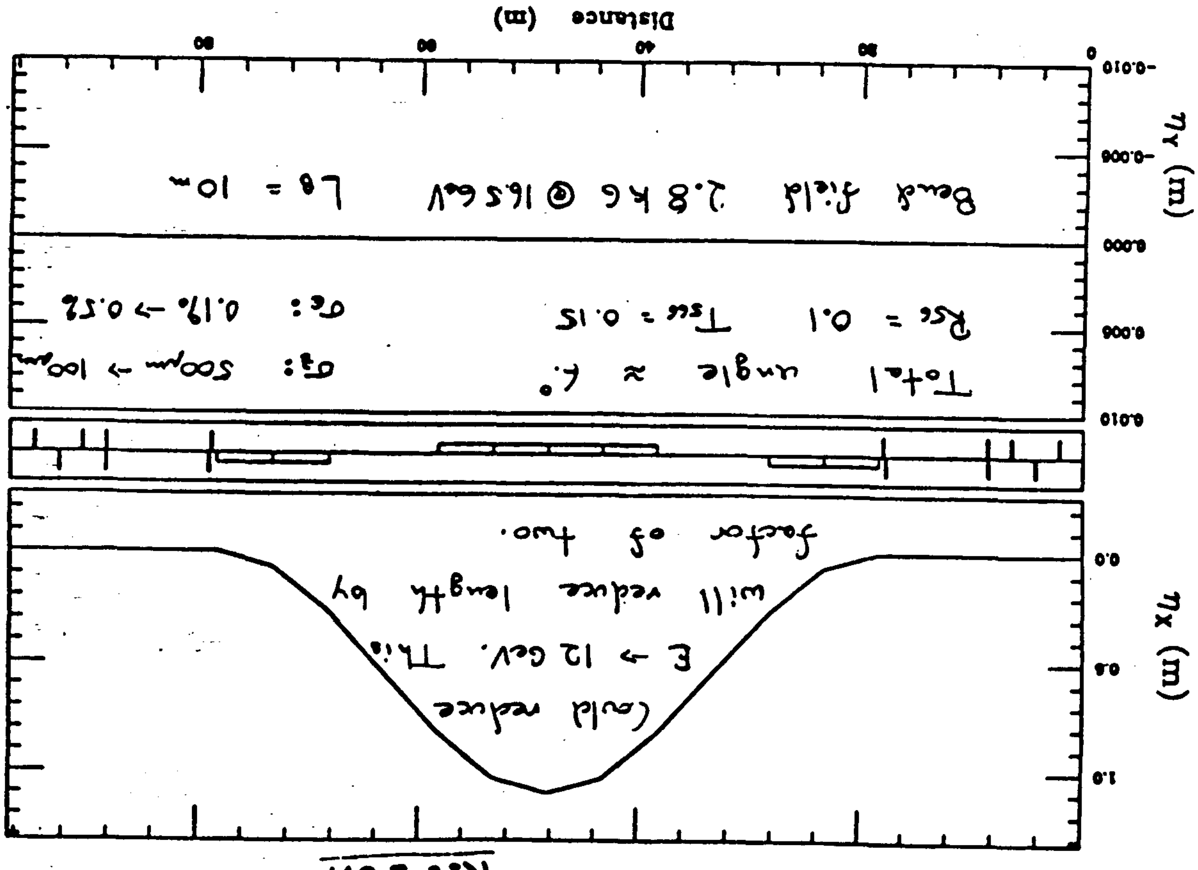
Bend field 12kG @ 1.8 GeV $L_B = 60$cm

$\hat{\eta} = 25$cm - length prop. to $\hat{\eta}$

smaller $\hat{\eta}$ ⇒ looser bend tolerances

NLCCOMP1

$R_{56} = 0.1$



Could reduce E → 12 GeV. This will reduce length by factor of two.

Total angle ≈ 6°

$R_{56} = 0.1$ $T_{566} = 0.15$

σ_z: 500μm → 100μm

σ_ϵ: 0.1% → 0.5%

Bend field 2.8 kG @ 16.5 GeV $L_B = 10$m

Bunch Compressor

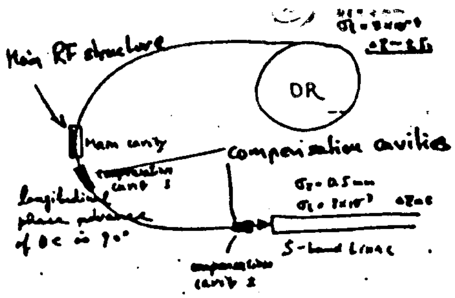
Presented by
J. Urakawa

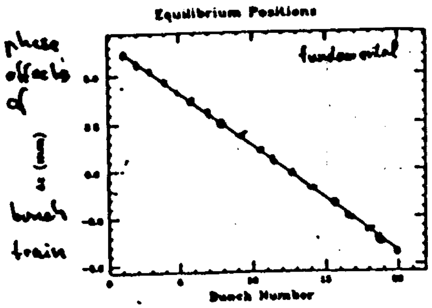
(M. Kikuchi / KEK)

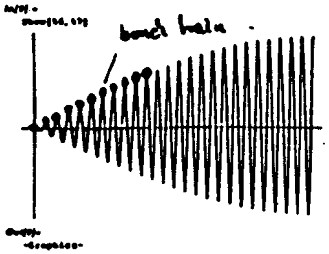
1 Introduction
  - definition of problem -
- Position shifts in DR
- Beam loading in Compressor cavity
- Energy spread at the entrance of linac

