DELAY LOOP

and

COMBINER RING DESIGN

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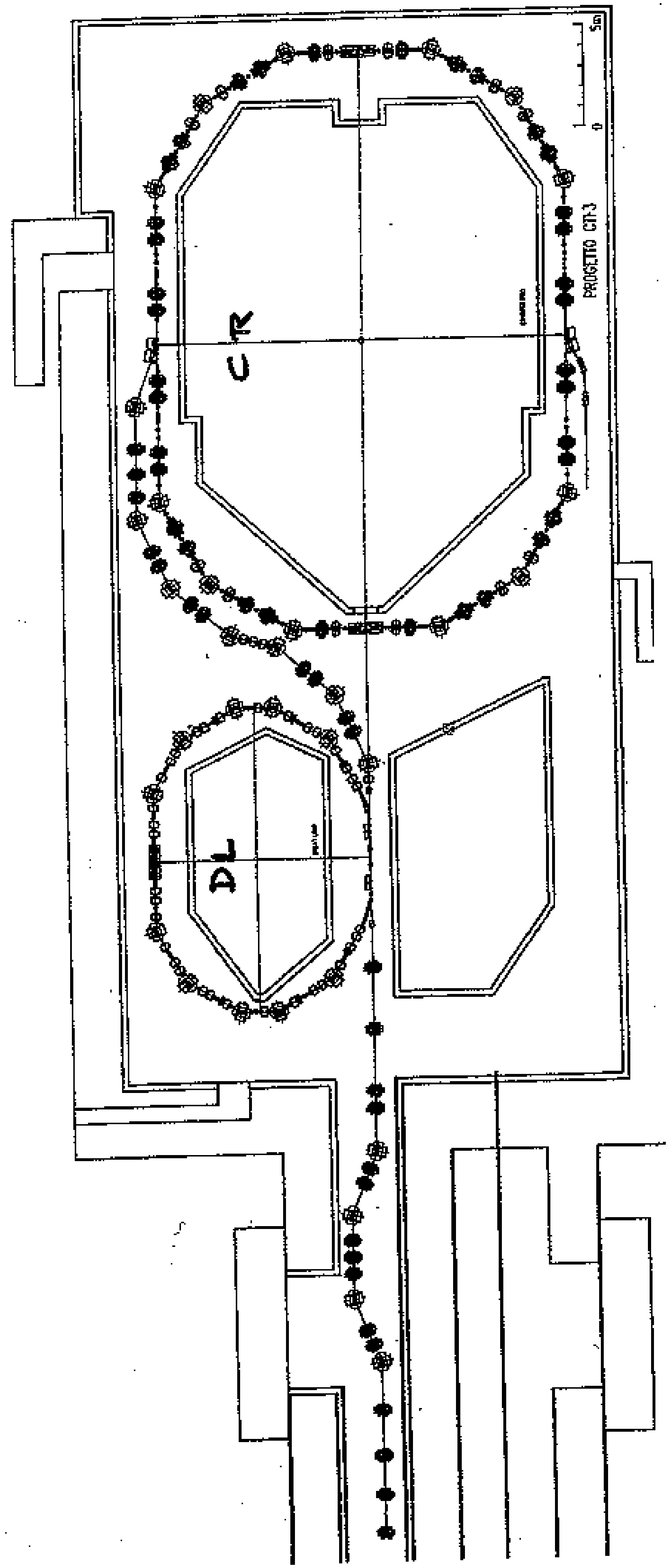
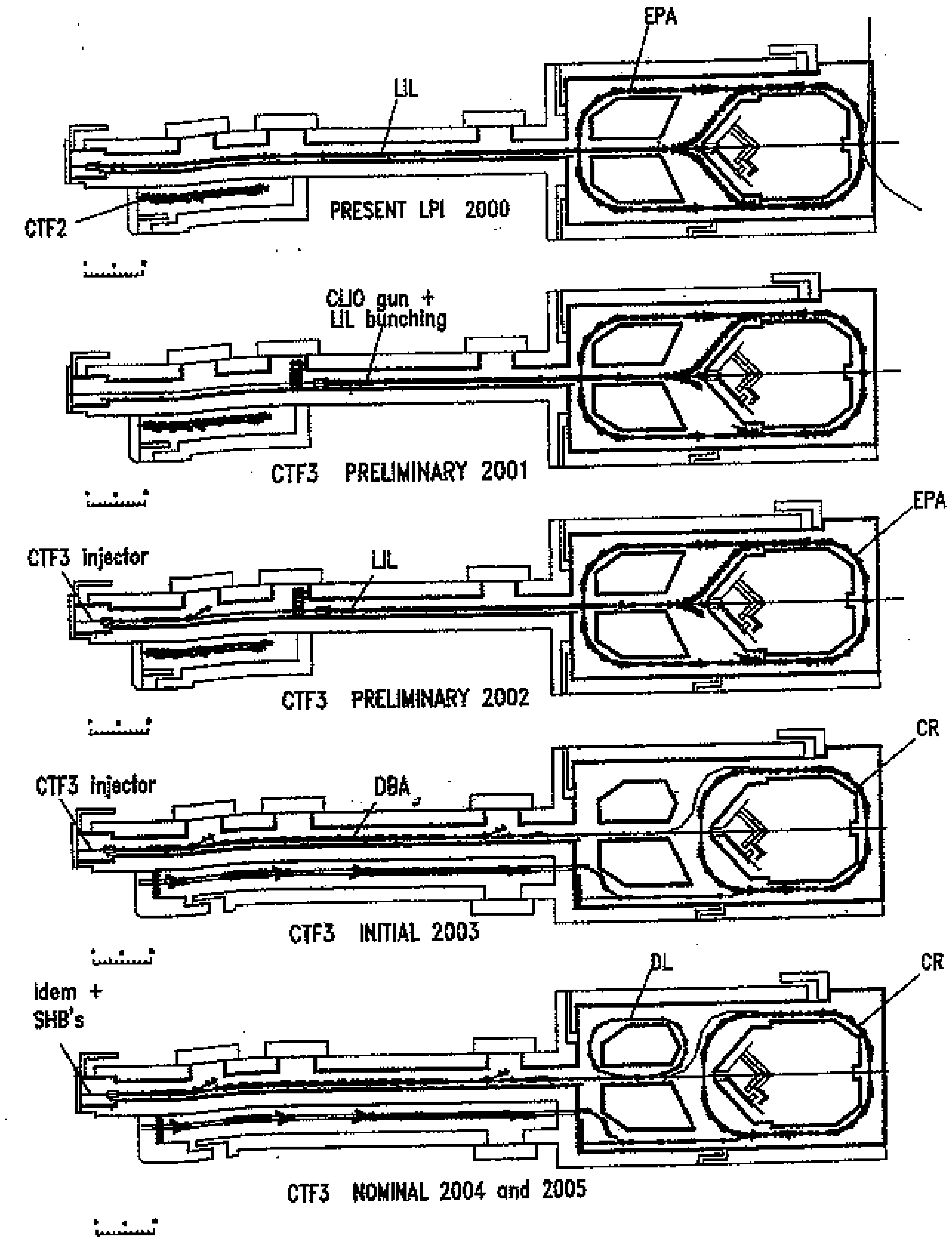
OUTLOOK

- **General considerations**
- **Combiner ring**
  - **Parameters**
  - **Optics design**
  - **Path length tuning**
  - **Isochronicity**
  - **Orbit/trajectory correction**
- **Delay loop**
  - **Parameters**
  - **Optics design (A and B)**
  - **TL Matching**
  - **Isochronicity**
- **Work in progress**
  - **CR as storage ring**





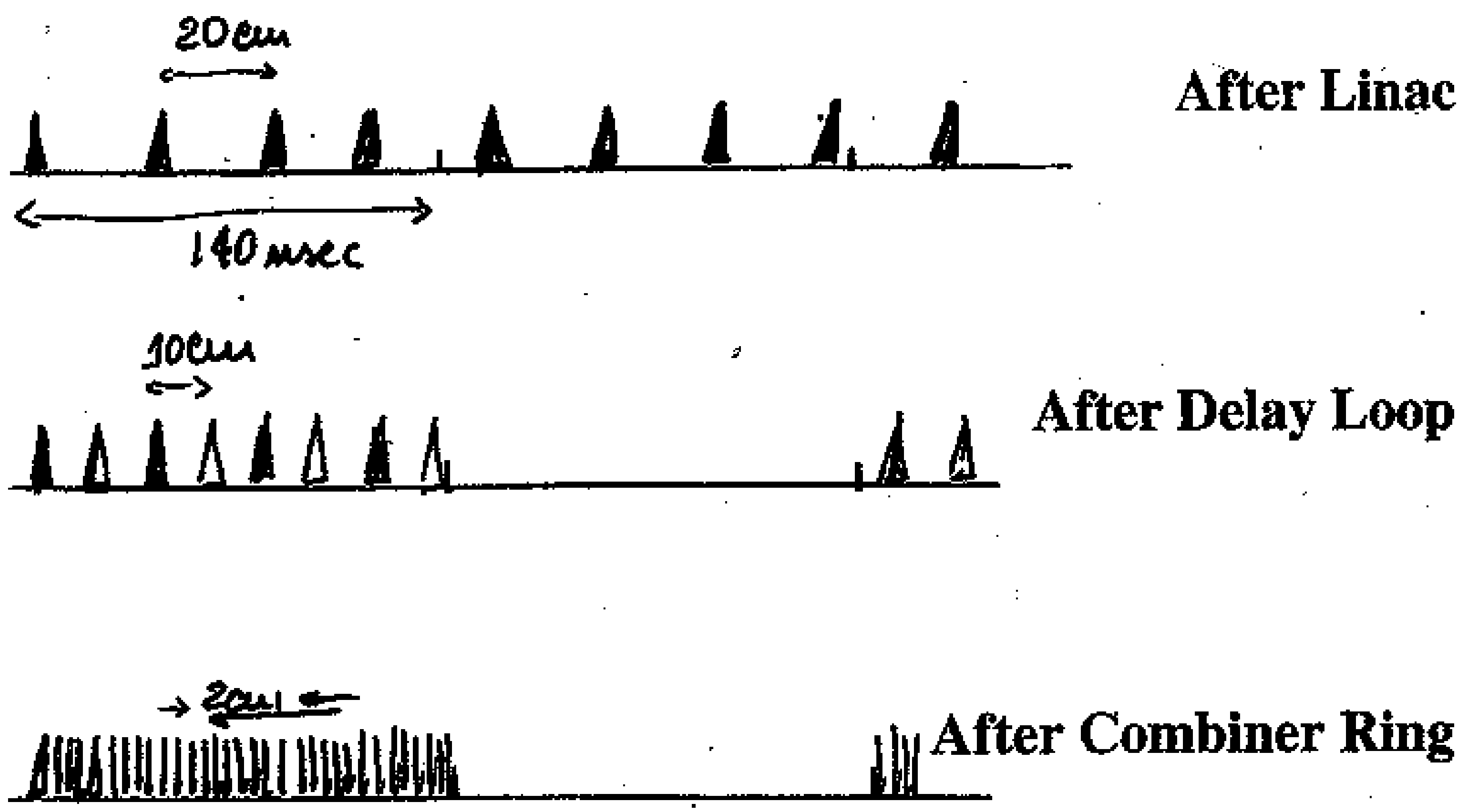
From LPI to CTF3

DBA = Drive Beam Accelerator
CR = Combiner Ring
DL = Delay Loop
SHB = Sub Harmonic Buncher

Drive Beam

High current in short bunches, low energy

Energy (MeV)	180 – 350
Emittance (mm mrad)	1 – 0.5
Bunch length (mm)	1
Bunch charge (nC)	2.3 – 1.0



Frequency multiplication must keep the bunch structure (longitudinal and transverse)

Control of bunch length + possibility of modifying it (to deal with CSR)

Isochronicity

Tunable R_{56}

Stretcher and compressors

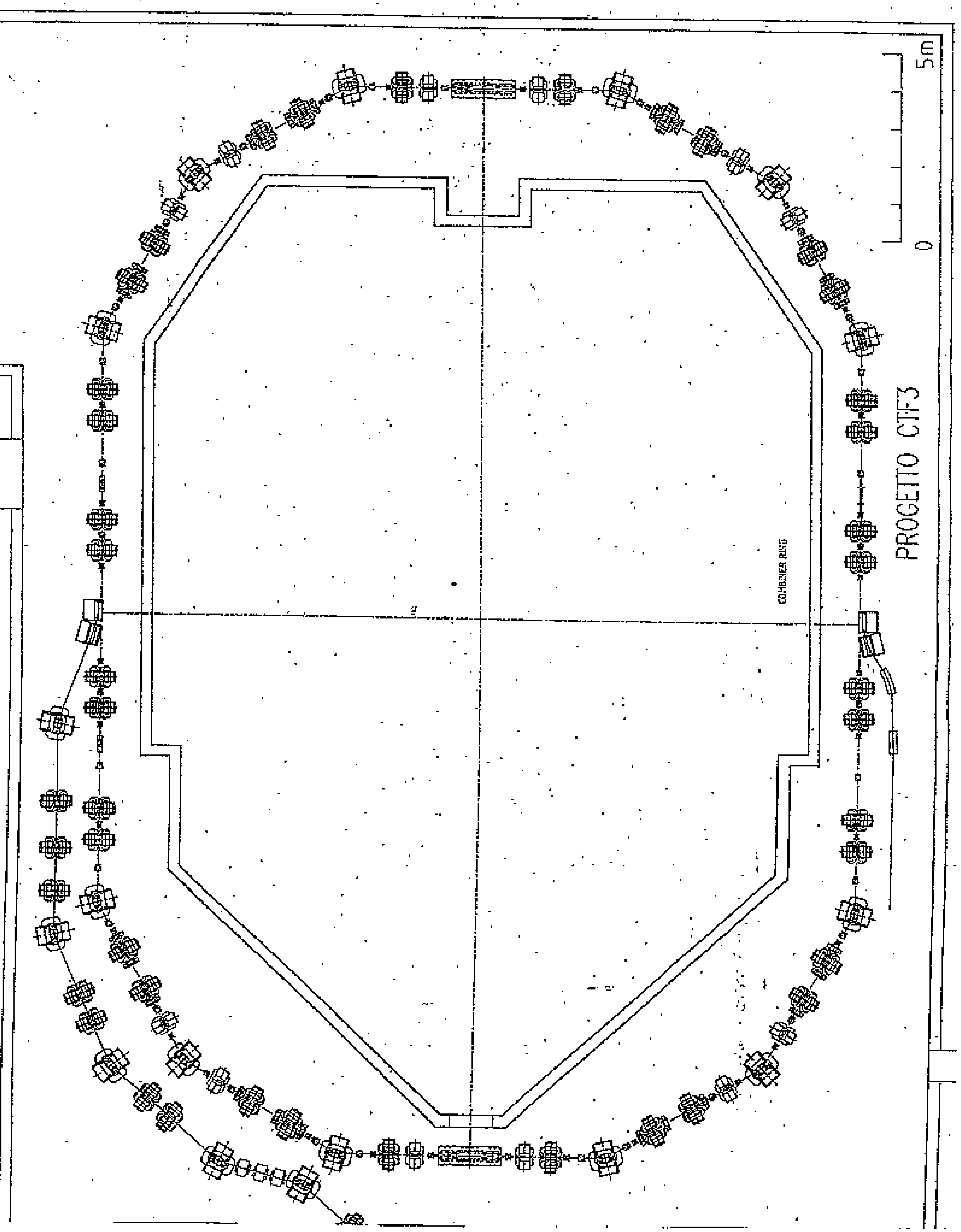
Path length tuning

Linac frequency

Wigglers

Space constraints +

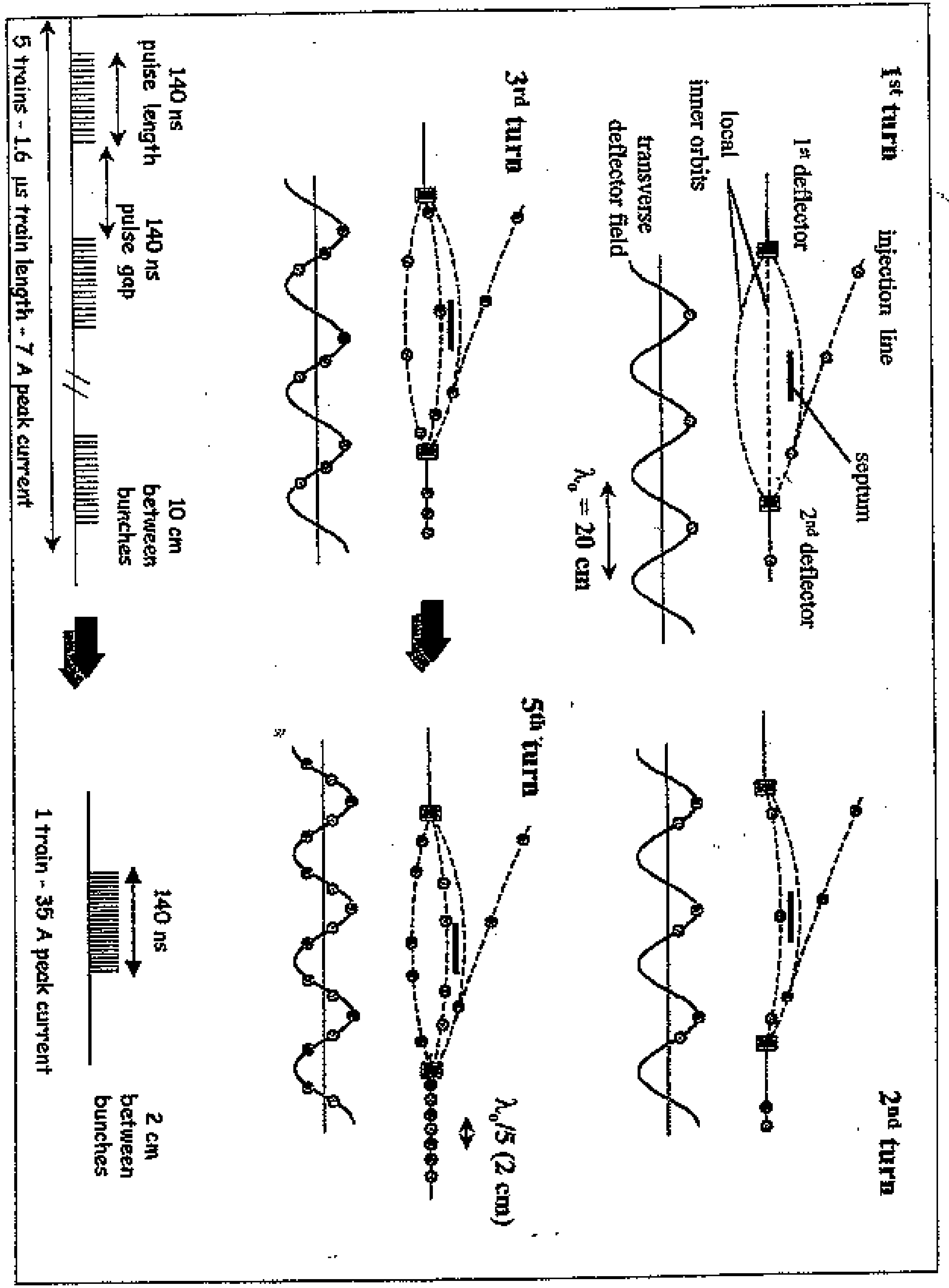
reusing when possible existing hardware, design material and documentation