2 Compensation scheme

3 Conclusion







'Beat' method (2 free parameters)

for example

$V_c = 19.25$ MV

2×10^{10}

$\varepsilon^*_o = 2.03 \times 10^{-7}$

$\varepsilon_\ell = 1.01 \times 10^{-6}$ ←

$\sigma_z = 1.14$ mm

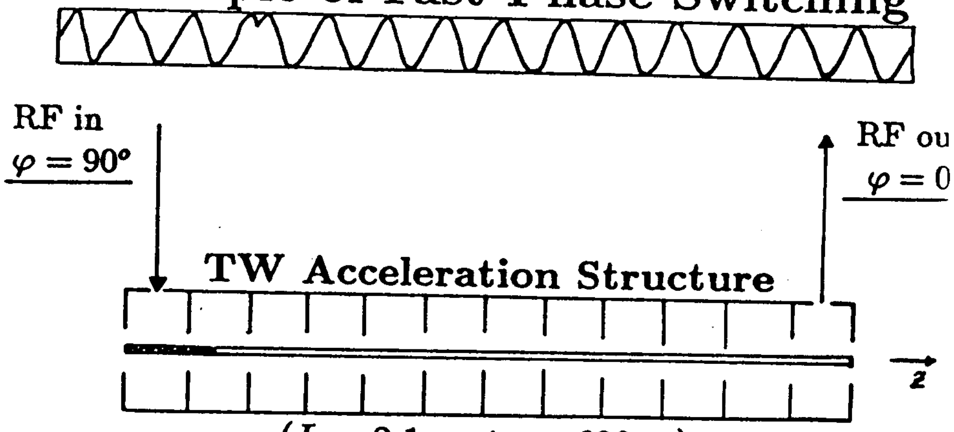
$|\Delta p/p| = 8.94 \times 10^{-4}$

Summary

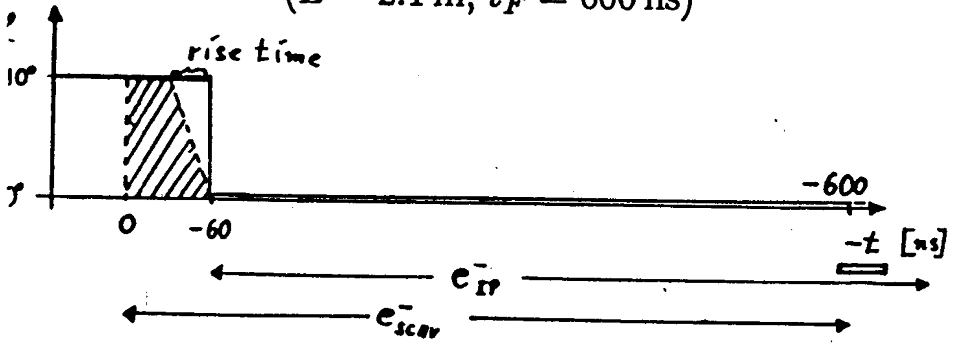
- Position shifts in DR can be compensated using 90° phase advance of bunch compressor
- Compensation for beam loading of compressor cavity is necessary
- "Beat" method can compensate for beam loading and energy shifts at the end of compressor which arises from position shifts in DR
- L-band system is preferable. bunch length deviates 10 X for S-band while for L-band ~ 3X

t-j. vec

Principle of Fast Phase Switching



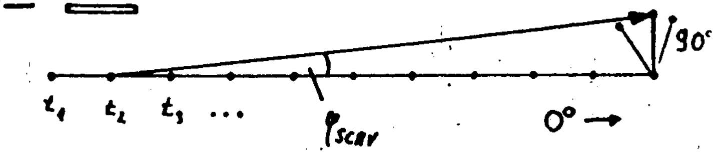
$(L = 2.1\,\text{m},\ t_F = 600\,\text{ns})$



$\rho_{IP} = 0^\circ$

$\rho_{scav} = \arctan 1/9 = 6.3^\circ$

$(A_{scav} < A_{IP})$



High current requirements

Some of the DR designs resemble
B-factory rings!

- Total current : good portion of an Ampere
- Many bunches : coupled bunch instabilities

Need to damp high Q resonances
in RF cavities, vacuum system
  - single cell, large beam tube cavities
    to minimize # of dangerous modes
  - passive damping (waveguides)
  - active feedback systems

Small interbunch spacing ⇒ wide bandwidth

- ATF DR at KEK is developing and will test the necessary hardware! Kubo
- BEP ring in Novosibirsk Shatunov

High power SR losses!
especially dangerous with high $\frac{\varepsilon_x}{\varepsilon_y}$ aspect ratios
W/mm^2 on vac. chamber

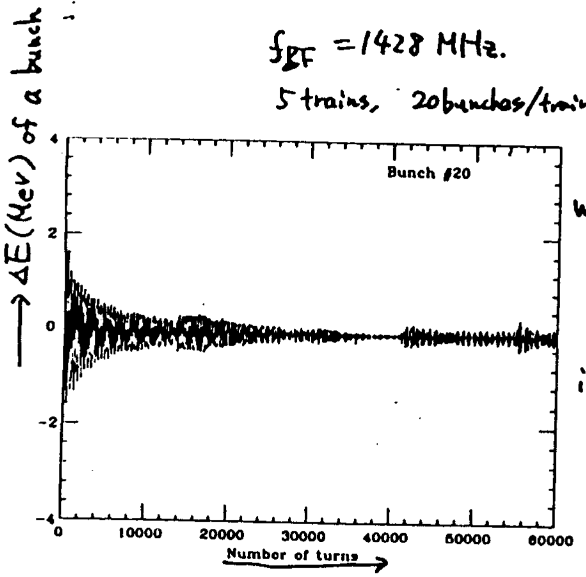
Total current requirements, power losses