COMBINER RING

COMBINER RING PARAMETERS

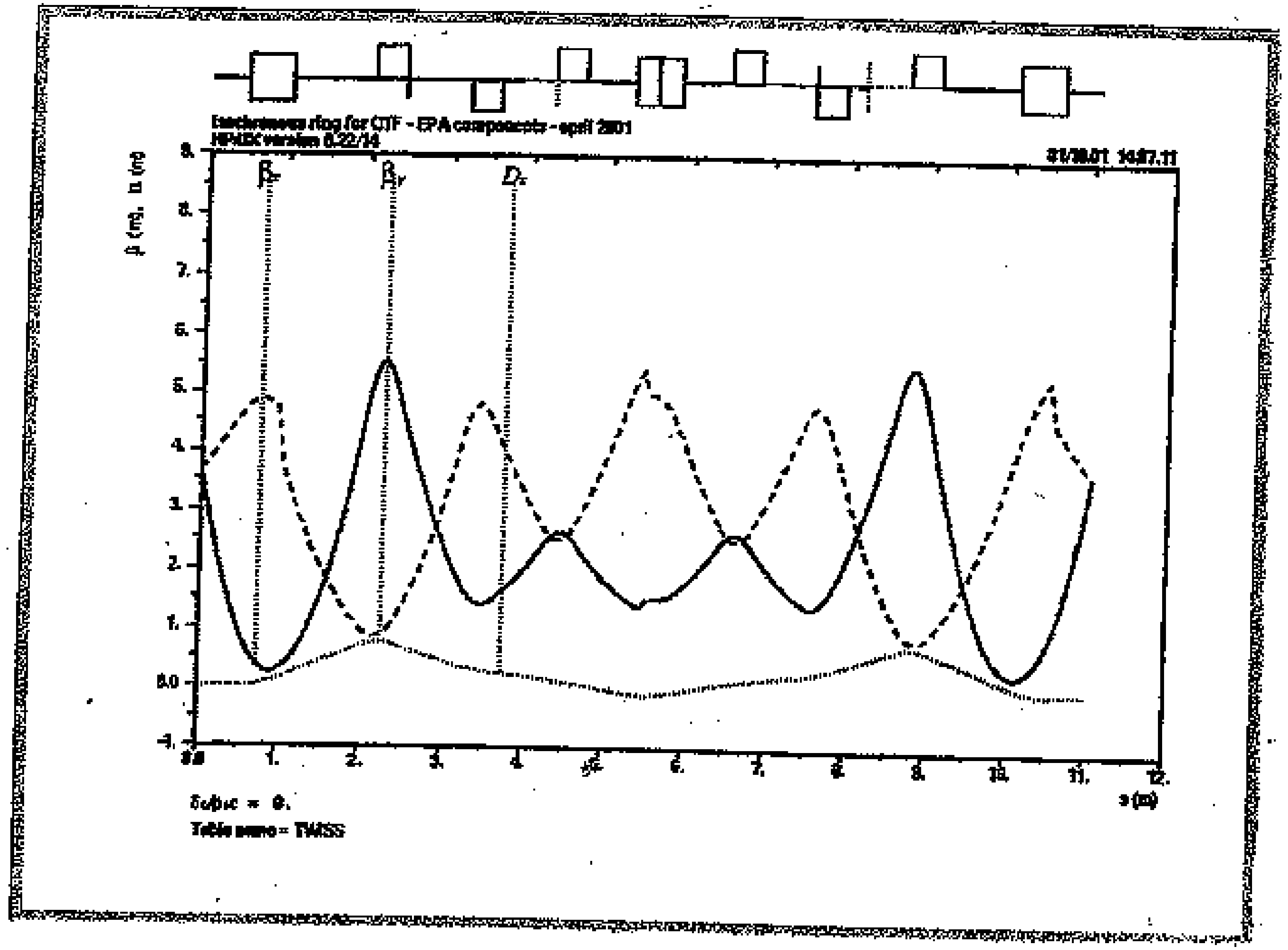
Energy (MeV)	180/350
Bρ (T m)	0.60/1.17
Circumference (m)	84.0
No. Cells	4
Max. beta (m) (H/V)	11.1/11.1
Max. Dispersion (m)	0.72
Betatron Tune (H/V)	7.23/4.14
Chromaticity (H/V)	-12.0/ -8.8
Momentum compaction	$<10^{-4}$
Horizontal emittance (mm mrad)	1.0/0.5
Vertical emittance (mm mrad)	1.0/0.5
Energy spread (%)	±1
Energy acceptance (%)	±2.5



Principle of x5 bunch frequency multiplication in the CR

Isochronous arc

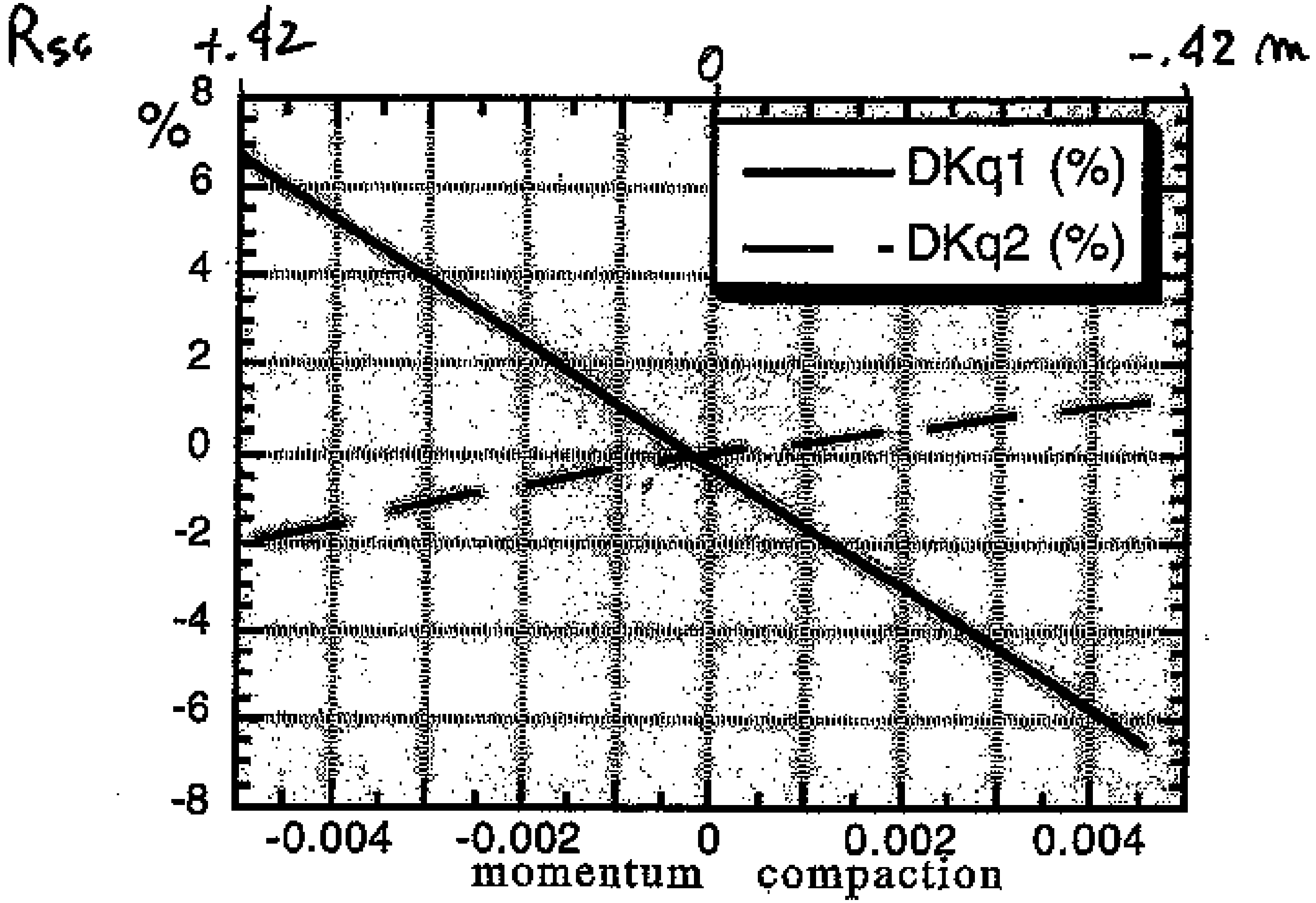
(three-bends achromat)

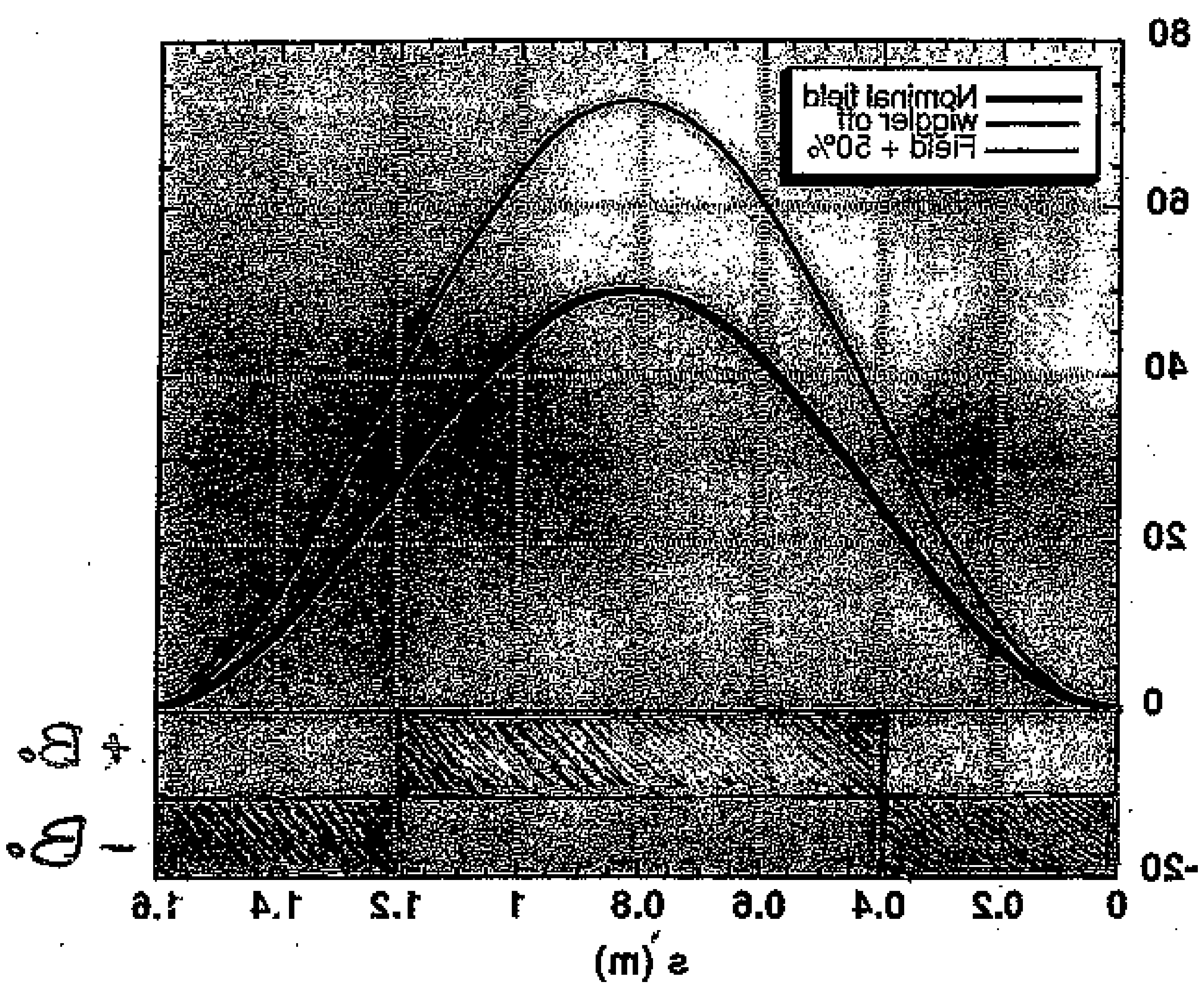


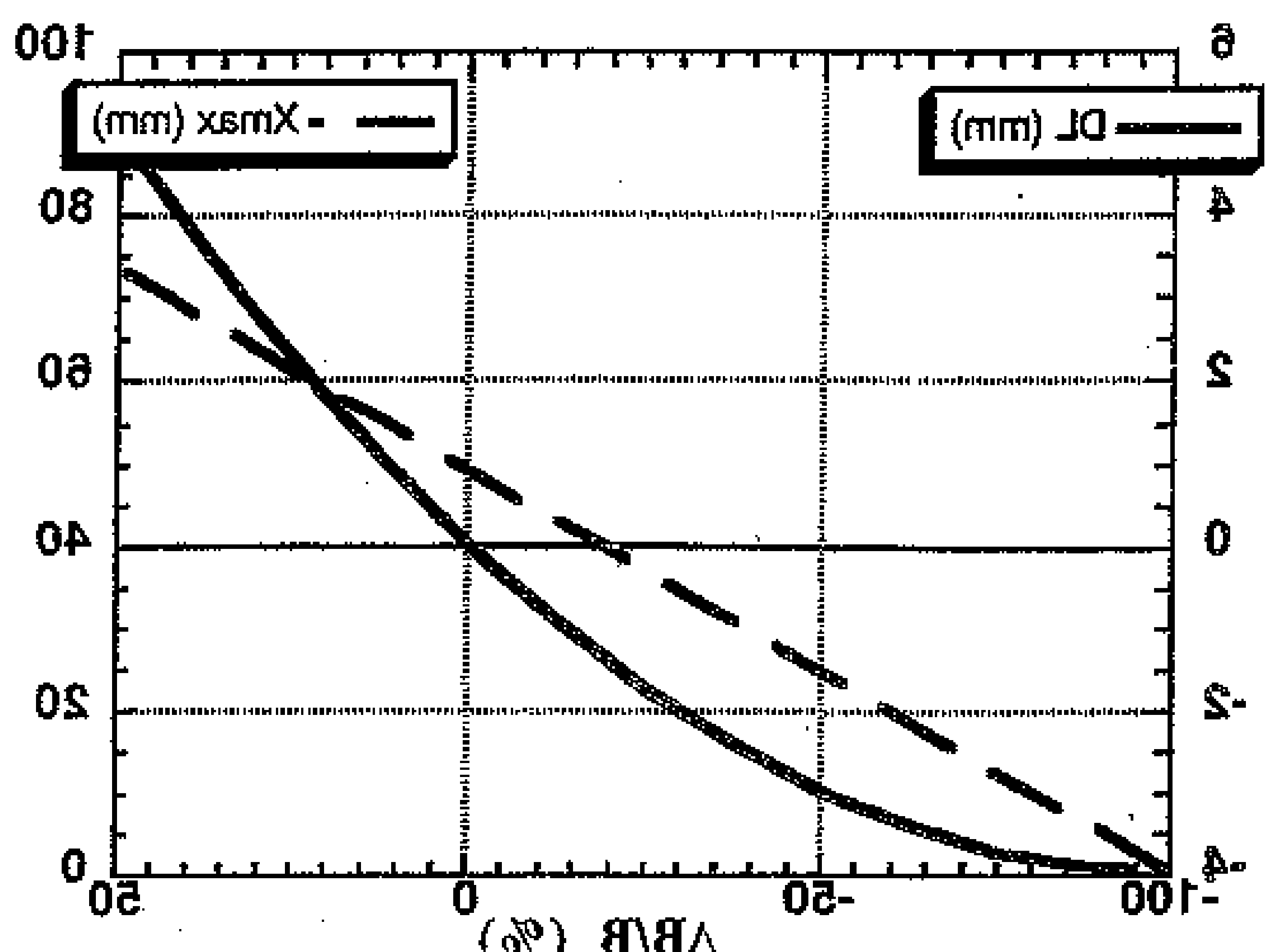
$$R_{56} = \int \frac{D}{\rho}\, ds = 0$$

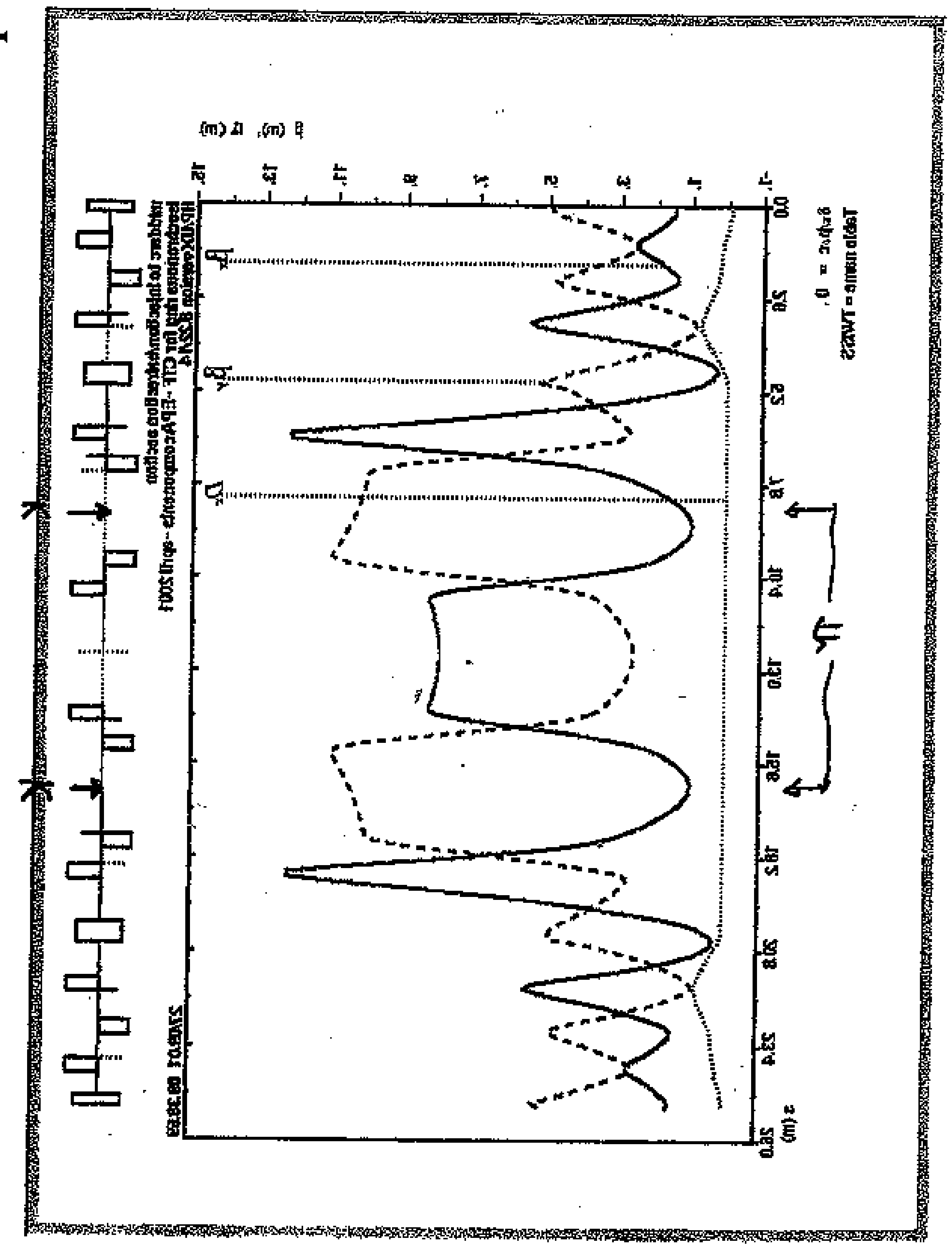
R_{56} tunability

$$D_o\ (\text{m}) = 40.218\ \alpha_c - 0.10278$$



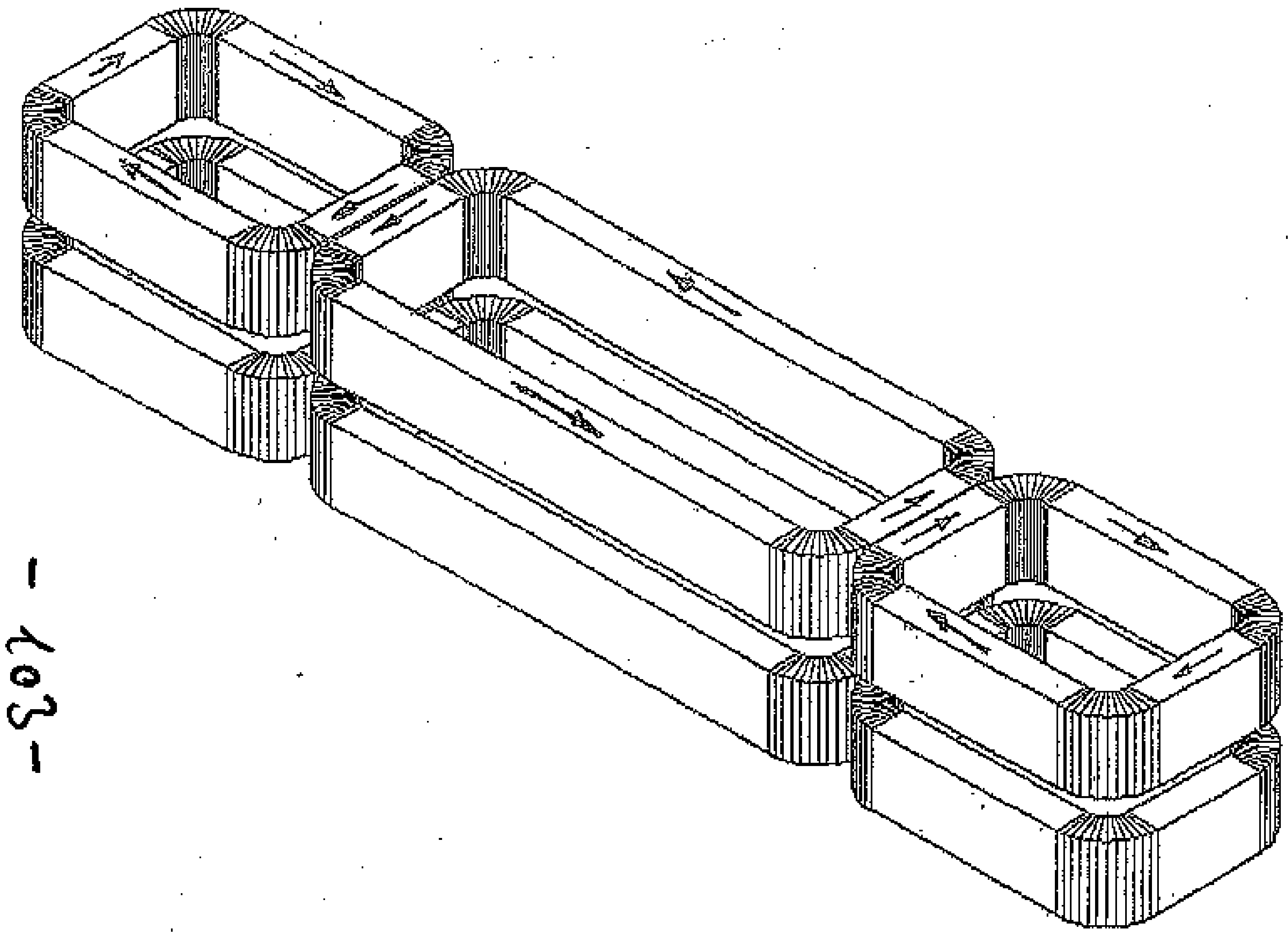






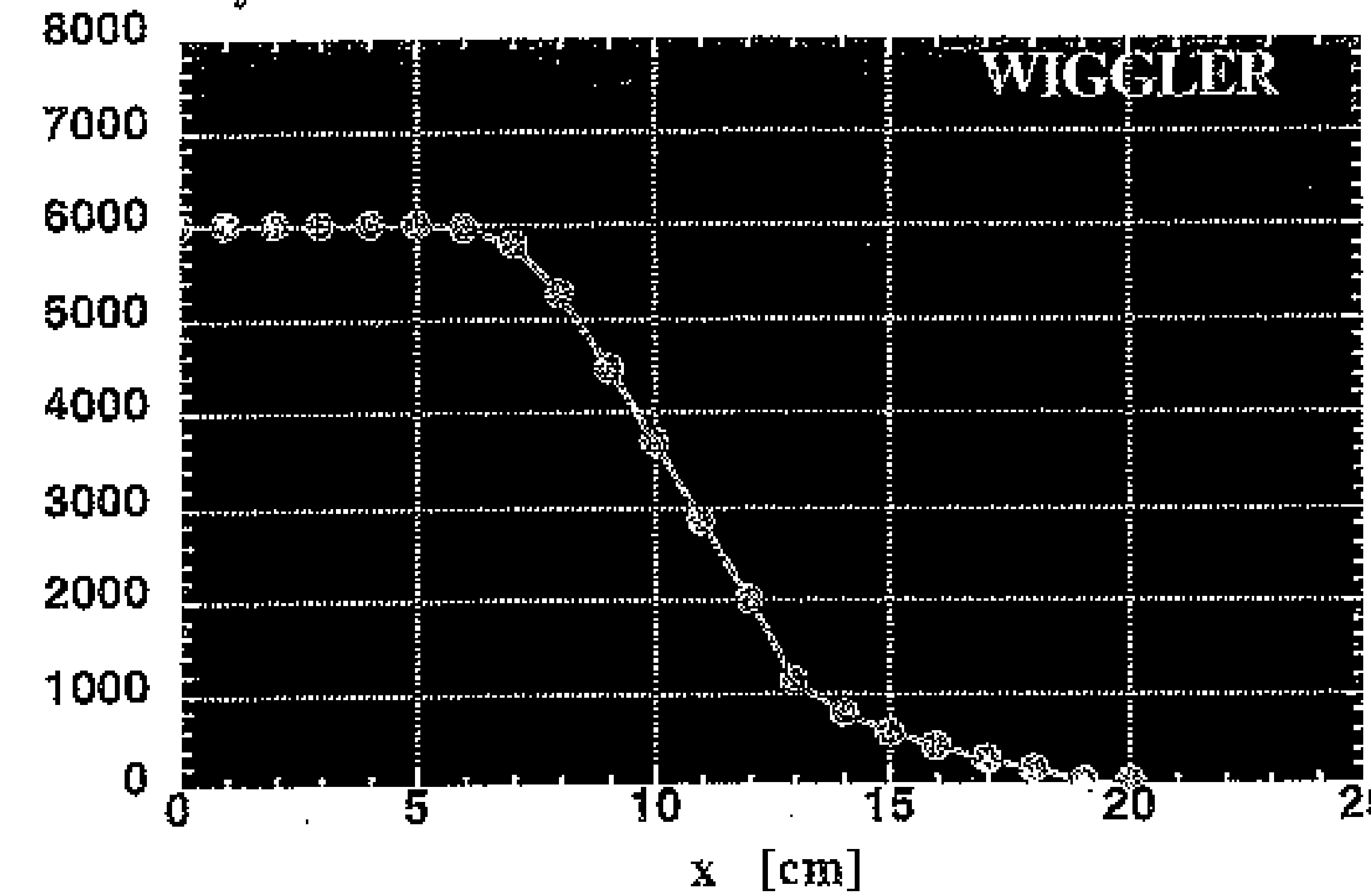
Optical functions of injection/extraction from midpoints of adjacent arcs

Path – length tuning wiggler field

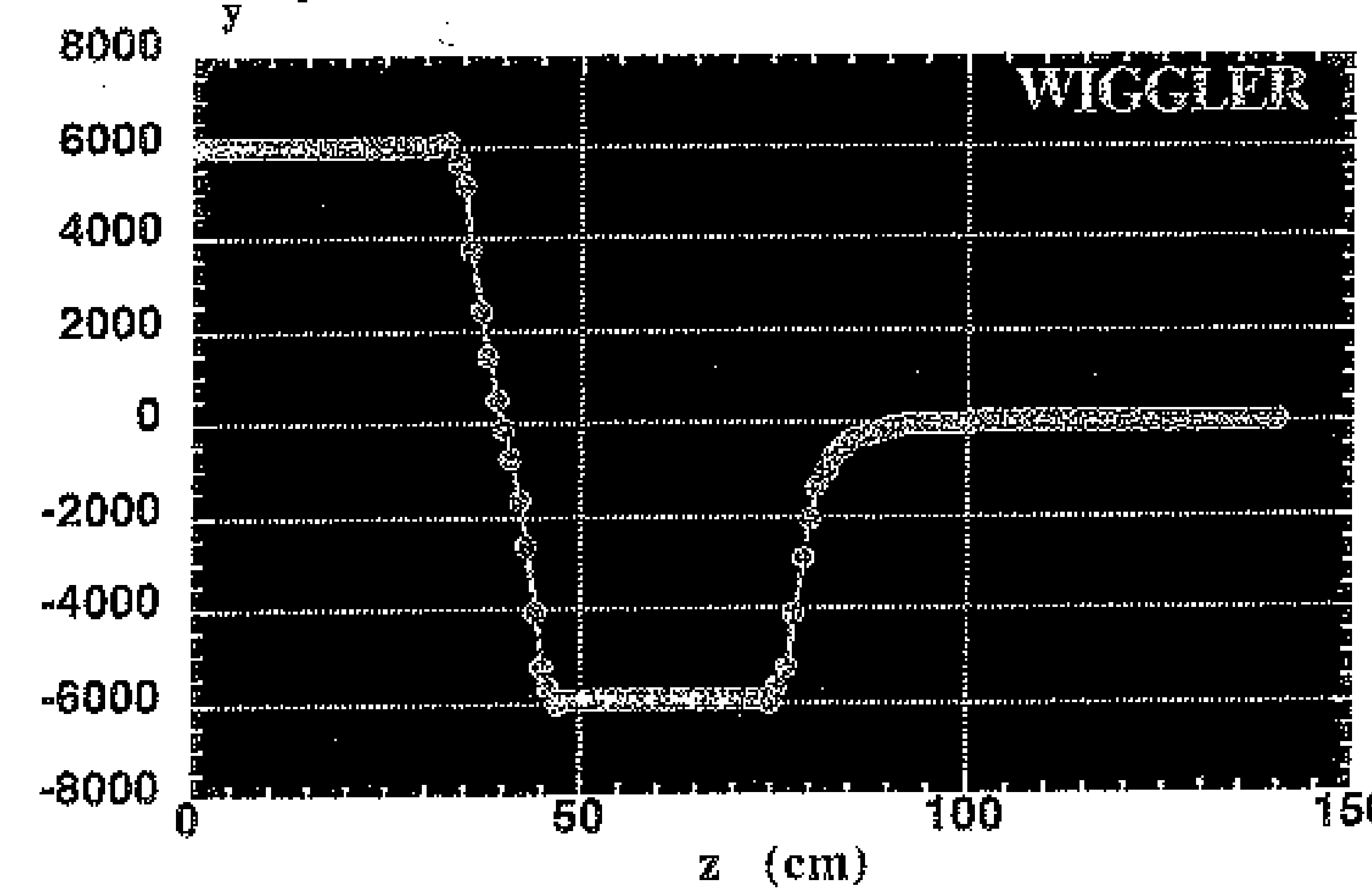


WIGGLER COILS

B_y (gauss) - transverse behaviour

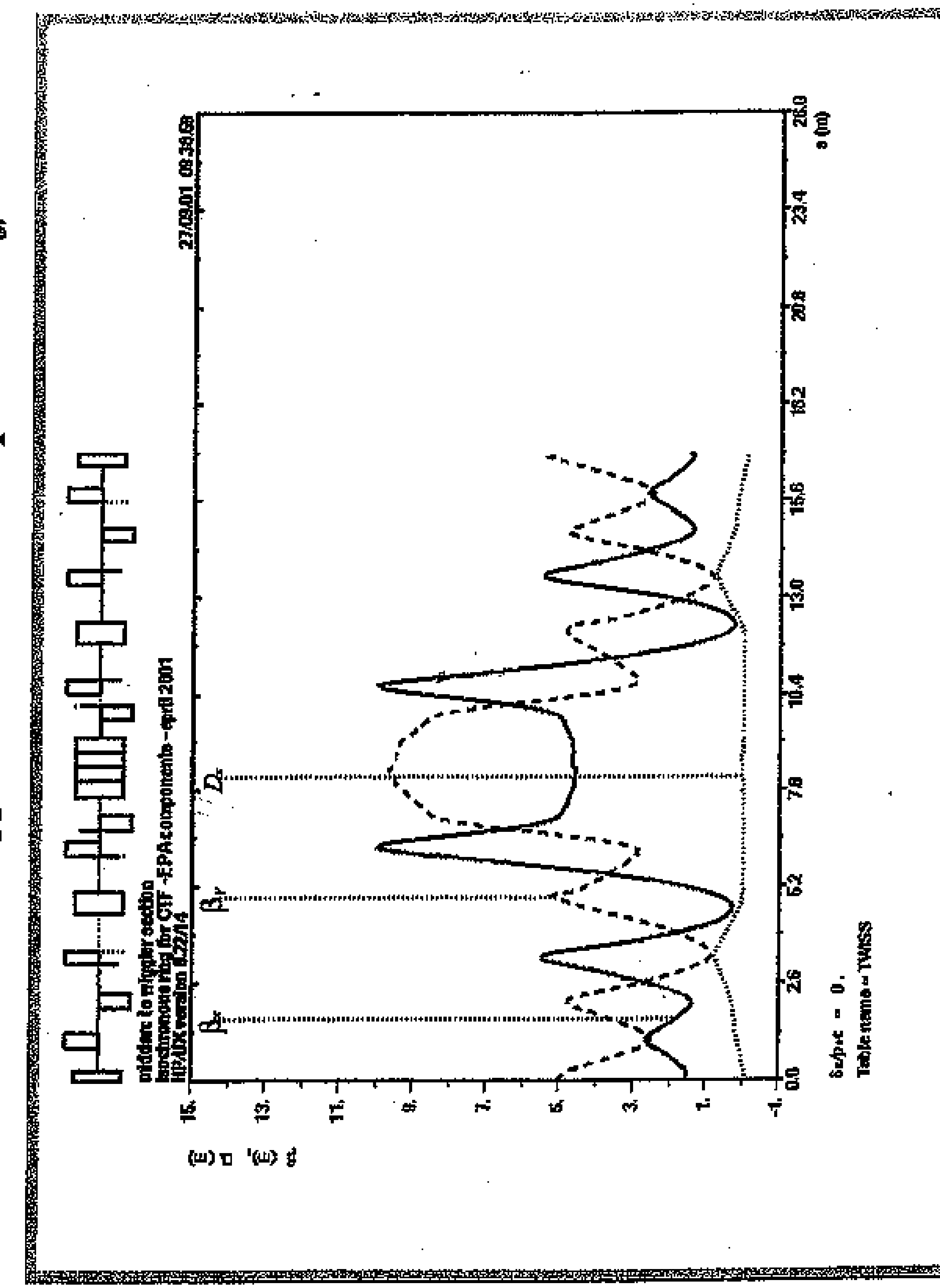


B_y (gauss) - longitudinal behaviour

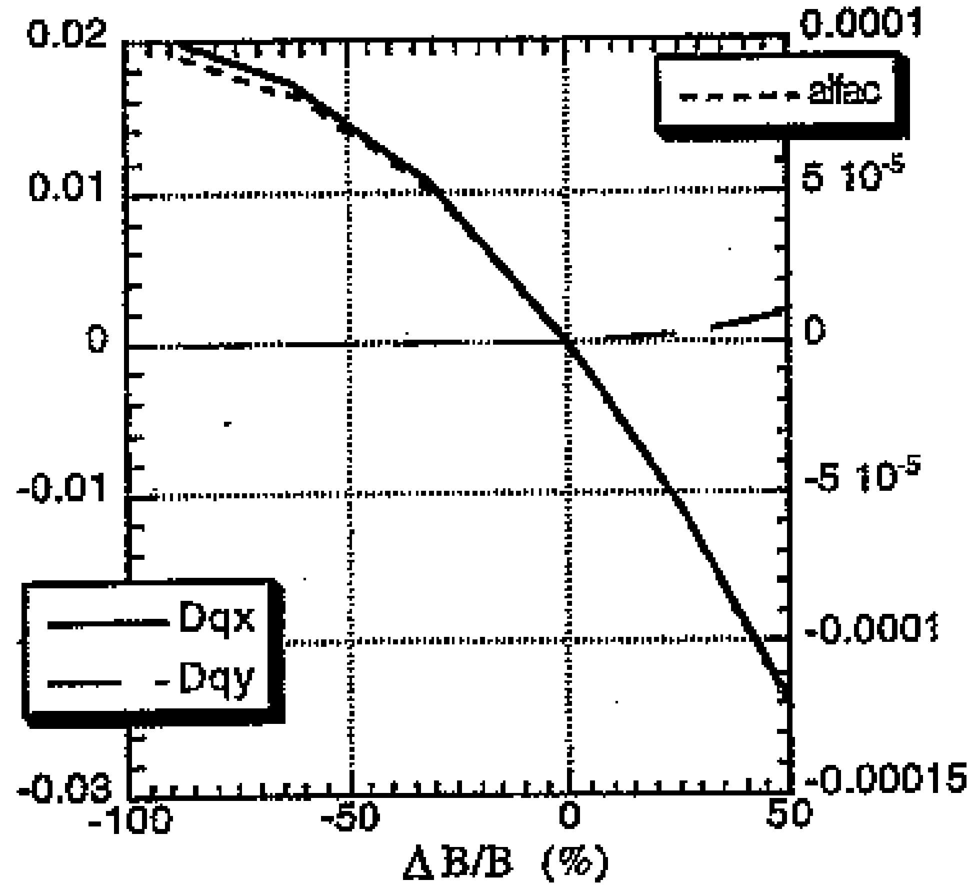


WIGGLER PARAMETER LIST
(3D calculations)

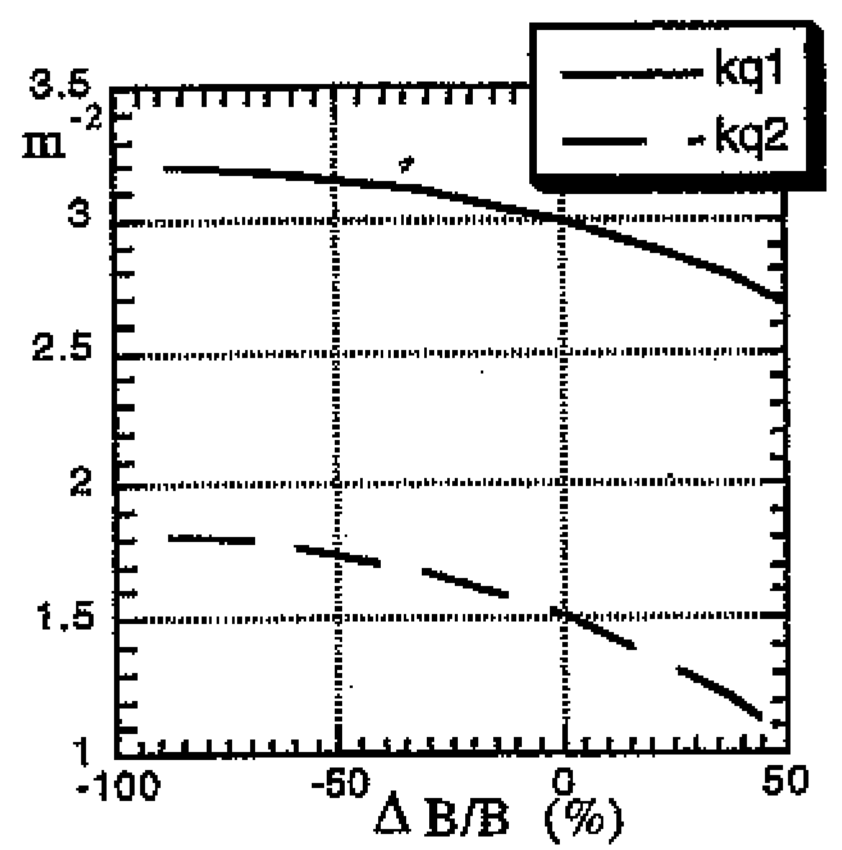
Nom. Magnetic Field	T	0.6
Nom. Magnet Gap	mm	40
Wiggler Period Length	m	1.6
Number of Periods		1
Number of Full Poles		1
Number of Half Poles		2
Wiggler Length	m	1.638
Ampere-turns per pole (full)	A	12330
Ampere-turns per pole (half)	A	9420
Turns per pole		40
Nom. Excitation Current (full pole)	A	308.25
Current Density (full pole)	A/ mm^2	4.36
Nom. Excitation Current (half pole)	A	235.5
Current Density (half pole)	A/ mm^2	3.33
Nom. Total Power Consumption	W	6410
Water Flow per magnet	l/min	9.3
Water Temperature Rise	°C	10
Iron weight	kg	1925
Copper conductor weight	kg	242



Optical functions of wiggler section from midpoints of adjacent arcs



Momentum compaction and change in betatron tunes as a function of wiggler field.