	Symbol	Unit	ATF-DR / KEK	CLIC / CERN	DLC / DESY-Da	JLC / KEK	NLC / SLAC	TESLA	VLEPP
Beam Parameters									
Energy	E	Gev	1.54	3.00	3.15	1.98	1.8	14	3.0
Circumference	C	m	138.6	451	650	339	155	6336	160
Particles per bunch	N	10**10	3	1	2	1	2	5	20
Number of bunches /trains	K_b / K_t	-	20 / 5	60 / 4	172	80 / 4	10 / 10	800	1
Total current	I	A	1	0.26	0.25	0.45	0.62	0.3	0.06
Power (SR losses)	P_{sr}	MW	.12	.26	.9	.5	.3	9	.06
Bunches / Trains spacing in the Damping Ring		ns	1.4/60	0.3/25	13			25	

Tracking simulation for feedback. ($V \propto \frac{\Delta E}{E}$) method (A)

$f_{RF} = 1428$ MHz.

5 trains, 20 bunches/train, 2×10^{10} e/bunch



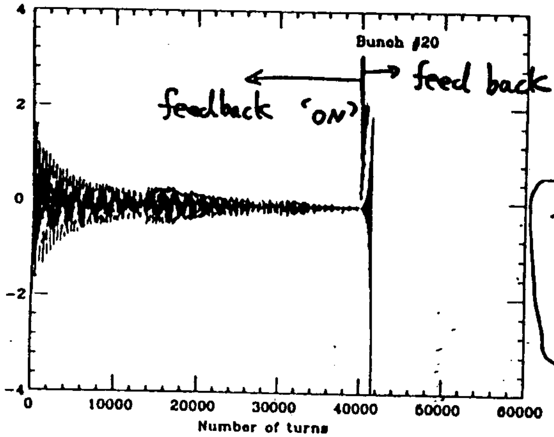
with feedback

$Q_{FB} = 1\times10^{4}$

including error of $\frac{\Delta E}{E}$

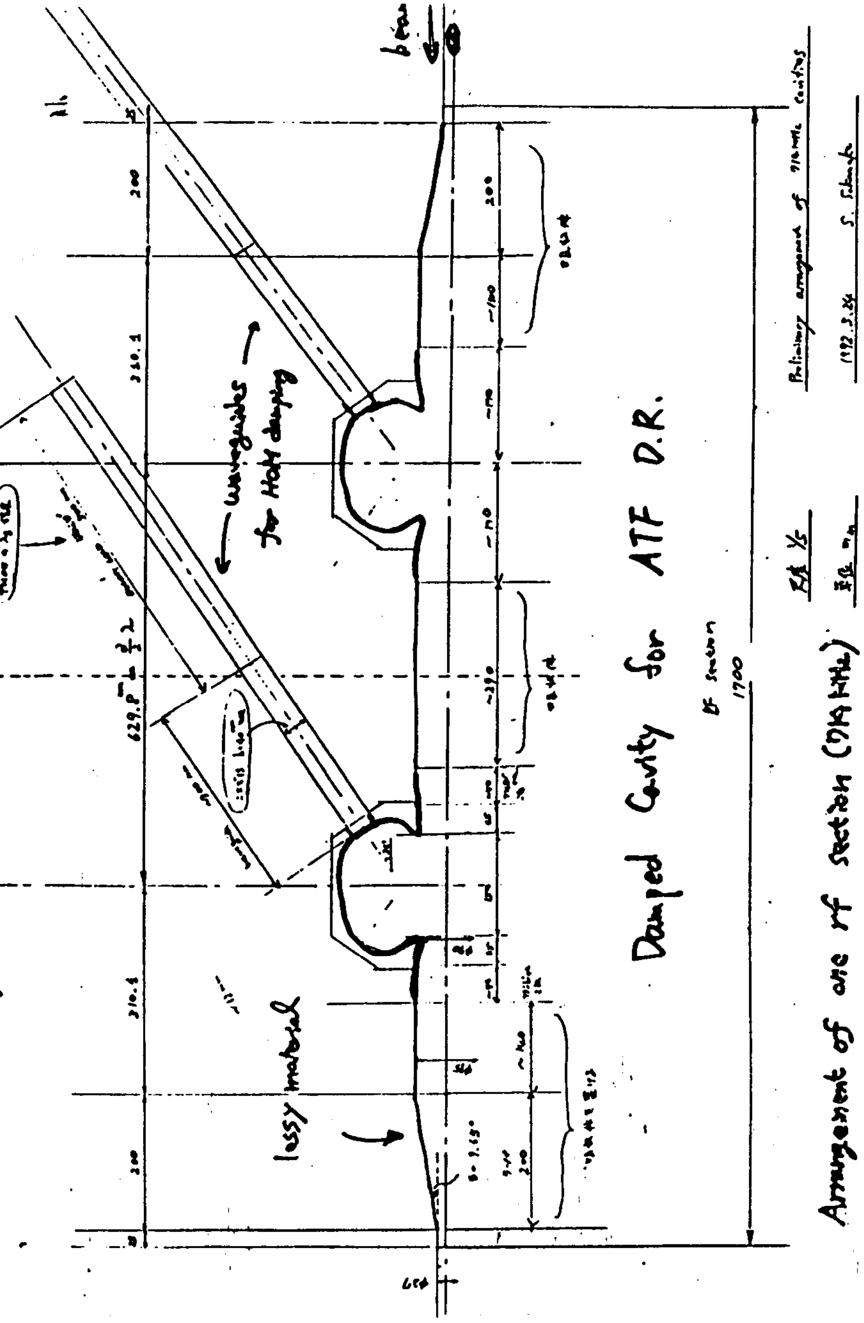
offset (fixed) 2×10^{-3}

bunch by bunch 2×10^{-3} (σ)



Bandwidth 143 KHz

S.Sakanaka (KEK)



Damped Cavity for ATF D.R.

Arrangement of one rf section (714 MHz)

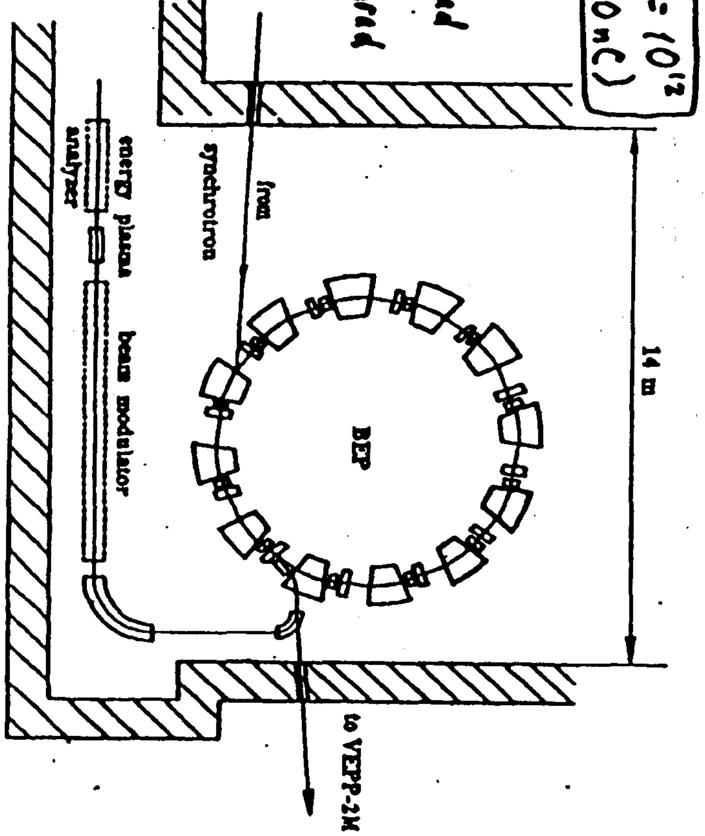
$E = 120 - 850$ MeV

$\boxed{I_{\parallel} = 2A \quad (N = 10^{12} \; 160\,nC)}$

$\sigma_z = 10$ cm

$\varepsilon_z = 10^{-4}$ mm·mrad

$\varepsilon_x = 6 \cdot 10^{-2}$ mm·mrad



Y. Shatunov

Single bunch: Long. impedance requirement

Design bunch current < turbulence threshold

Longitudinal impedance of the ring should be less th

$$\left|\frac{Z}{n}\right|_{th} = 2\pi F \frac{E \cdot \alpha}{I_p} \delta^2 \qquad (\text{take } F = 1)$$

E - energy of the ring
α - momentum compaction
δ - relative energy spread
I_p - peak current

Recent SLC DR experience is a good warning why we want to stay below threshold

"sawtooth" instability T. Limberg

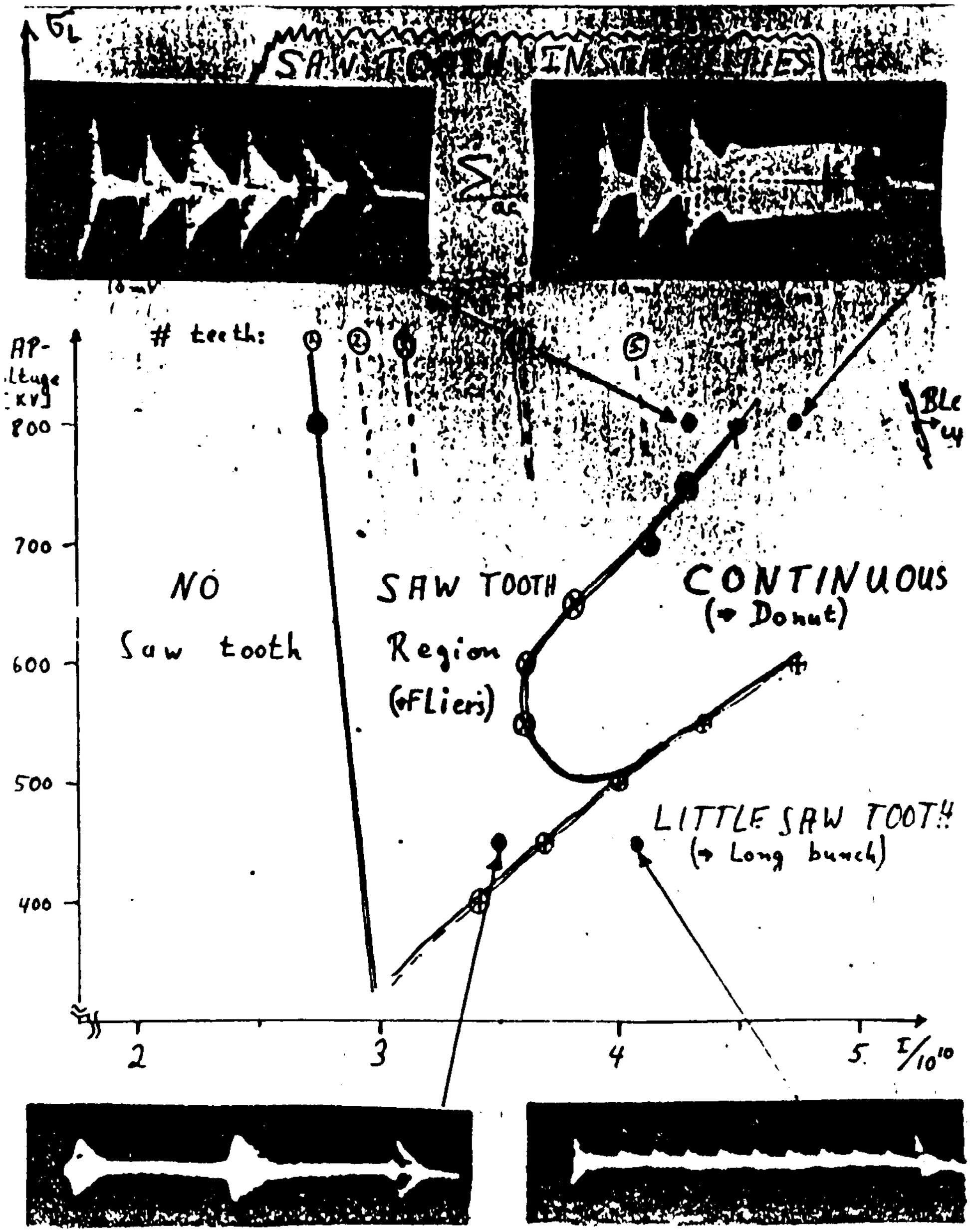
changing bunch length in the compressor makes operating conditions very difficult!