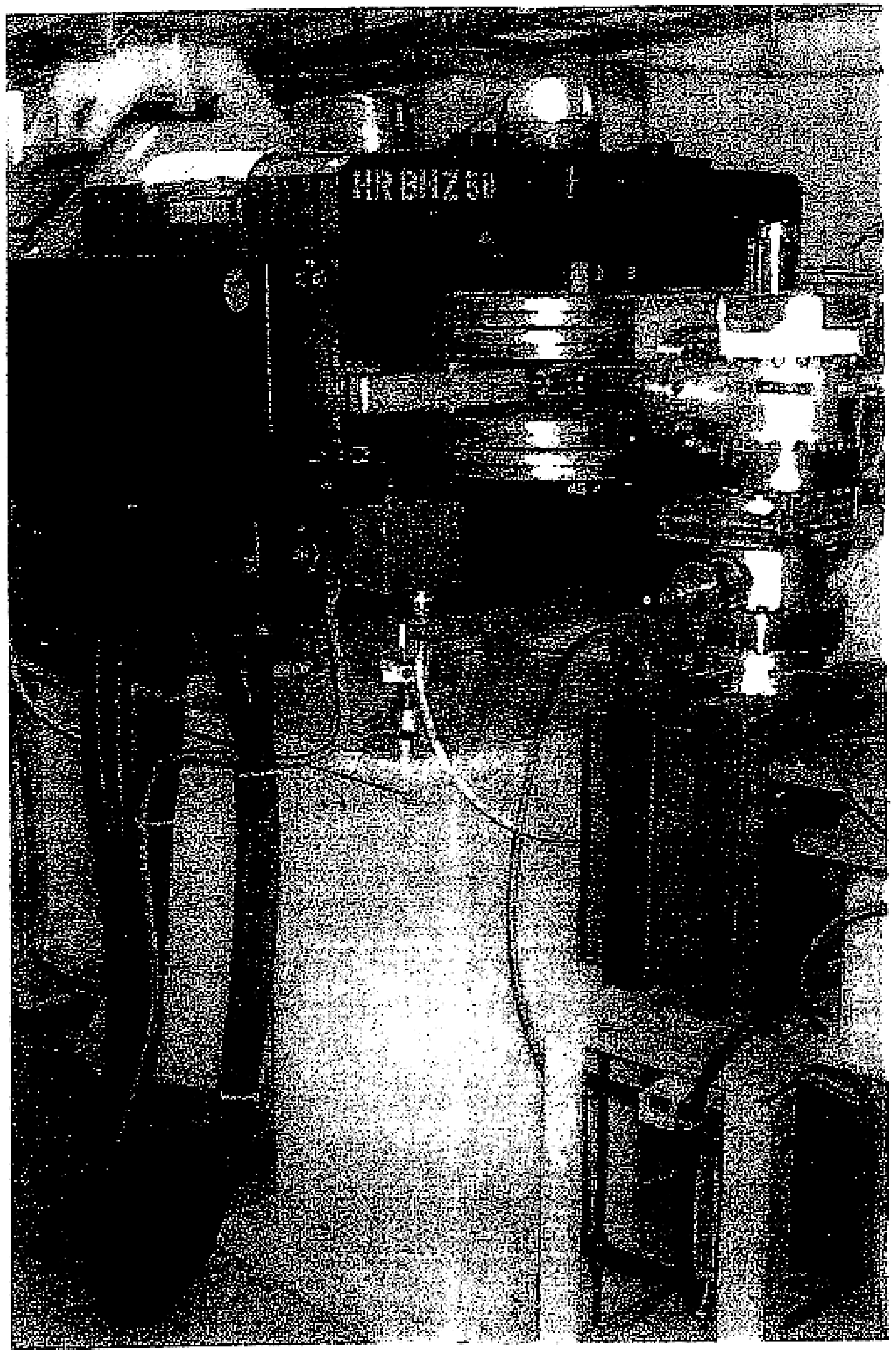


Strength of the wiggler section quadrupoles which match transverse betatron waists at the wiggler center as a function of wiggler field

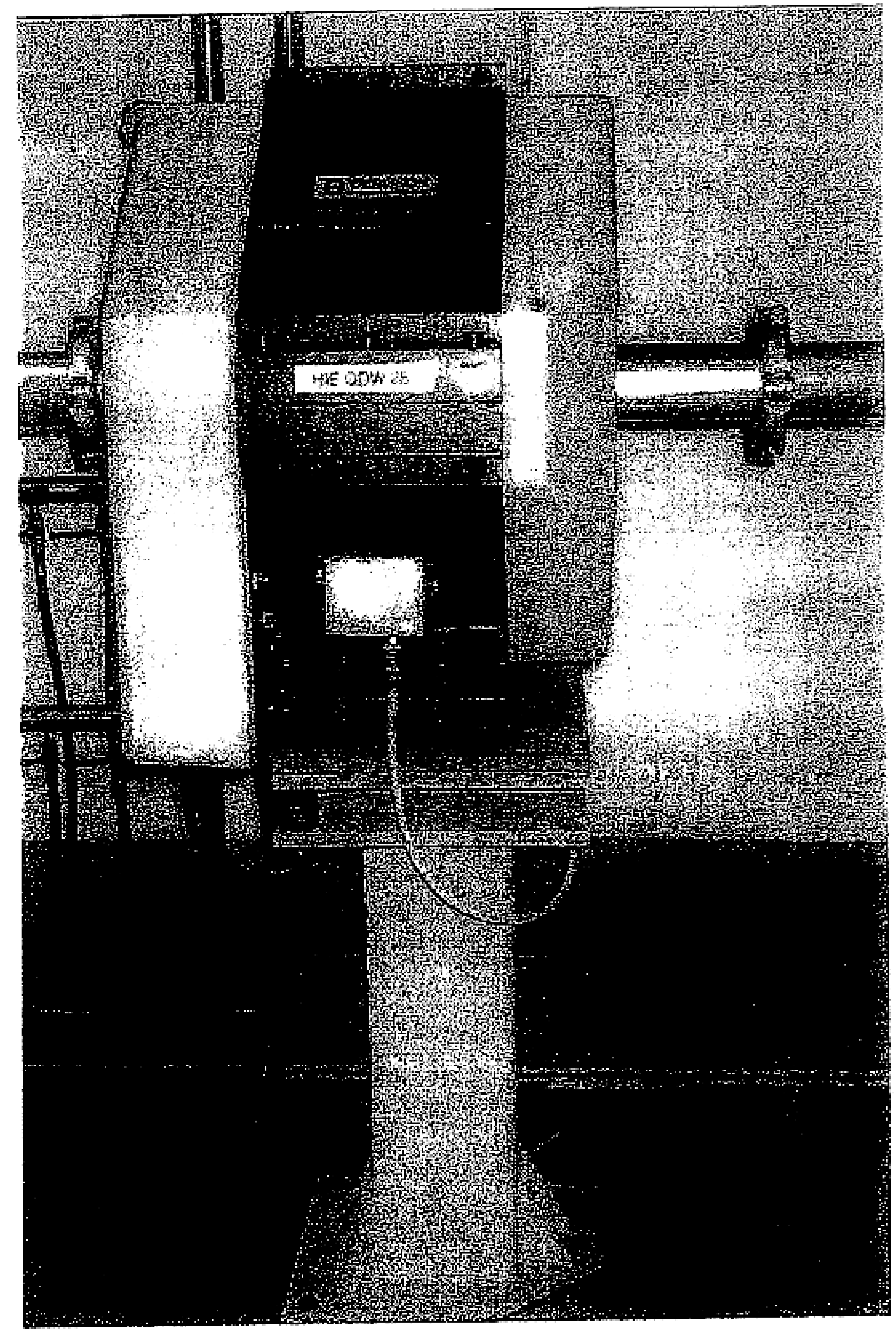
COMBINER RING MAGNETS

A)	N. of Dipoles (type 4.7)	12
	Dipole Field (T)	0.55/1.07
	Dipole Bending Radius [m]	1.09
	Pole width [mm]	230
	Gap height [mm]	45
B)	N. of Quadrupoles	48
	N. of Quadrupoles type 4.8.2	12
	Magnetic length [m]	0.38
	Maximum K_1 [m^{-2}]	2.24
	Maximum gradient [T/m]	0.51/0.99
	Quadrupole families (minimum/preferred)	2/3
	Pole width [mm]	140
	Available aperture [mm]	200
	N. of Quadrupoles type 5.3	36
	Magnetic length [m]	0.38
	Maximum K_1 [m^{-2}]	3.54
	Maximum Integrated Gradient [T]	0.81/1.57
	Quadrupole families (minimum/preferred)	7/12
	Pole width [mm]	134
	Available aperture [mm]	184
C)	N. of sextupoles	24
	Magnetic length [m]	0.10
	Maximum K_2 [m^{-3}]	100
	Max Integrated Gradient [T/m]	6/11.7
	Sextupole families	3
	Available aperture [mm]	108
D)	N. of Path Length Tuning Wigglers	2
	Pole width [mm]	150
	Gap height [mm]	40

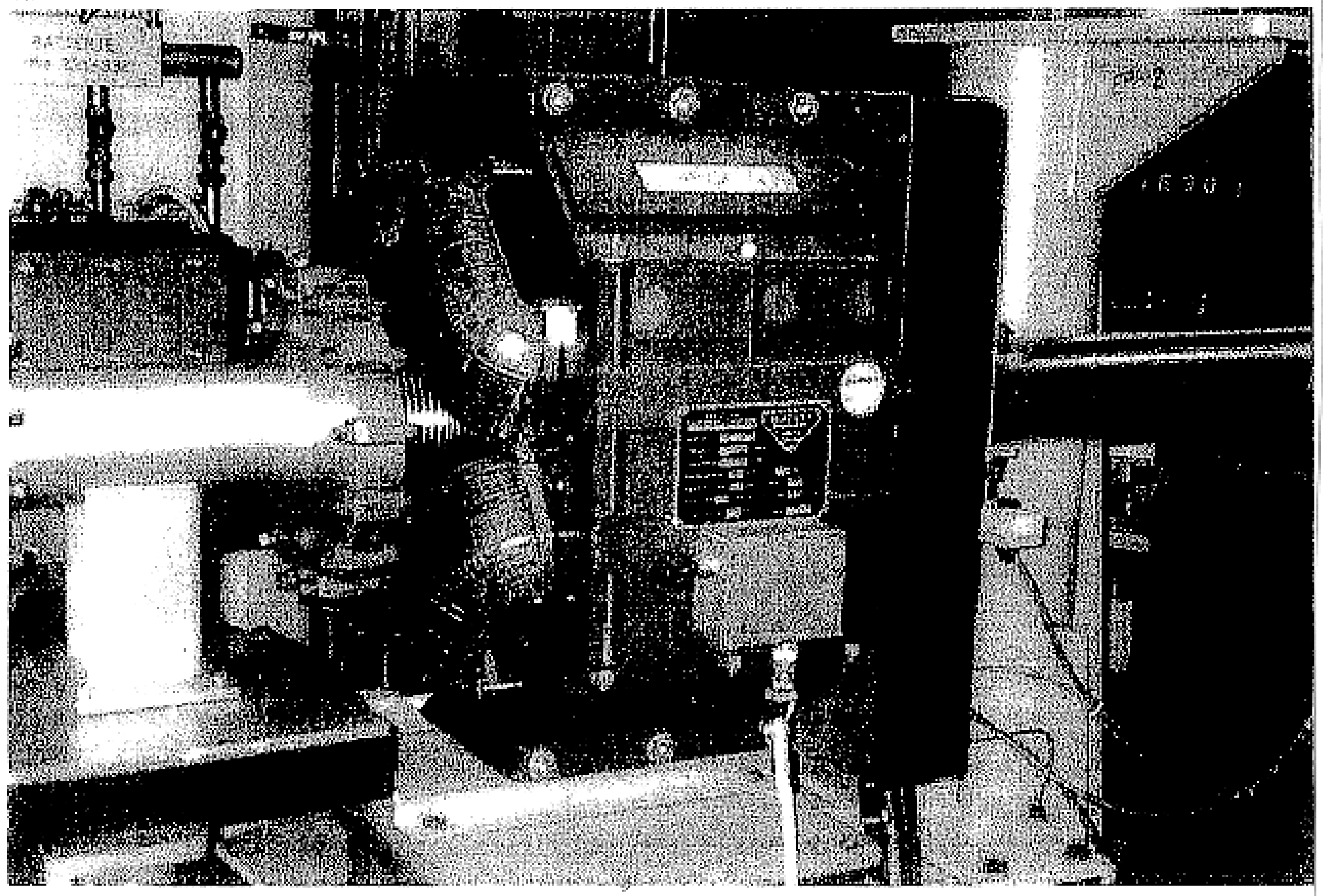
EPA DIPOLE



EPA QUADRUPOLES



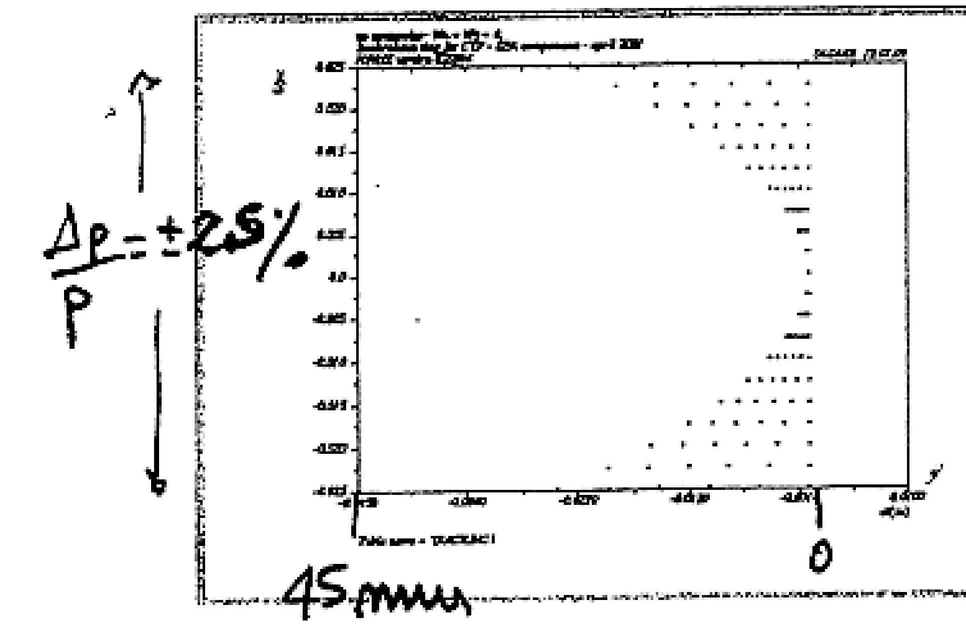
EPA QUADRUPOLES



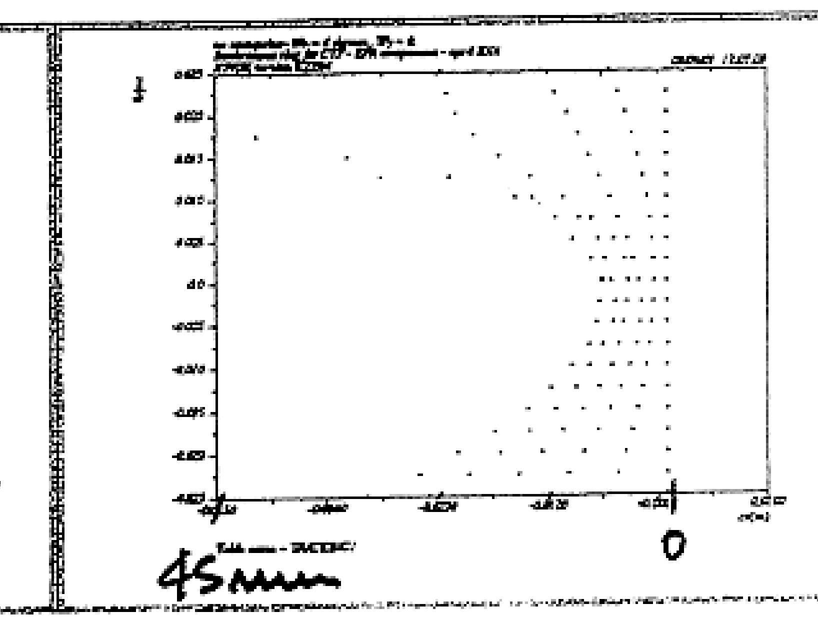
Isochronicity

$$c\Delta t = R_{56}\,\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2 + \ldots$$

[redacted]

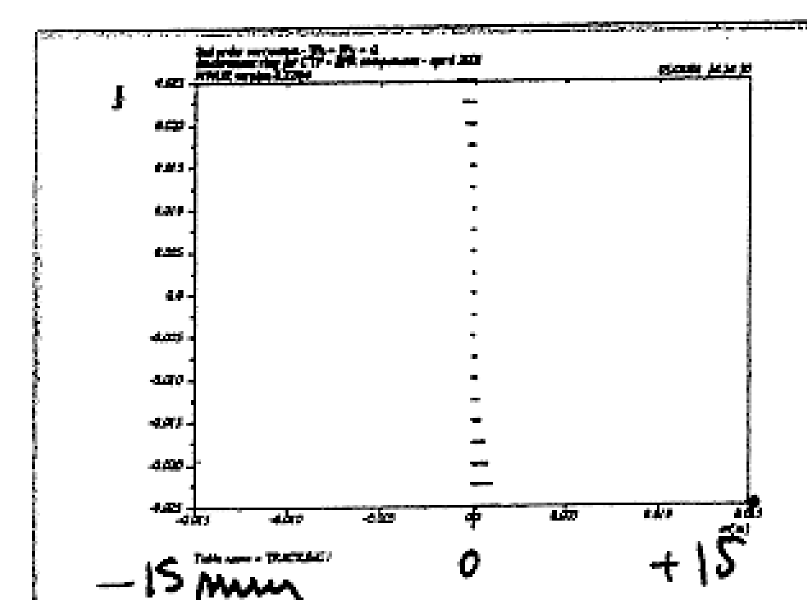


x = y = 0



x = 3 σ$_x$; y = 0

[redacted]



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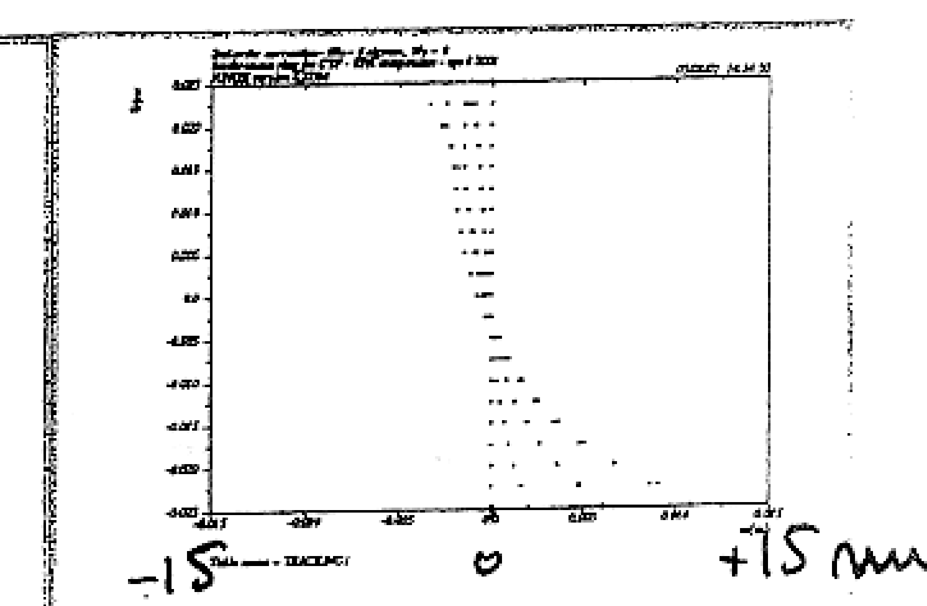