simulations of the effect K. Bane

At present this is a limiting factor for the beam intensity at the SLC

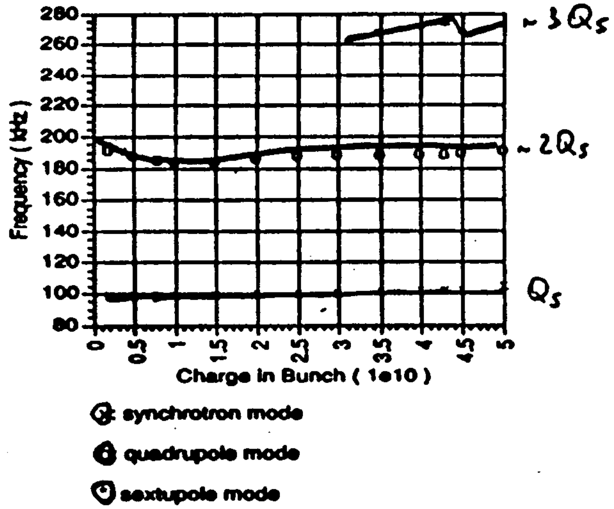
Very interesting accelerator physics...

T. Limberg

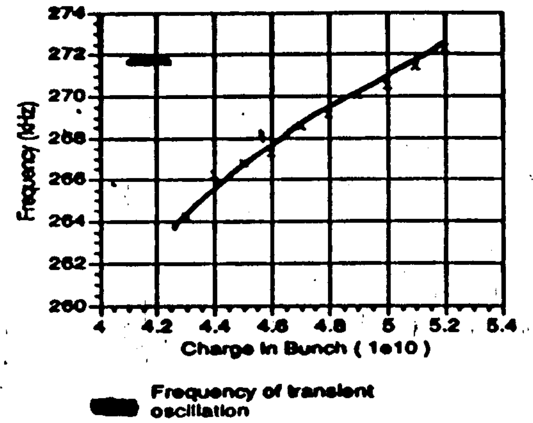


Mode Frequencies vs. Beam Current

(800 KV Gap Voltage)



'Sextupole' Frequency vs. Beam Current



Longitudinal impedance requirements

	Symbol	Unit	ATF-DR / KEK	CLIC / CERN	DLC / DESY-Da	JLC / KEK	NLC / SLAC	TESLA	VLEPP
Beam Parameters									
Energy	E	Gev	1.54	3.00	3.15	1.98	1.8	14	3.0
Particles per bunch	N	10**10	3	1	2	1	2	5	20
Bunch Length	σ_L	m m	5.0	1.46	3.7	5.0	5.0	7.0	9.8
Peak current	I_p	A	115	130	103	38	77	137	391
Momentum Spread	σ_ε/E	10**-4	8.0	15.0	11.5	9.0	10.0		16.0
Momentum compaction	α_p	10**-4	22	2.4	1.7	14	12		17
Longitudinal Impedance Threshold	$(Z/n)_{th}$	Ω	0.1	0.08	0.04	0.4	0.2		0.2
"Radiation impedance"	$(Z/n)_r$	Ω	0.3	0.03	0.03	0.08	0.2		
Vacuum chamber cut-off frequency	f_r	GHz	3.6	6.4	4.8	3.6	5		
Impedance reduction factor			0.3	0.08	0.3	0.3	0.6		
Low frequency limit of the threshold impedance	$(Z/n)_0$	Ω	0.3	1	0.13	1.3	0.3		

irement on long. impedance : e.g. CLIC

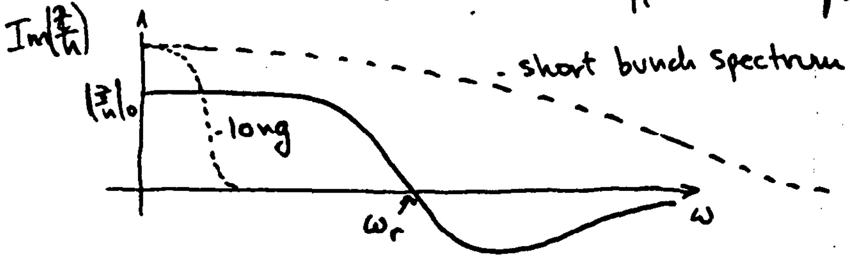
$I_p\,(\mathrm{D}1\cdot 10^{10}) = 130\,A \qquad (\sigma_s = 1.5\,\mathrm{mm})$

$\alpha = 2.4\cdot 10^{-4}$

$\delta = 1.5\cdot 10^{-3} \qquad \left|\frac{Z}{n}\right|_{th} \simeq 0.08\,\Omega\,!$

$E = 3\,\mathrm{GeV}$

But a short bunch sees lower effective impedance



Overlap of bunch spectrum with impedance

For broad band resonator impedance (B. Zotter)

$$\left|\frac{Z}{n}\right|_{eff} = 2\,(\omega_r \sigma_z)^2 \left|\frac{Z}{n}\right|_0$$

ω_r - frequency of the resonator

σ_z - bunch length in units of time

$\left|\frac{Z}{n}\right|_0$ - low frequency limit of impedance

e.g. CLIC : $2(\omega_r \sigma_z)^2 \simeq 0.08$

$$\left|\frac{Z}{n}\right|_{0\,th} \simeq 1\,\Omega$$

(we assumed $\omega_r \approx$ pipe cut-off frequency)

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Short bunches are good for you!

e.g. in LEP the effective impedance

$$\left|\frac{Z}{n}\right|_{eff} \simeq 0.025$$

about ×10 lower then $\left|\frac{Z}{n}\right|_0$.

Possible lower limit on impedance

"Radiation impedance" or "curvature imp."

$$\left|\frac{Z}{n}\right|_r \simeq 300 \frac{h}{R}$$

h - half-height of v.c.

R - gross radius

e.g. CLIC $\left|\frac{Z}{n}\right|_r \approx 0.03$

Need theory, experimental data on this possible lower limit on effective impedance!

- test DR facilities: BEP, ATF DR...
- third generation SR sources (ALS, ElEttra)

very careful design of the vacuum system -

We used these simple estimates to compare impedance requirements for different designs

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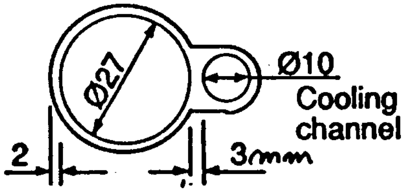
Design of Vacuum Chambers

Vacuum · chambers are made of extruded aluminum alloy.

1991 : Design of the wiggler chamber, flanges and bellows.
(I = 200 mA)

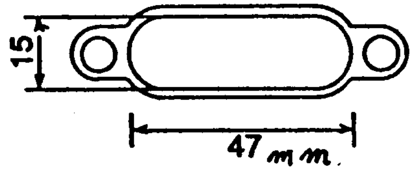
Basic structure

Vacuum chamber for arc section. + Straight Section



Vacuum chamber for wiggler section.