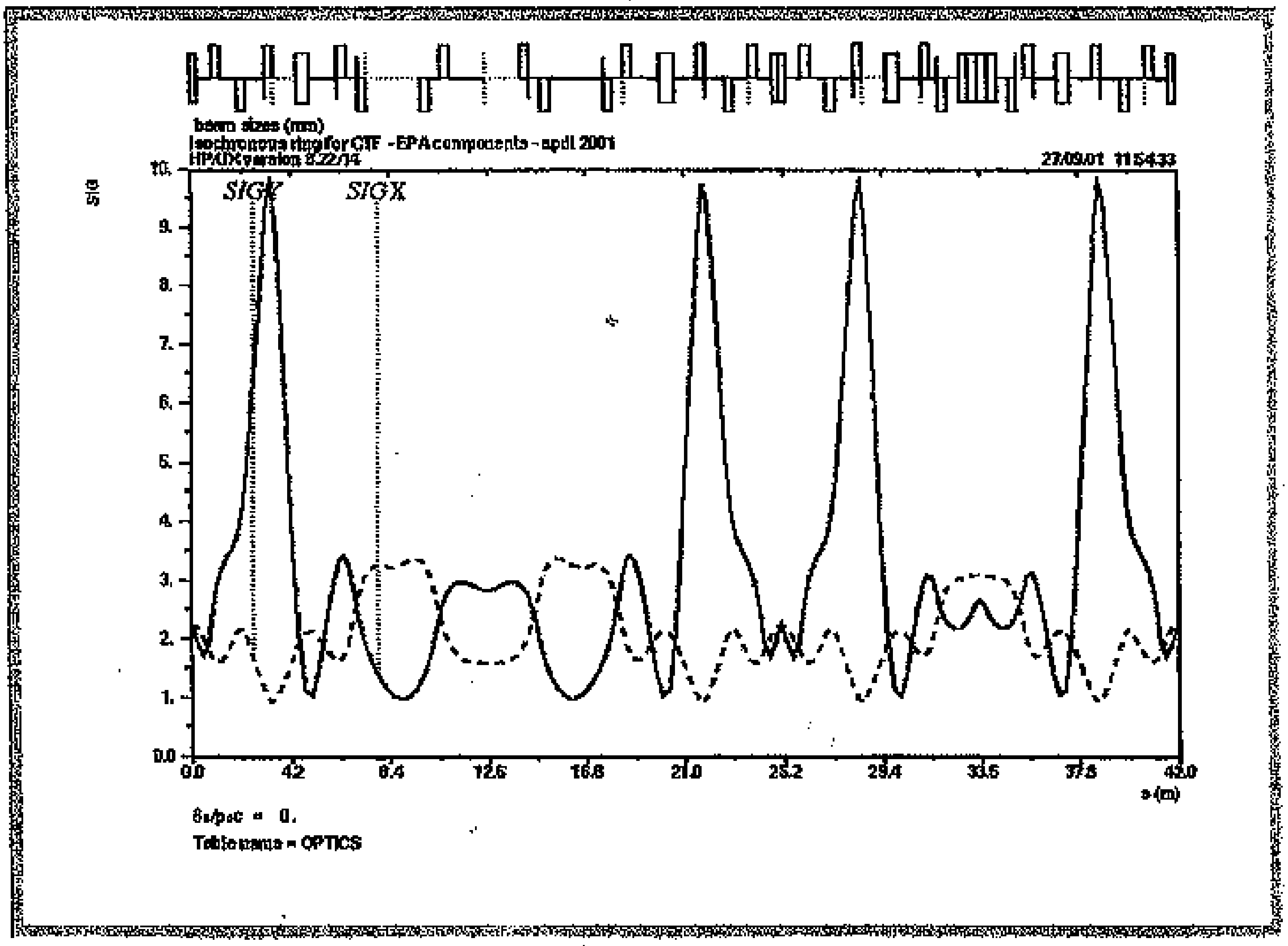
x = 3 σ$_x$; y = 0

$\frac{\Delta p}{p} = \pm 1\%$ → $3\sigma_x < 1$ mm
$3\sigma_y < 2$ mm

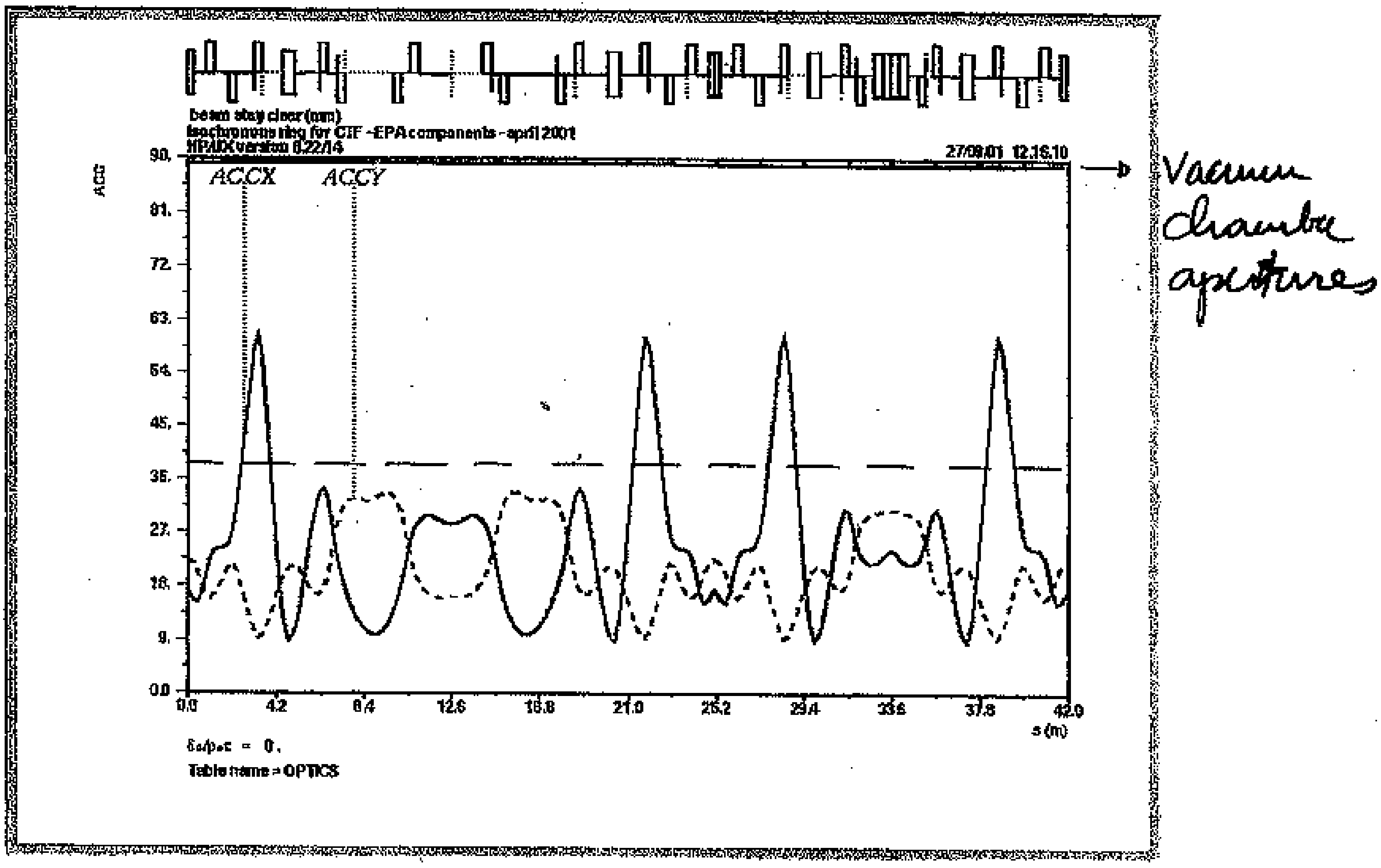
CR – Beam sizes $\sigma_x = \sqrt{\varepsilon_x \beta_x} + \frac{\Delta p}{p} D_x \quad \sigma_y = \sqrt{\varepsilon_y \beta_y}$

$\varepsilon_x = \varepsilon_y = 1$ mm mrad

$\Delta p/p = 0.01$

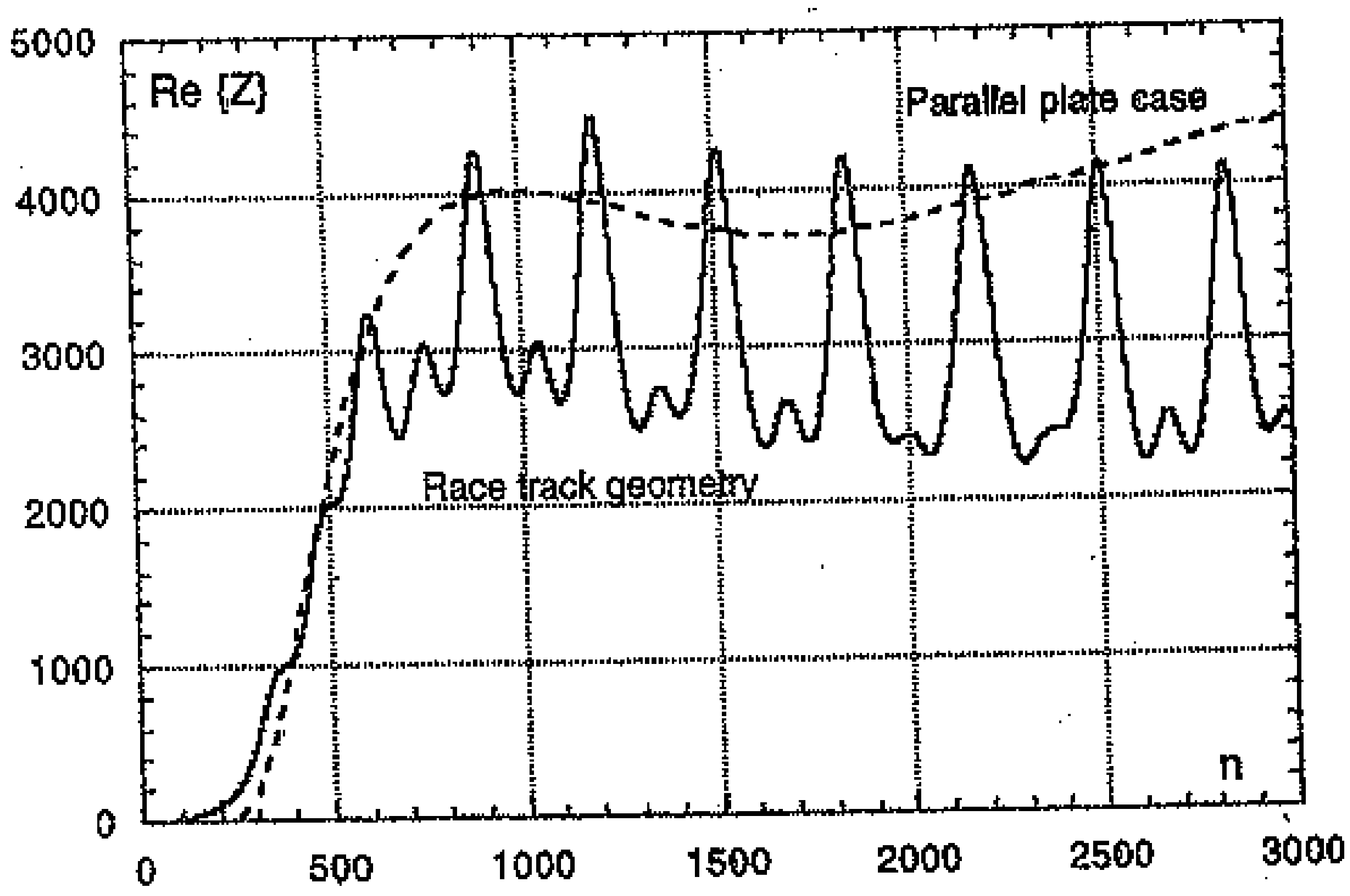


Beam Stay Clear $A_x = 10\sigma_x + 0.05 D_x \qquad A_y = 10\sigma_y$



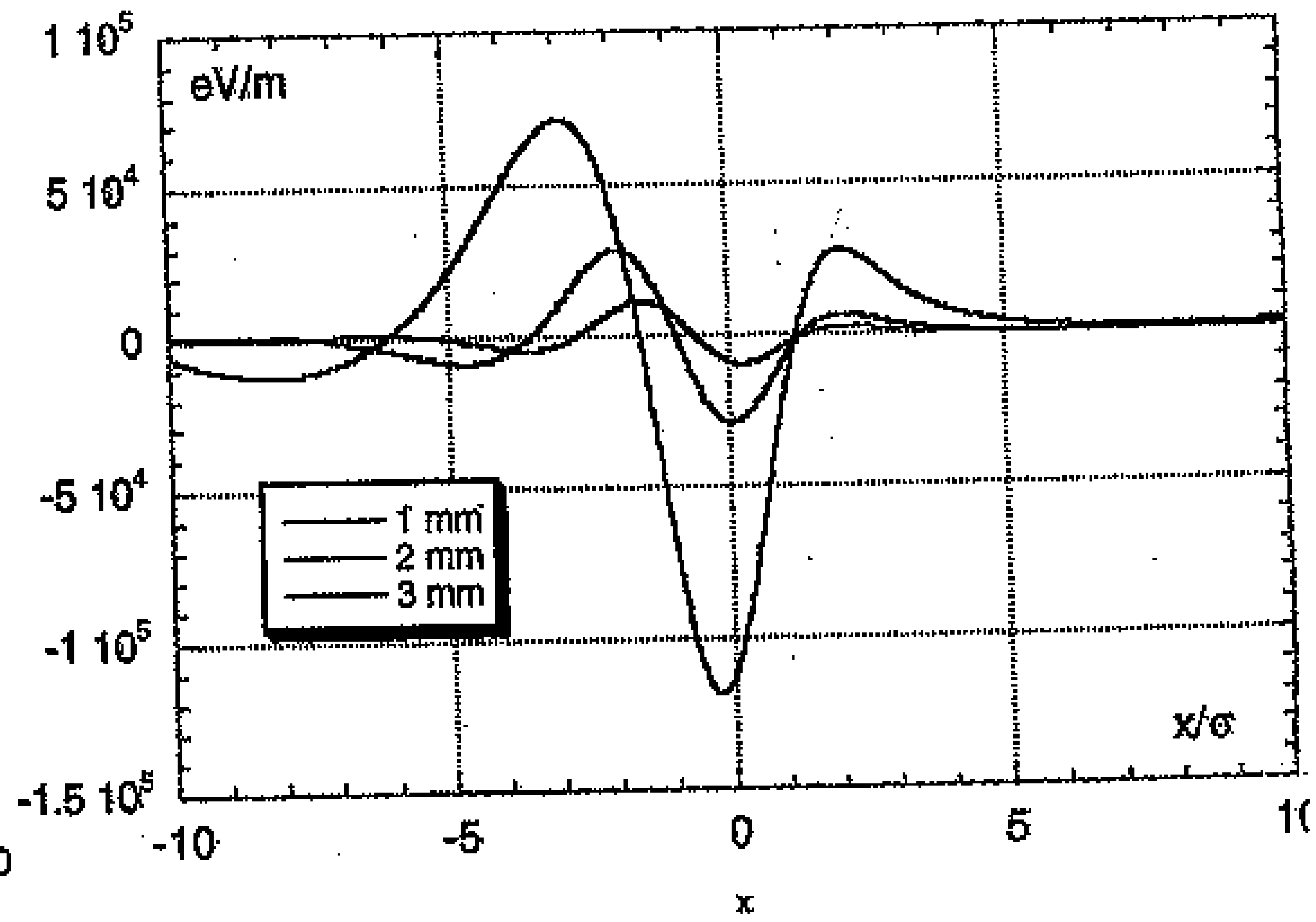
CSR in CTF3 COMPRESSOR RING MAGNETS

CSR IMPEDANCE (real part)

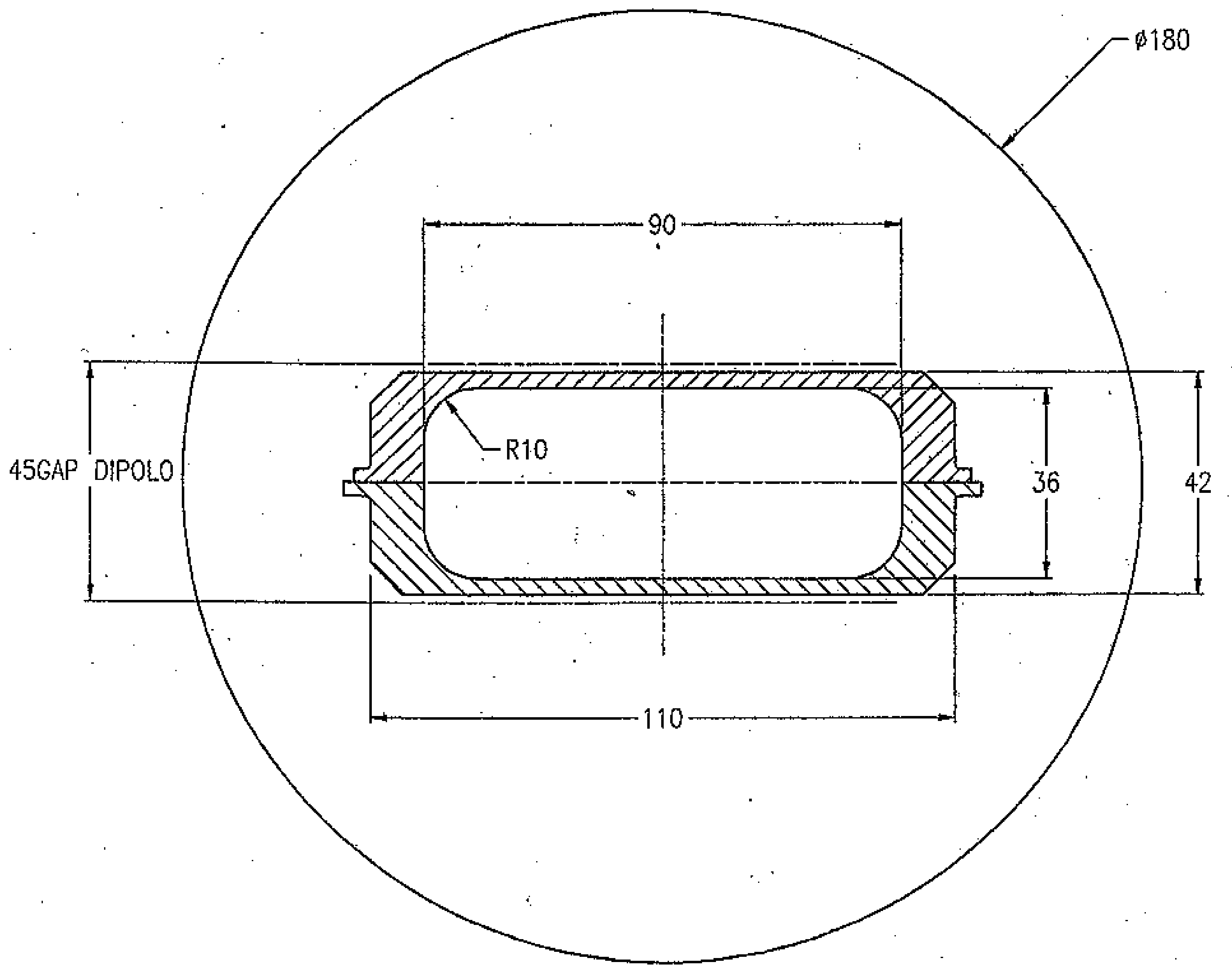


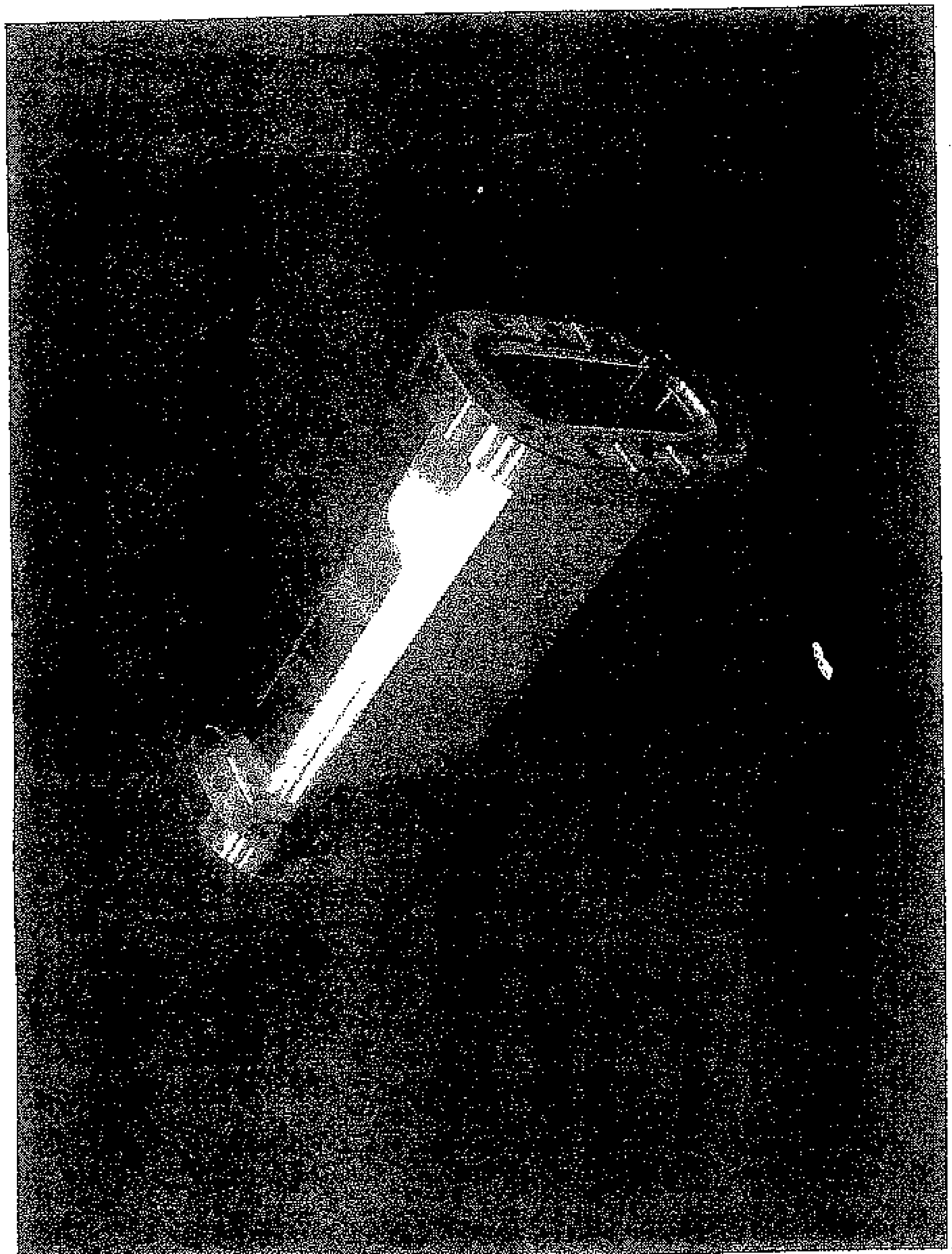
For EPA magnets incorporated in CTF3 compressor ring design and the vacuum chamber of 90x36 mm^2 the parallel plate approximation can be applied to estimate the energy loss and energy spread

CSR WAKE FORCE (for different bunch length)



For a bunch of 2 mm long with a charge 2.33 nC the energy spread due to CSR after 5 turns is contained within ±0.5% of the nominal ring energy





Orbit and trajectory correction

The correction procedure of the closed orbit and/or the trajectory in the combiner ring has been discussed only preliminarily.

Correcting the closed corrects also the trajectory when the combiner ring is used for the recombination. The trajectory in the first five turns oscillates around the corrected closed orbit with amplitudes determined by the injection offset.

Simulations : misalignments in the quadrupoles

$$\Delta x = 200\ \mu$$

$$\Delta y = 100\ \mu$$

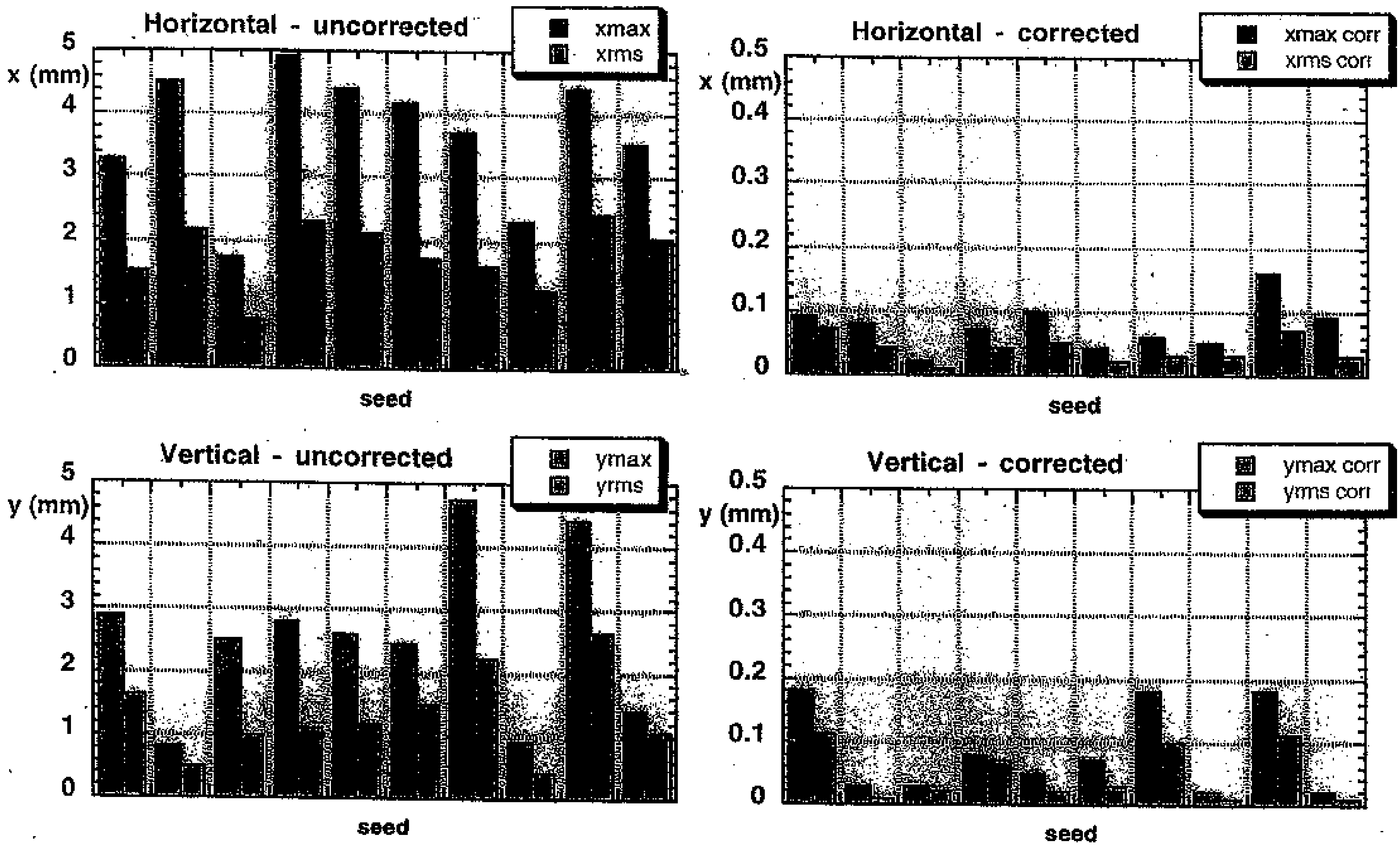
$$\Delta\theta = 0.02\ \text{mrad}$$

20 correctors and 20 monitors per plane

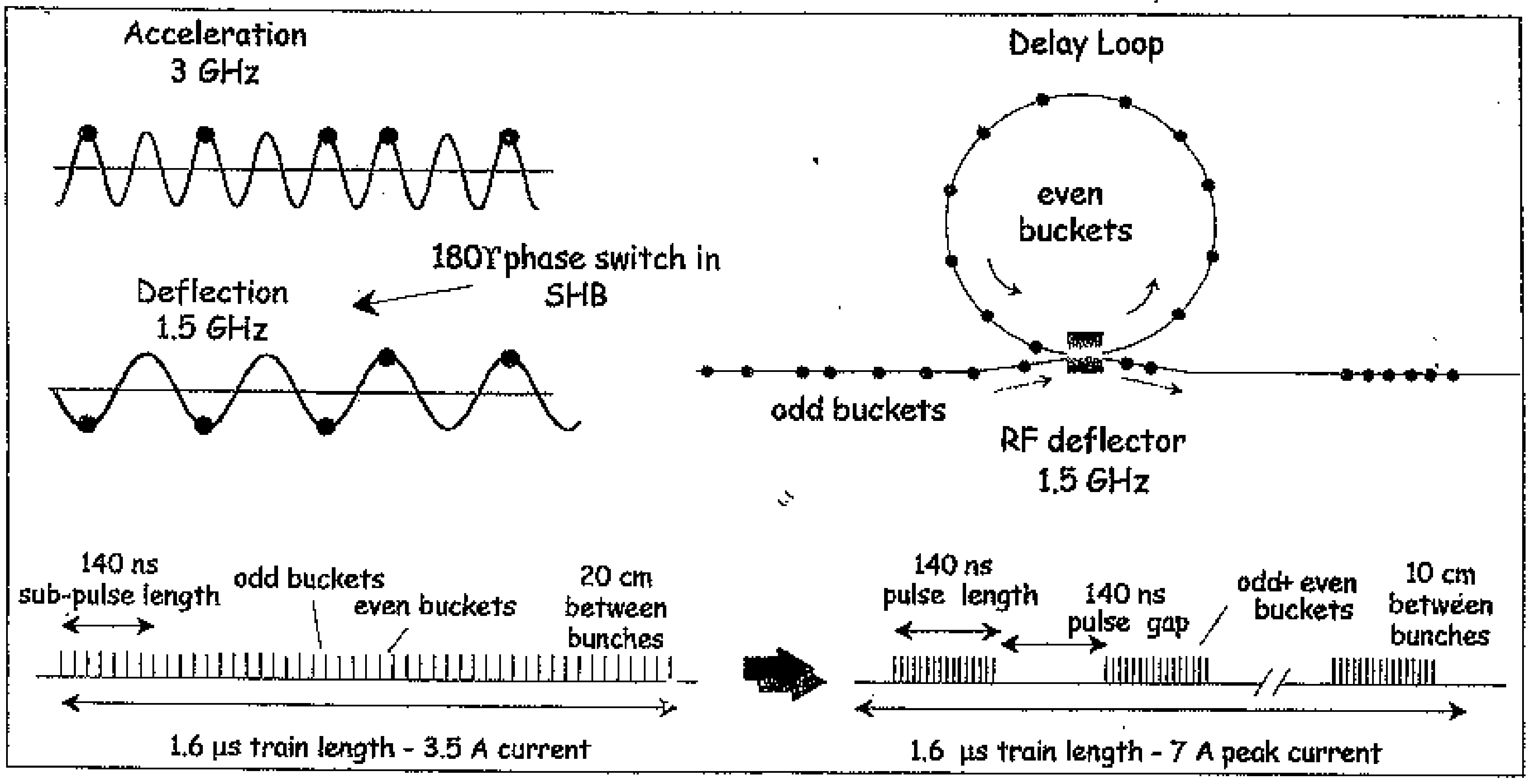
maximum corrector kick less than 1mrad

	before correction	after correction
x_{max} (mm)	3.8 ± 1.0	0.08 ± 0.04
x_{rms} (mm)	1.9 ± 0.5	0.04 ± 0.02
y_{max} (mm)	2.8 ± 1.3	0.11 ± 0.07
y_{rms} (mm)	1.5 ± 0.7	0.06 ± 0.04

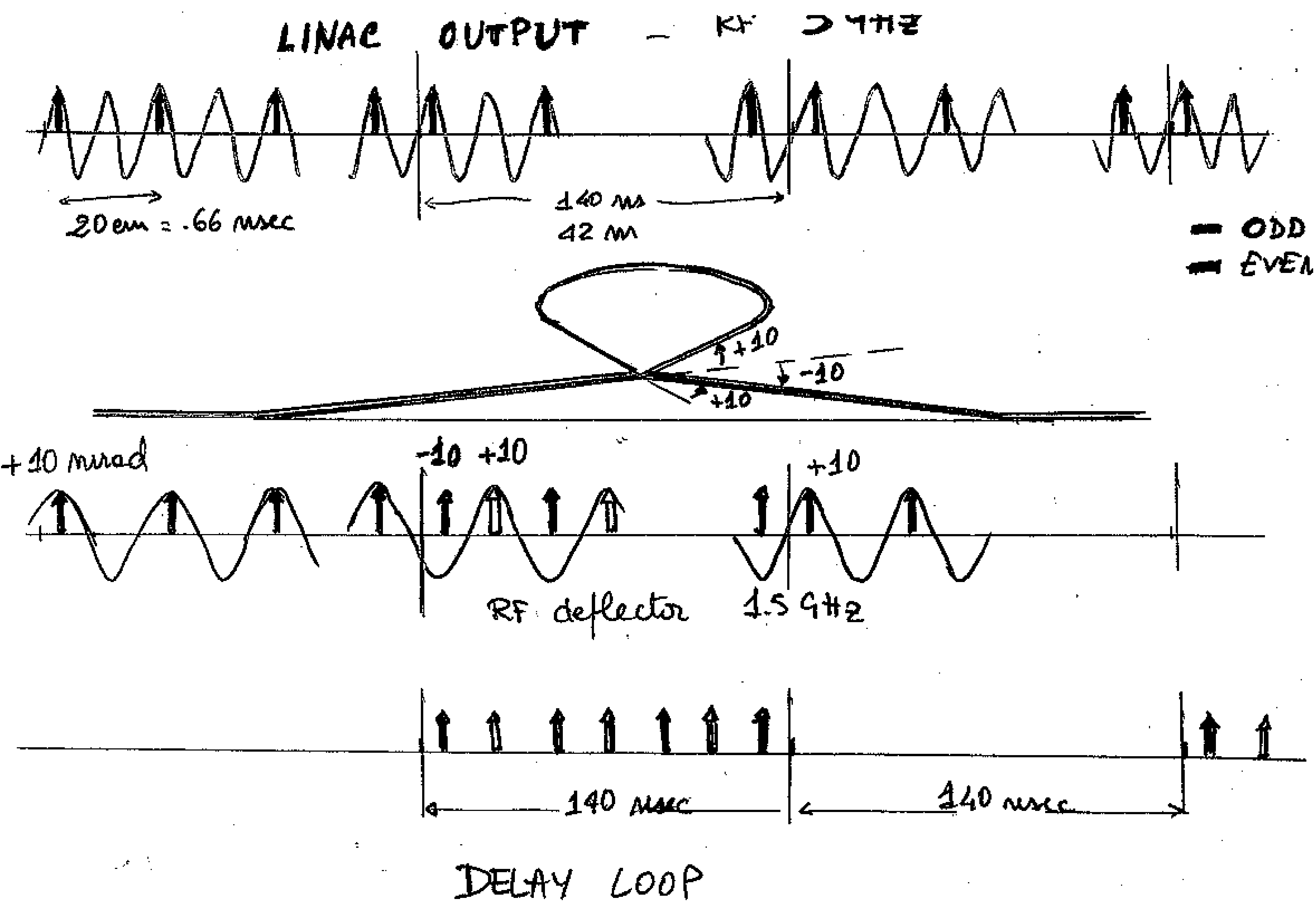
SIMULATION OF ORBIT/TRAJECTORY CORRECTION

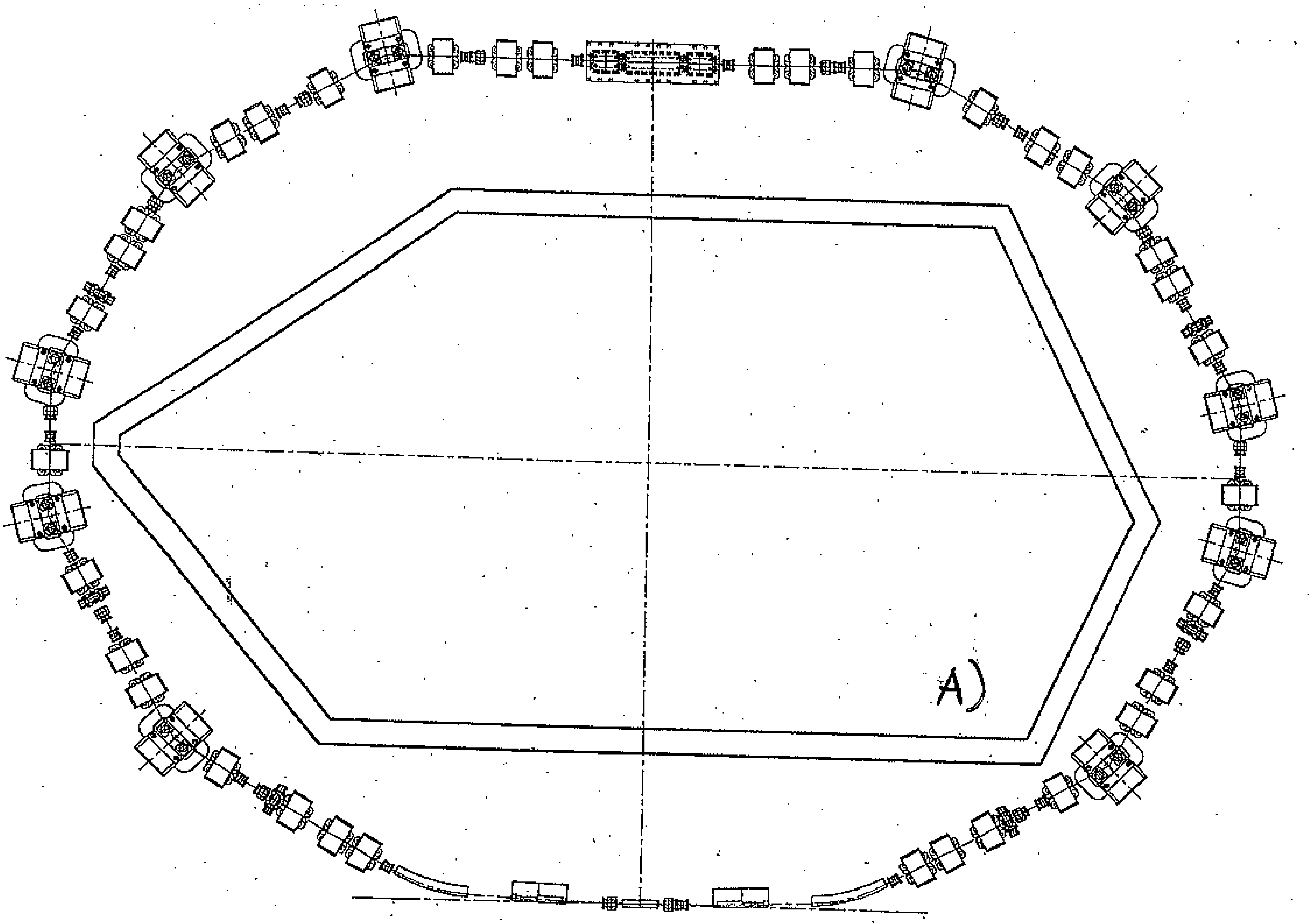


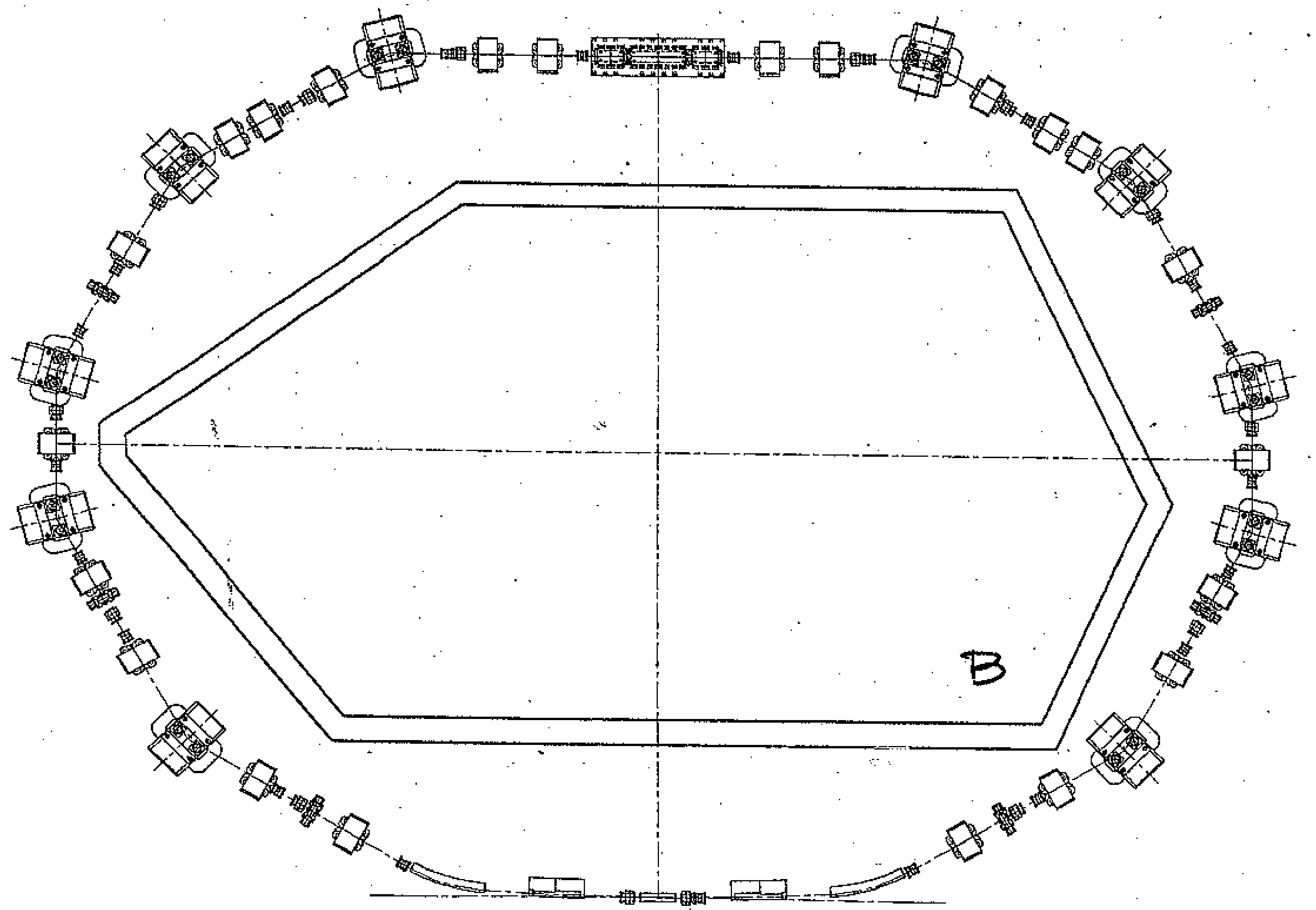
DELAY LOOP



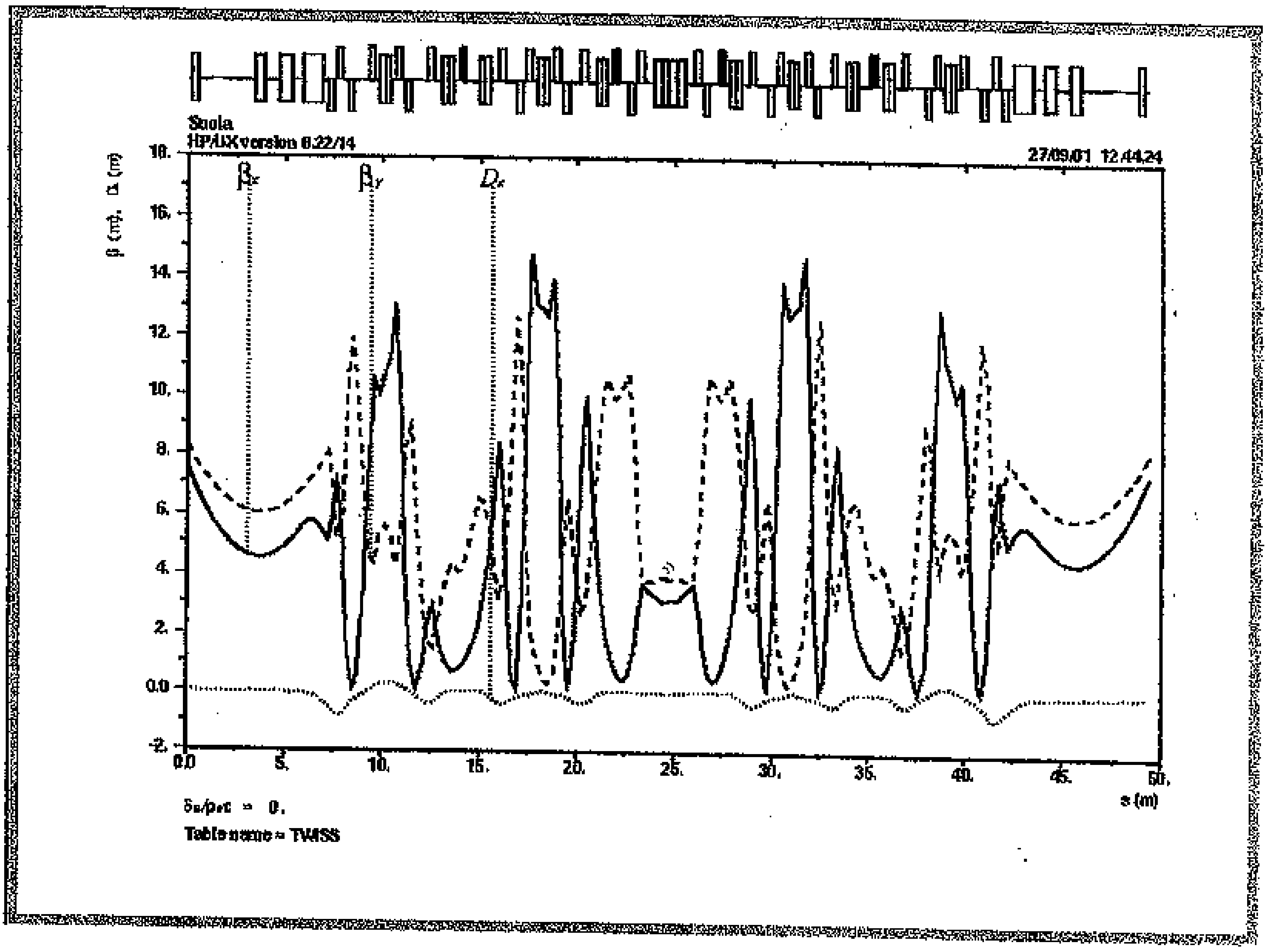
Principle of x2 bunch frequency multiplication in the DL