Race-track cross section



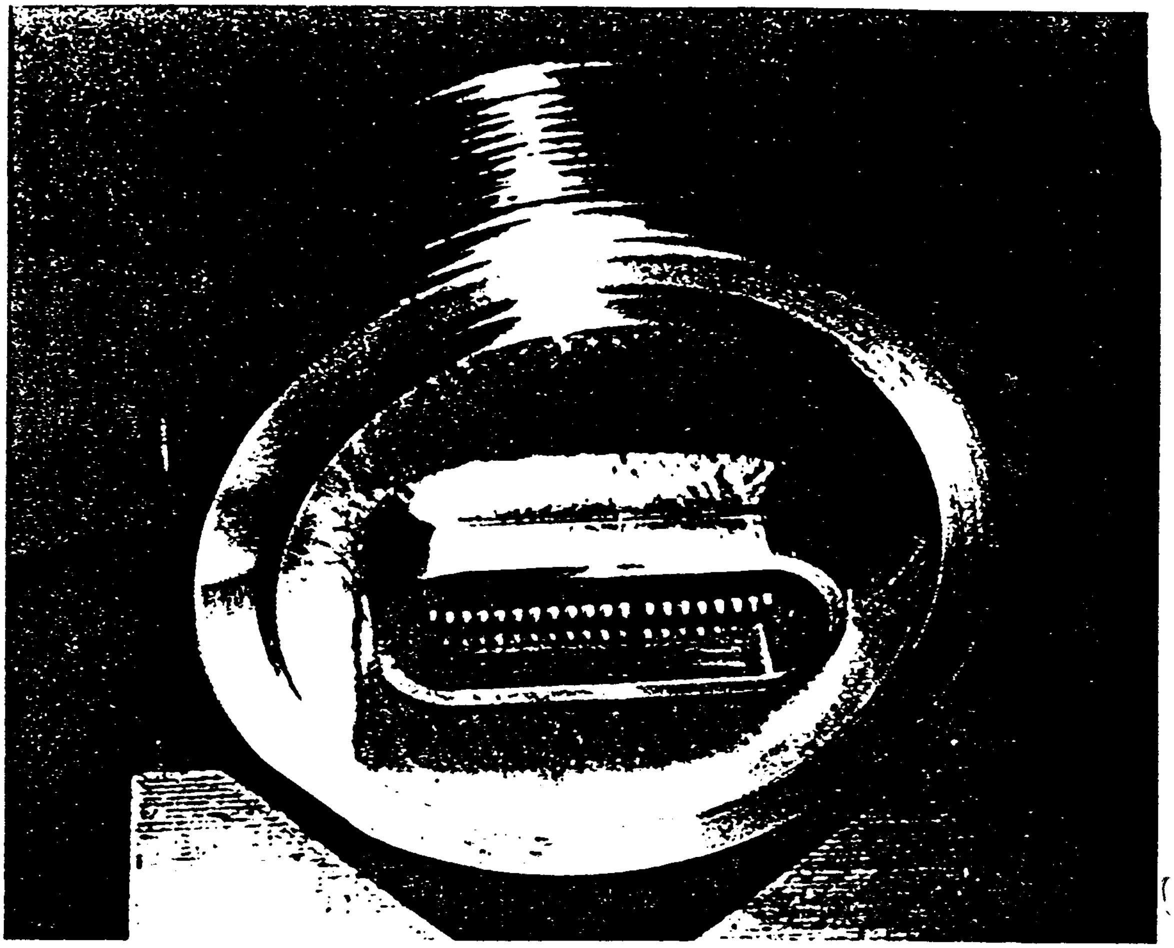


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Table 1: Longitudinal Impedance evaluated by TBCI and T3.

Components	$\lvert Z_{\parallel}/n \rvert$ (Ω)	Number	$\lvert Z_{\parallel}/n \rvert^{(total)}$ (Ω)
Cavities	0.02	4	0.08
Vacuum pump holes	5.4×10^{-8}	$1.5 \times 10^{5}/100m$	0.01
Vacuum pump slots	6×10^{-7}	$1300/25m$	0.001
Monitor electrodes	2×10^{-5}	4×60	0.005
Bellows	3.5×10^{-4}	200	0.07
Septum chamber	6.8×10^{-4}	2	0.001
RF quadrupoles	6.4×10^{-3}	2	0.01
Transitions	1.5×10^{-3}	4	0.006
Clamp chain flanges	4×10^{-5}	100	0.004
Gate valves	8×10^{-4}	8	0.006
Photon absorbers	* * * 5×10^{-4}	200	* * * 0.10
Total			0.29

assume D filling fac ~ 1/10

0.25
{Cavity, Bellows
Absorber

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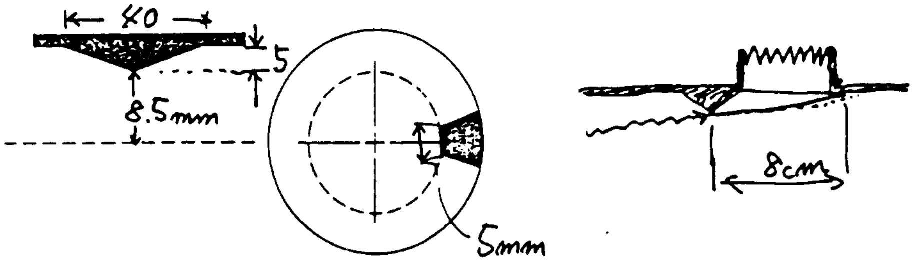
Photon Absorbers

The absorber sits only outer (and inner) wall of the vacuum chamber.



Assume the azimuthal filling factor, (not confirmed by T3).

inner radius ~ 8.5 mm, absorber width ~ 5 mm.

$\Delta / 2\pi r = 5 / 2\pi \times 8.5 \sim 1 / 10$

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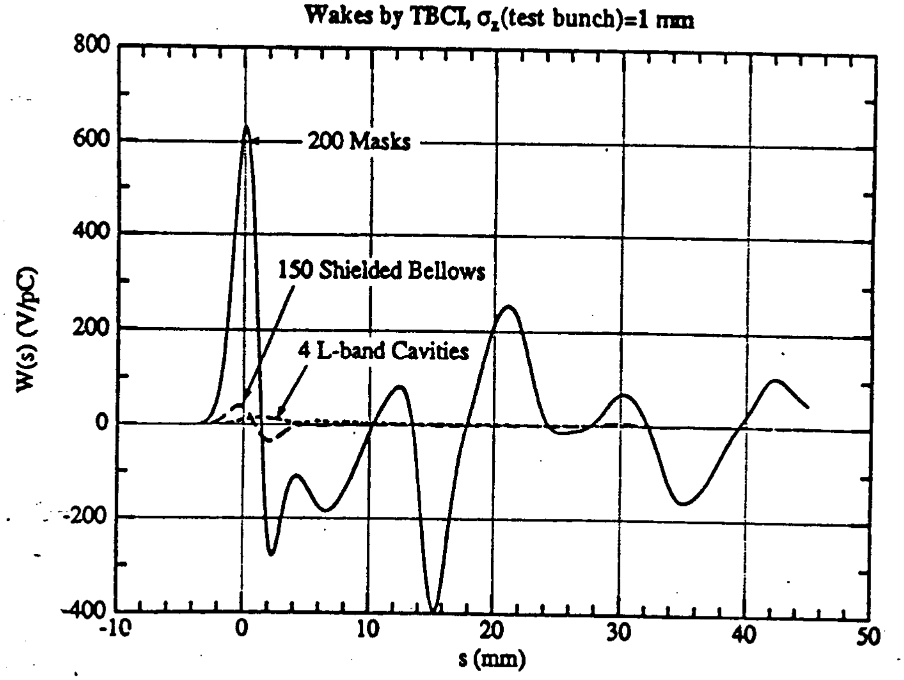


Wakes by TBCI, σ_z(test bunch)=1 mm

Coherent synchrotron radiation

Bunch radiates coherently in wavelength region

$\lambda \gtrsim \sigma_s$ $\quad\quad P_{coh} \propto N^2$!!