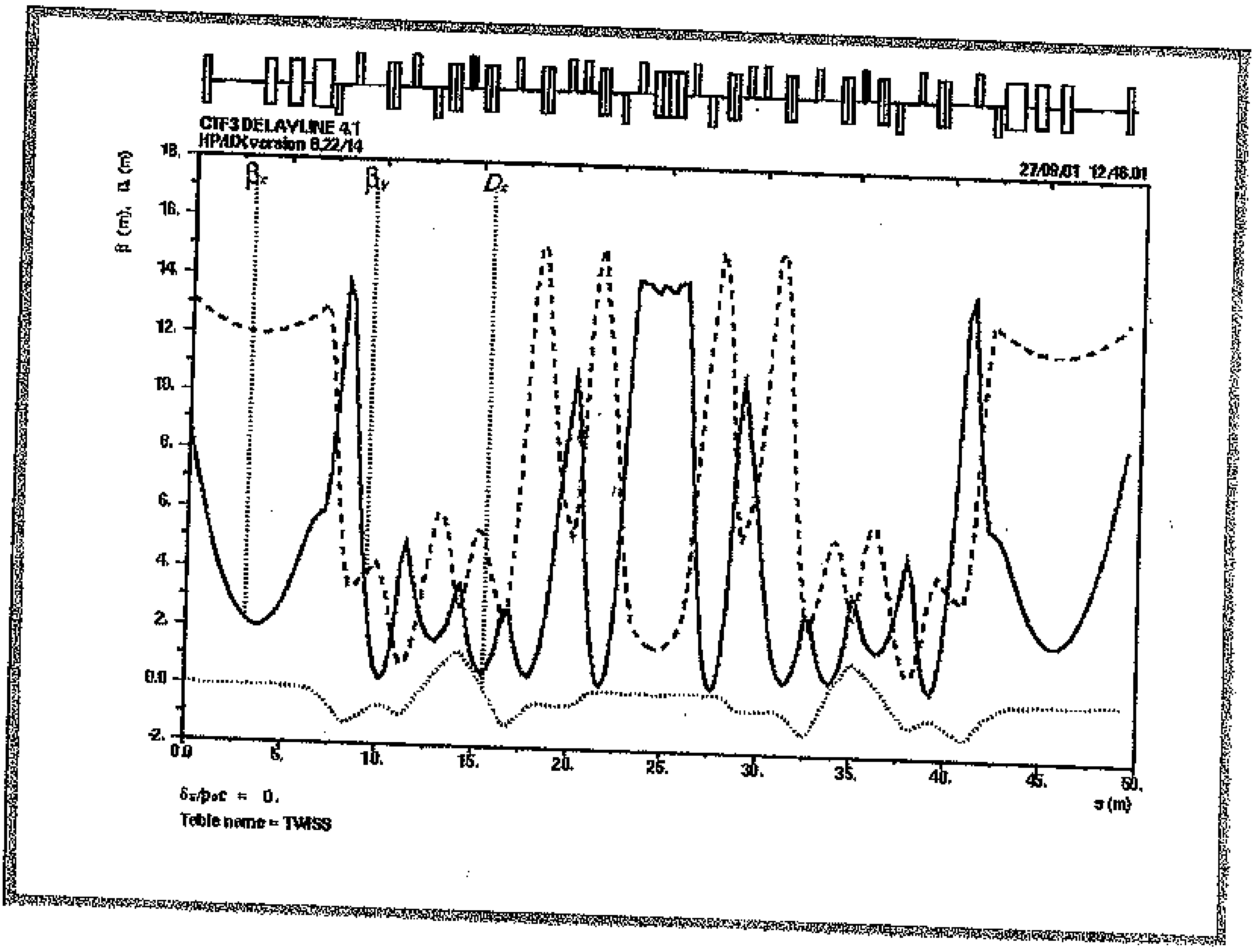

A)


B

Delay Loop Optical Functions – Solution A



Delay Loop Optical Functions – Solution B



Delay Loop Linear Lattice

$$ct = (ct)_0 + R_{56}\frac{\Delta p}{p}$$

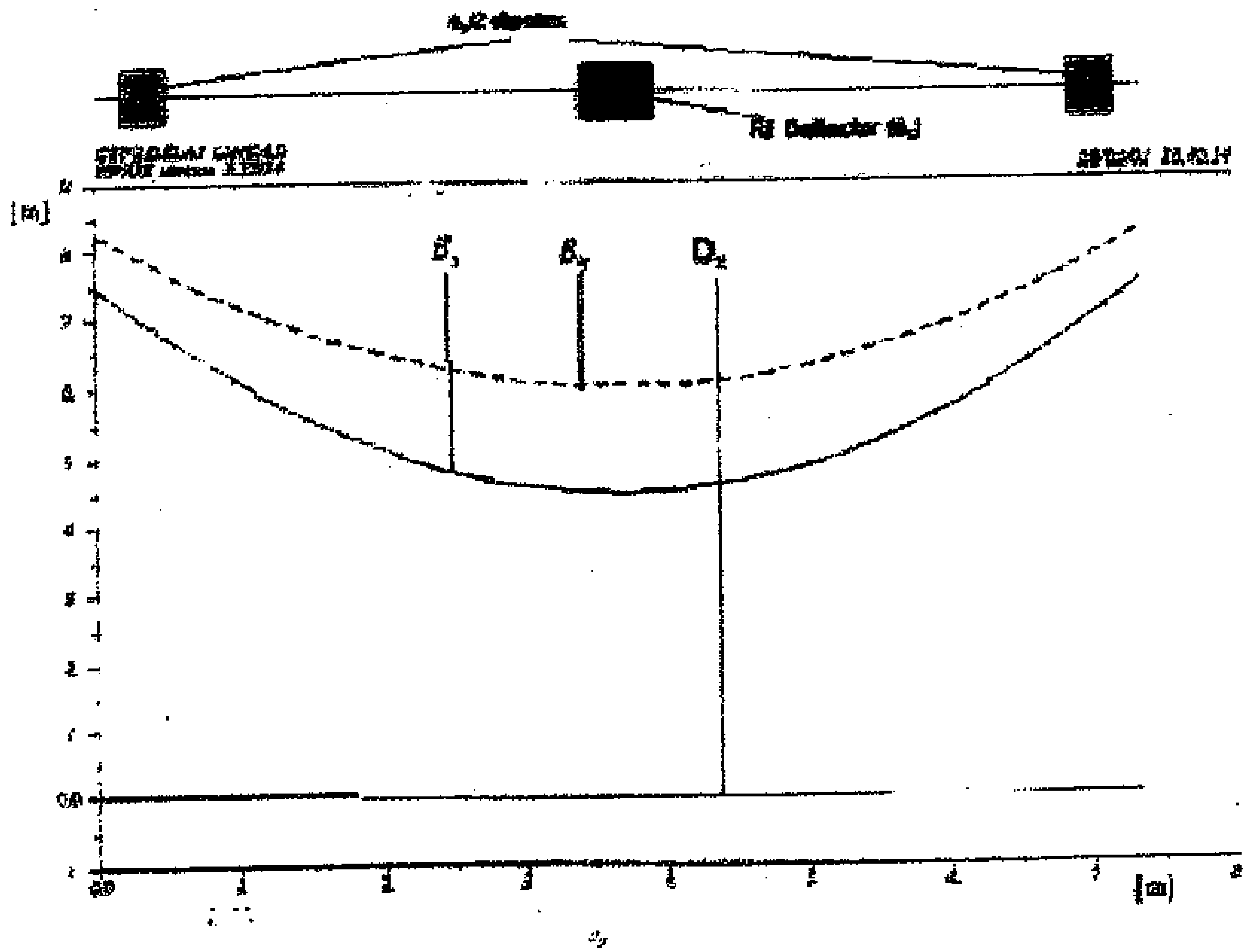
$$R_{56} = \int \frac{D_x}{\rho} ds = 0$$

$$|\alpha_p| \le 5 \cdot 10^{-4} \qquad |R_{56}| \le 2.1 \cdot 10^{-2}\ m$$

Main Parameters

	A)	B)
Max. Horizontal Beta [m]	14.8	11.5
Max. Vertical Beta [m]	12.7	14.5
Max. Dispersion [m]	0.85	1.3
Horizontal Betatron Tune	5.90	4.0
Vertical Betatron Tune	2.19	1.4
Horizontal chromaticity	-18.9	-6.4
Vertical chromaticity	-10.2	-8.6

Even Bunches Line Matching



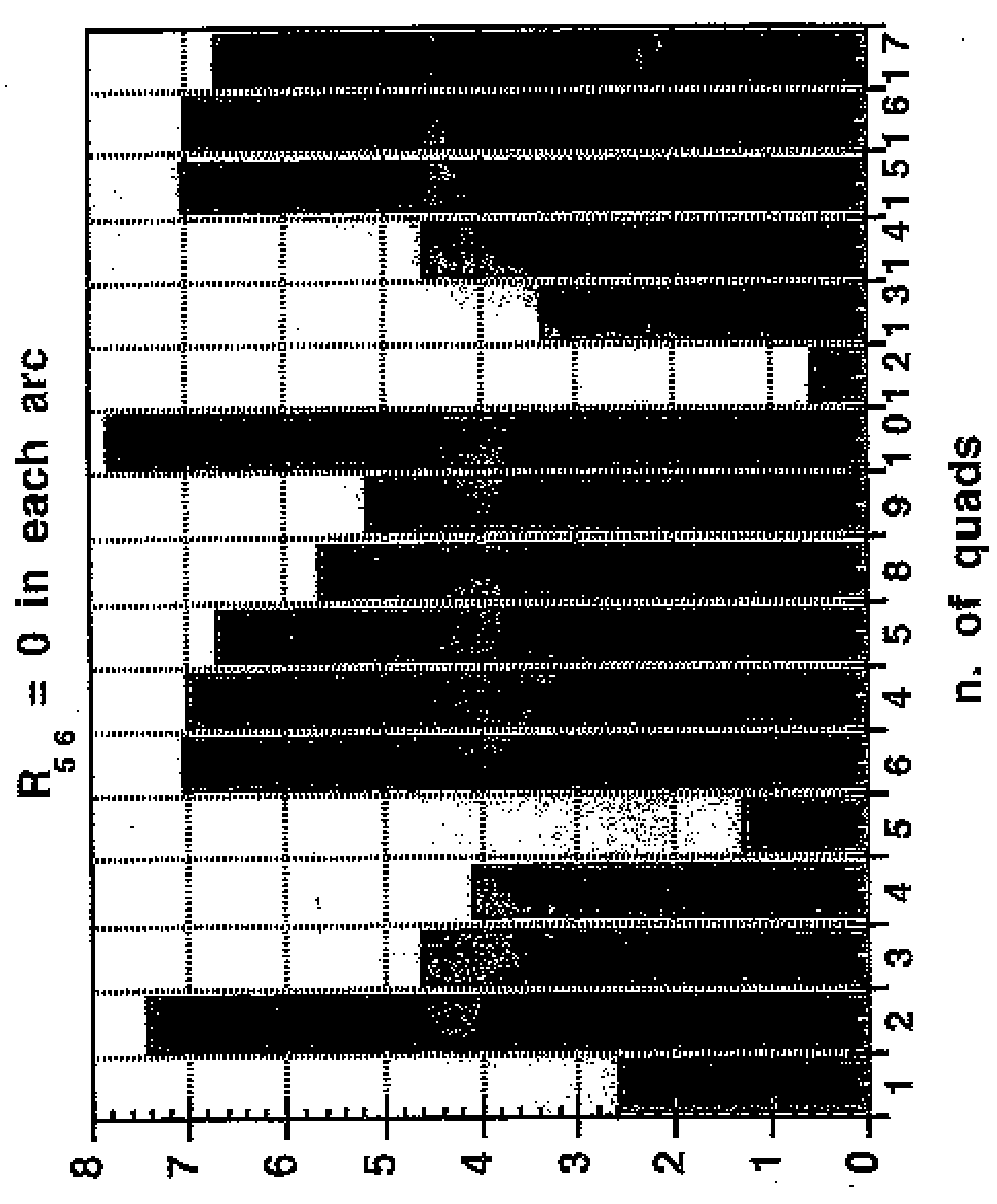
Even Bunches Line Optical Functions

Dispersion is self-matched and beta functions and derivatives present the same values of the ones see by the odd bunches at the end of the DL

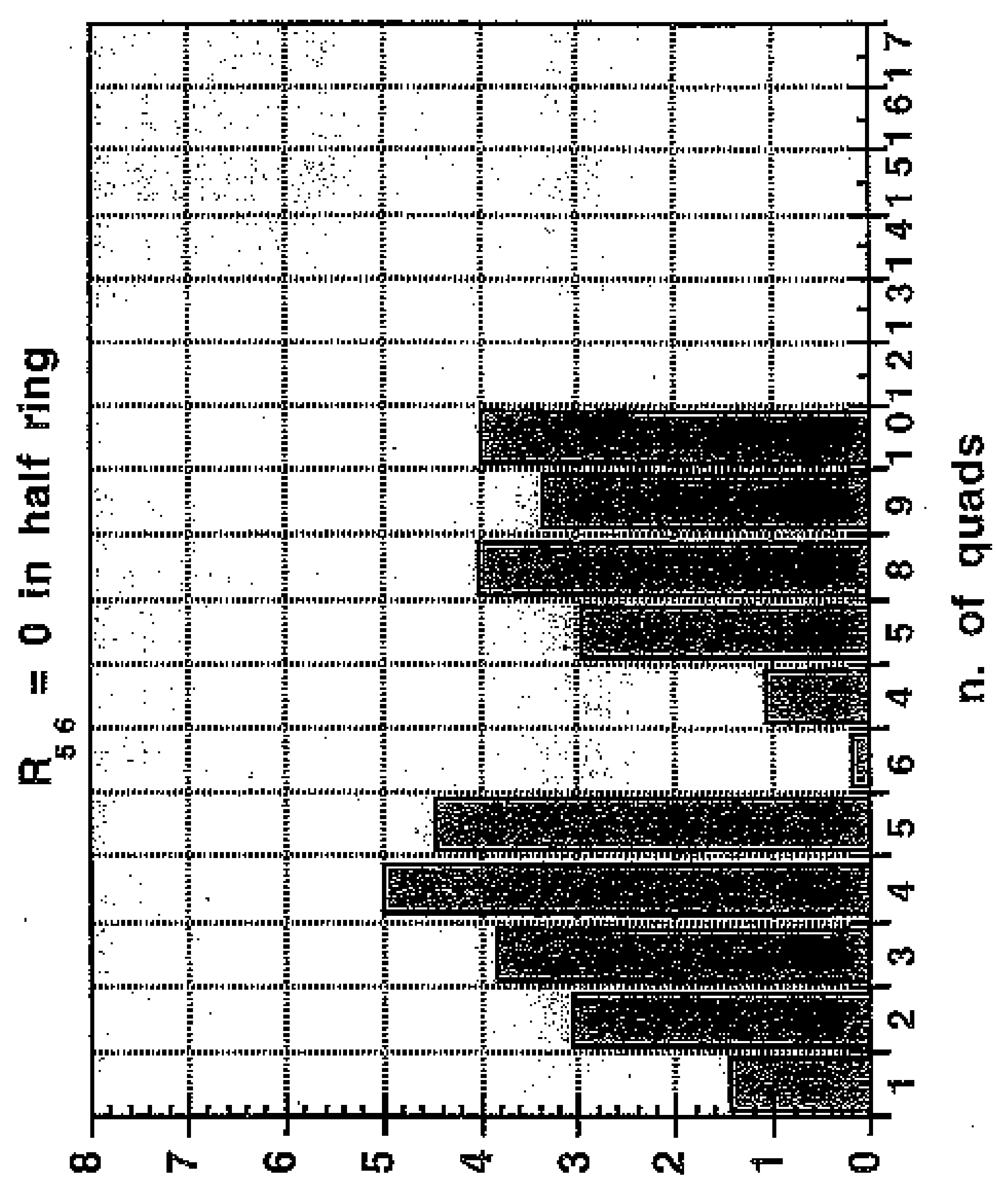
The Isochronicity condition is not completely fulfilled but the very small value of R_{56} at the line output (0.2 mm) does not require any particular care

Delay Loop Magnetic Elements

	A)	B)
A) Number of Dipoles (EPA-like)	10	10
Dipole Bending Radius [m]	1.079	1.079
Dipole Bending Angle [deg]	30	30
Dipole Field [T] (180/350 MeV)	0.60/1.1	0.60/1.1
Integrated Quadrupole Coeff. in Dipoles [T] (180/350 MeV)	0.2/0.4	0.2/0.4
B) Number of Quadrupoles (DAΦNE Accumulator-like)	34	22
Max. Integrated Gradient [T] (180/350 MeV)	1.4/2.7	0.9/1.3
Quadrupole Families (minimum/preferred)	14/18	11
C) Number of Sextupoles (DAΦNE Accumulator-like)	10	?
Max Integrated Gradient [T/m] (180/350 MeV)	11/22	?
Sextupole Families	5	?
D) Number of Path Length Tuning Wiggler	1	1
E) Number of 2° Septa (DAΦNE Accumulator-like)	2	2
F) Number of 27°.14 Septa (DAΦNE Accumulator-like)	2	2
G) Injection Dipoles Number	2	2
Injection Dipoles Bending Angle [mrad]	5	5



A



B

Second Order Isochronicity

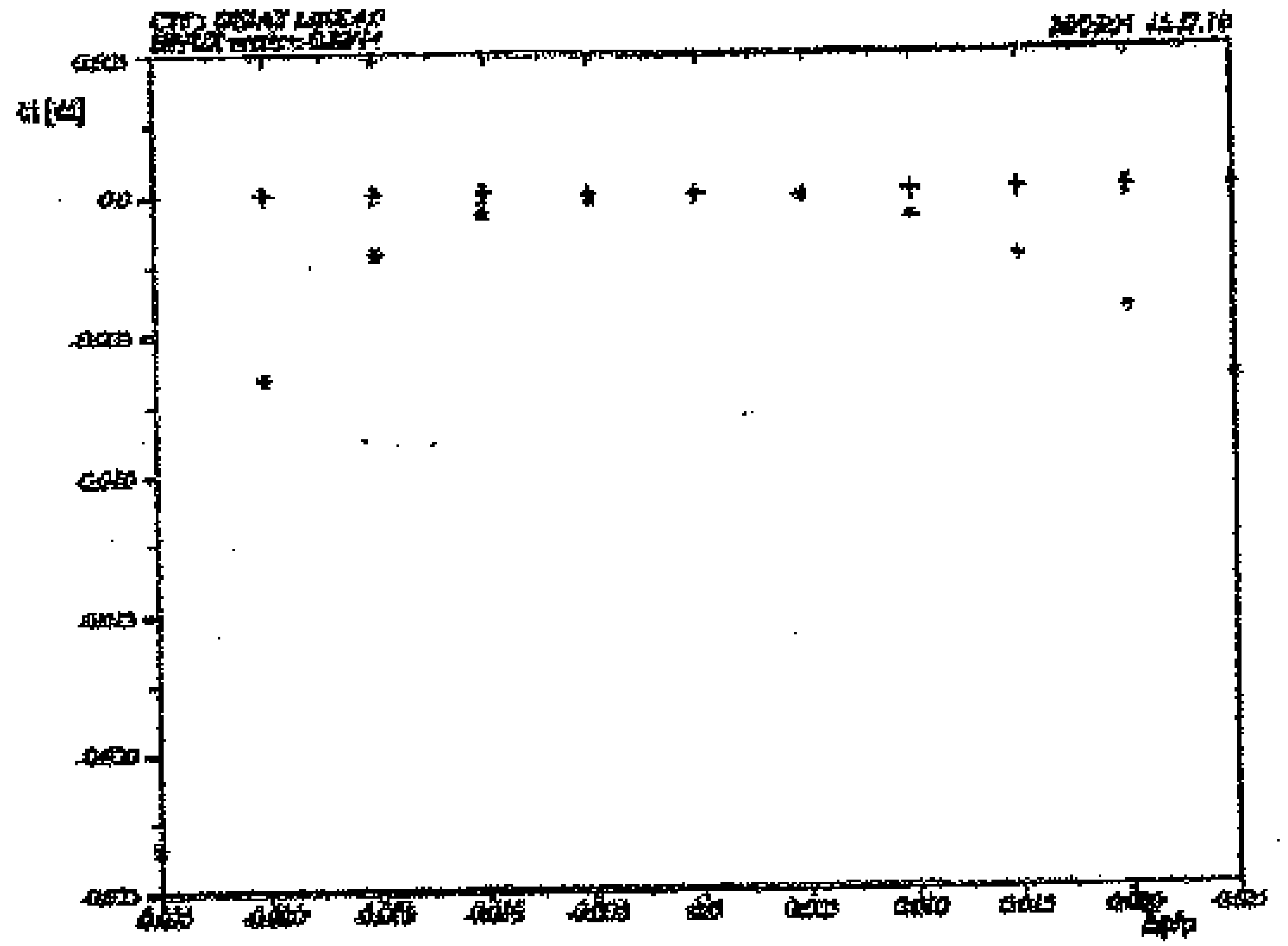
$$ct = (ct)_{0+} R_{56}\frac{\Delta p}{p} + T_{516}\ x_0\frac{\Delta p}{p} + T_{526}\ x_0'\frac{\Delta p}{p} + T_{536}\ y_0\frac{\Delta p}{p} + T_{546}\ y_0'\frac{\Delta p}{p} + T_{556}\ (ct)_0\frac{\Delta p}{p} + T_{566}\left(\frac{\Delta p}{p}\right)^2$$