Shielding due to vacuum chamber strongly suppresses the effect

Bunch length has to be << chamber ⊥ dimensions to radiate coherently

Simple shielding model (Schiff '45, Nodvick & Saxon '54, Hofmann &

$$\frac{P_{coh}}{P_{incoh}} \simeq \frac{1}{2}\left(\frac{h}{\sigma_s}\right)^2 \left(\frac{\rho}{\sigma_s}\right)^{4/3} \frac{N}{\gamma^4}$$

The cut-off wavelength for SR in a waveguide (Heifets & Mikhailichenko, Warnock '91)

$$\lambda_{crit} \simeq 2\sqrt{h^3/R}$$

Shielding effects need detailed experimental checks

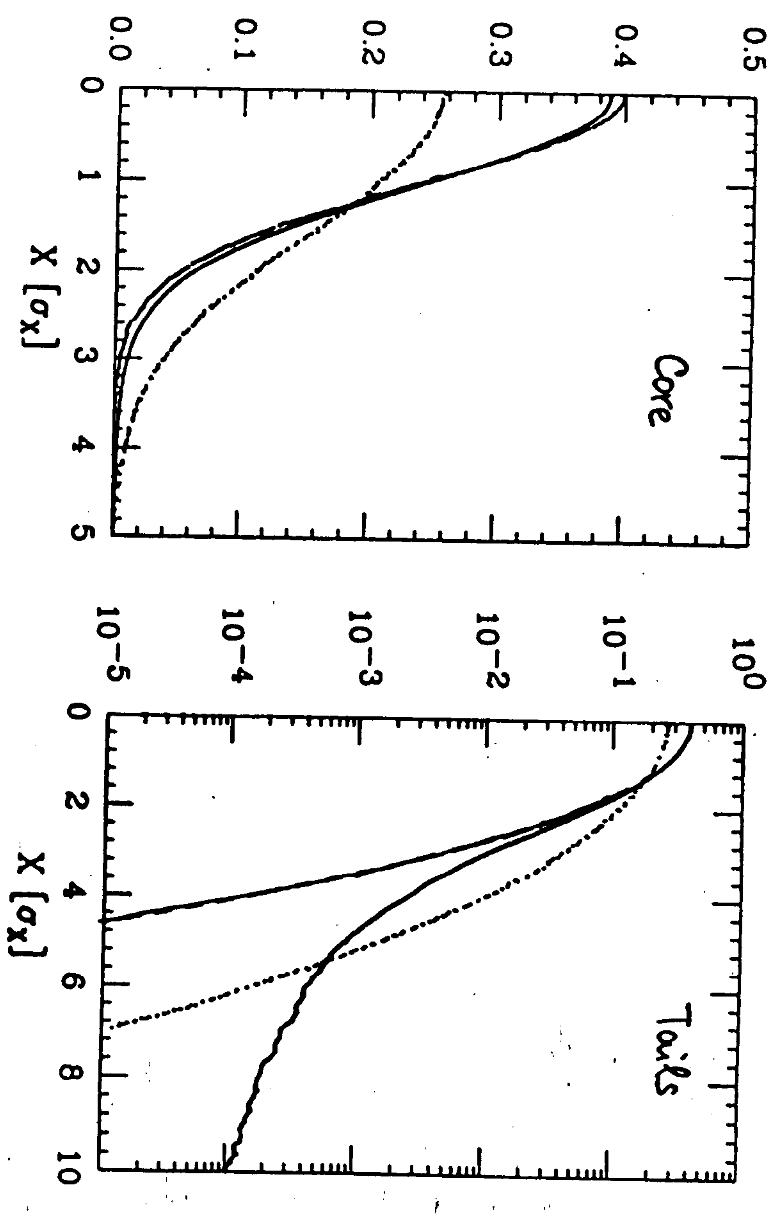
e.g. we estimate for ATF DR @ KEK

$\frac{P_{coh}}{P_{incoh}} \simeq 15\%$ $\quad\quad \lambda_{crit} \simeq 1\,mm$

If we open up the vacuum chamber radius to decrease the effective impedance $\left|\frac{Z}{n}\right|_{eff} \propto \frac{1}{h^2}$

coherent radiation loss may become significant

Beam Distribution in NLC DR w/ IBS.



Single bunch: Transverse impedance requirement

Design bunch current < instability threshold

We have made similar simple estimates for different designs:

$$Z_\perp \lesssim \frac{3.5\,E}{\langle\beta\rangle\, I_B}\,\alpha\cdot\delta$$

$\langle\beta\rangle$ - average β function (x or y)
I_b - bunch current

Typically the transverse impedance requirements are less stringent then requirements on longitudinal impedance.

Concluding remarks

→ Damping Rings are quickly becoming high current machines, many bunches

Need very careful vacuum system and RF design

→ Test facilities (BEP, ATF DR, SLAC) should provide necessary experimental checks on key assumptions

→ There are problems with every design

But we feel they will be solved.