T_{ijk} elements of the second order transfer matrix

Isochronicity is achieved when:

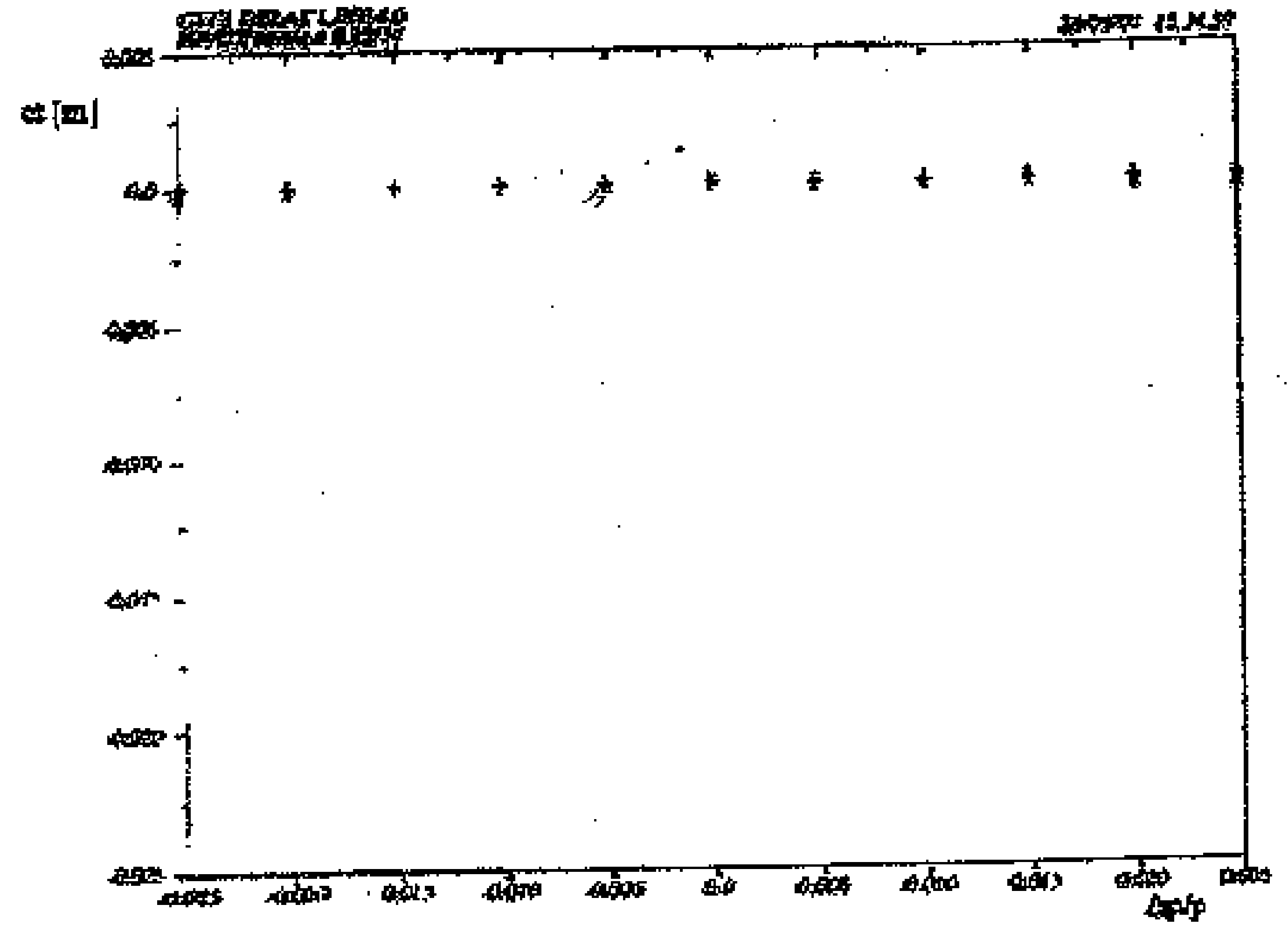
$$T_{5i6} = 0 \qquad \forall\ i$$

⇨ Need of strong focusing sextupoles



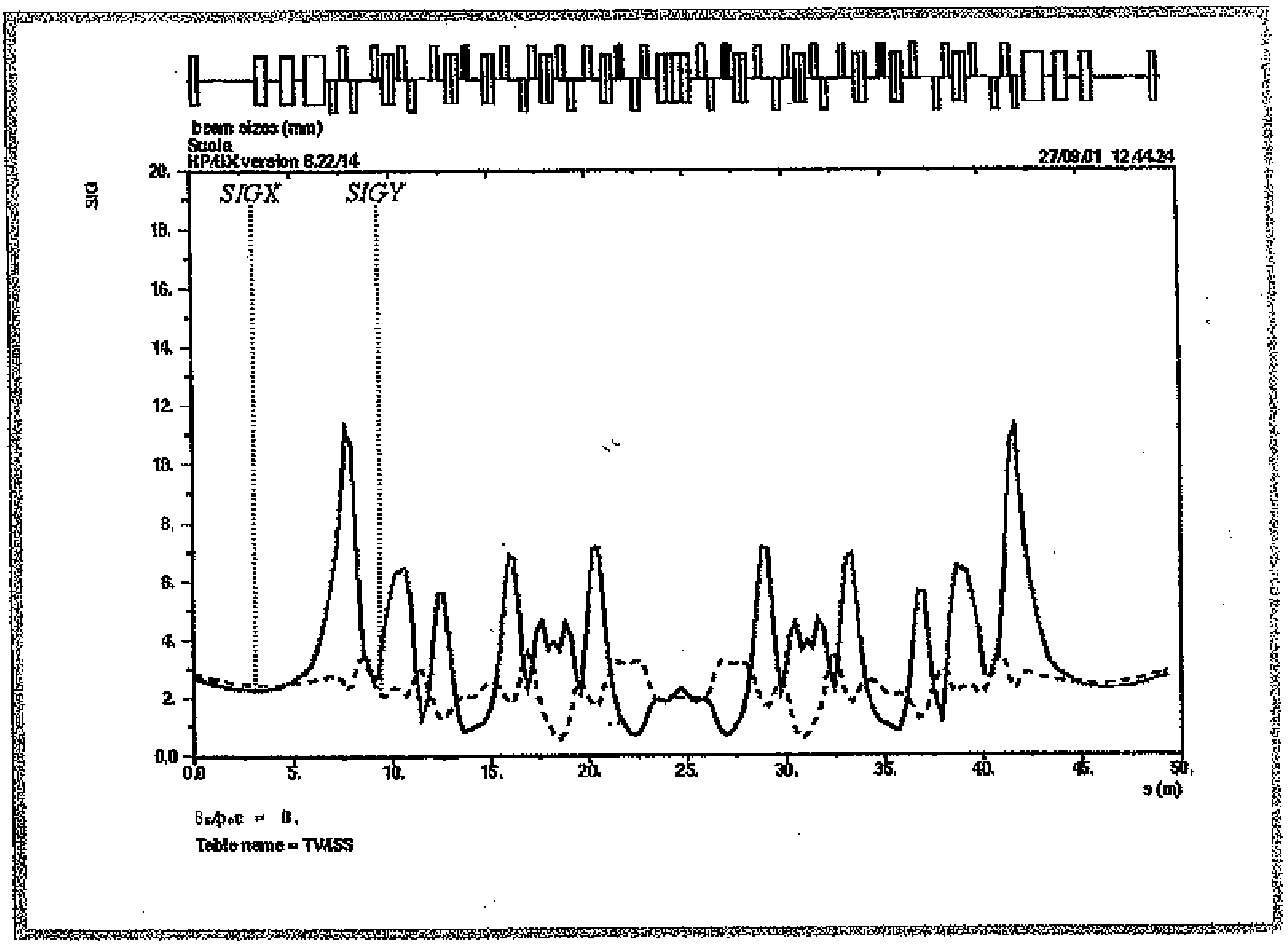
Off-energy Particles Longitudinal Position at DL Input (Crosses) and Output (Dots)

First Order Correction

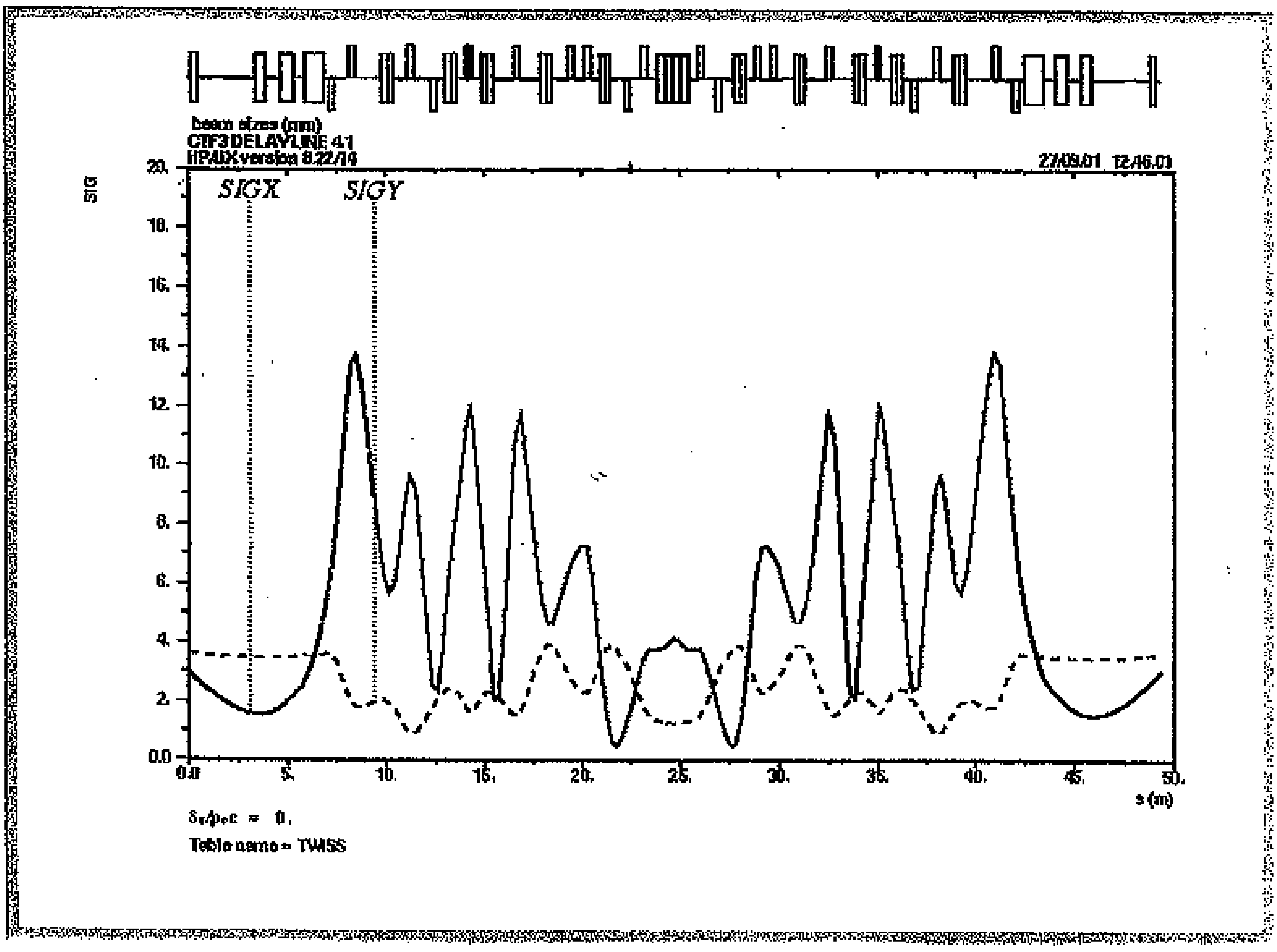


Second Order Correction

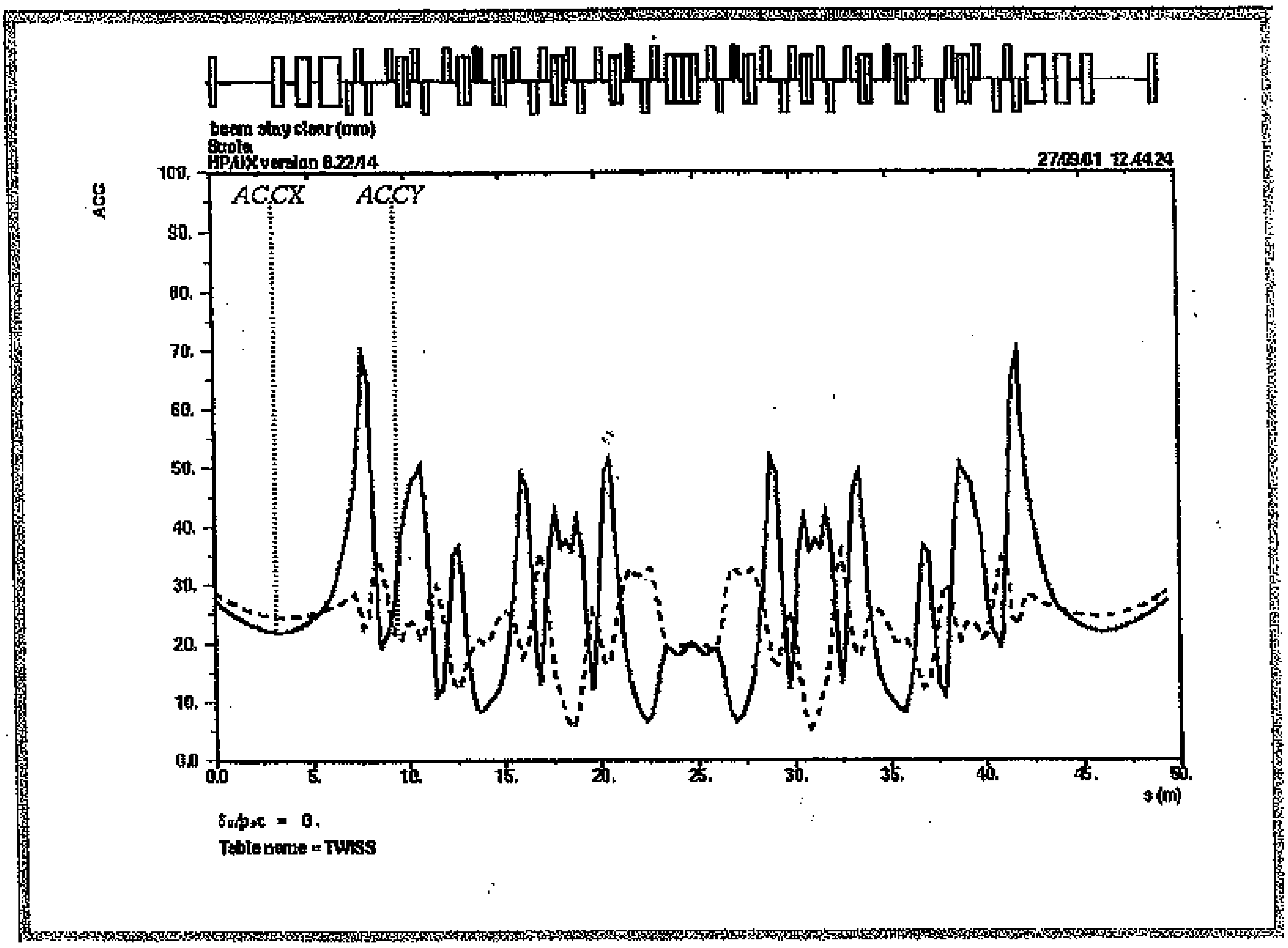
Delay Loop Beam sizes – Solution A



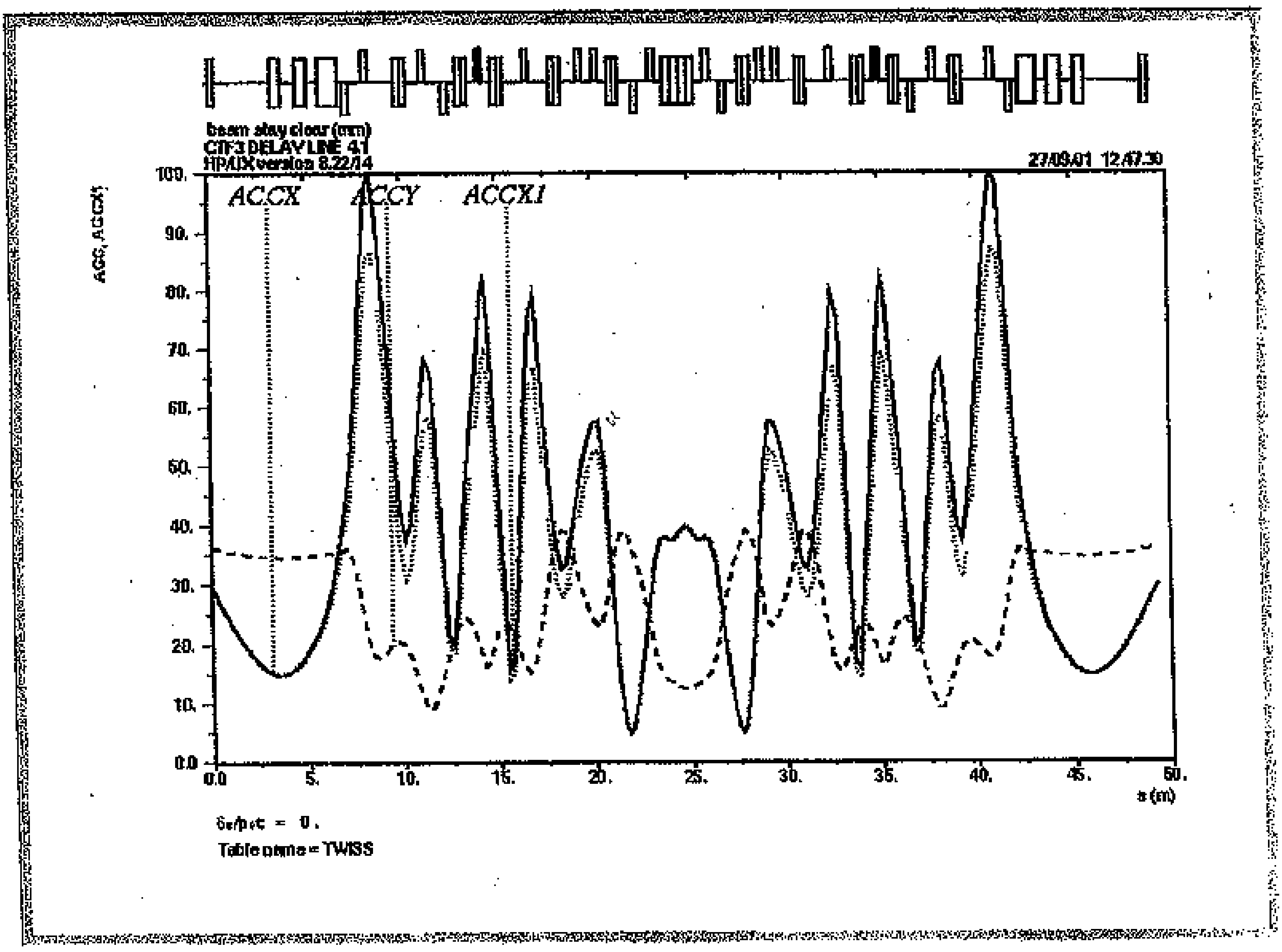
Delay Loop Beam sizes – Solution B



Delay Loop Beam Stay Clear – Solution A



Delay Loop Beam Stay Clear – Solution B



Work in progress

- Six-dimension particle tracking
- Definition of corrector dimensions + positioning of the monitors + analysis of other kind of errors (dipole misalignments, dipole and quadrupole field errors, monitor errors,...) + trajectory correction in the combiner ring without the option of storing the beam
- Solution B for the Delay Loop
- Storage ring option for the Combiner Ring

Combiner ring => Storage ring

Storing a beam would allow **DC measurements of orbit and betatron functions (machine modelling)**, although the lattice for beam storing has to be modified with respect to the nominal one since it cannot be isochronous.

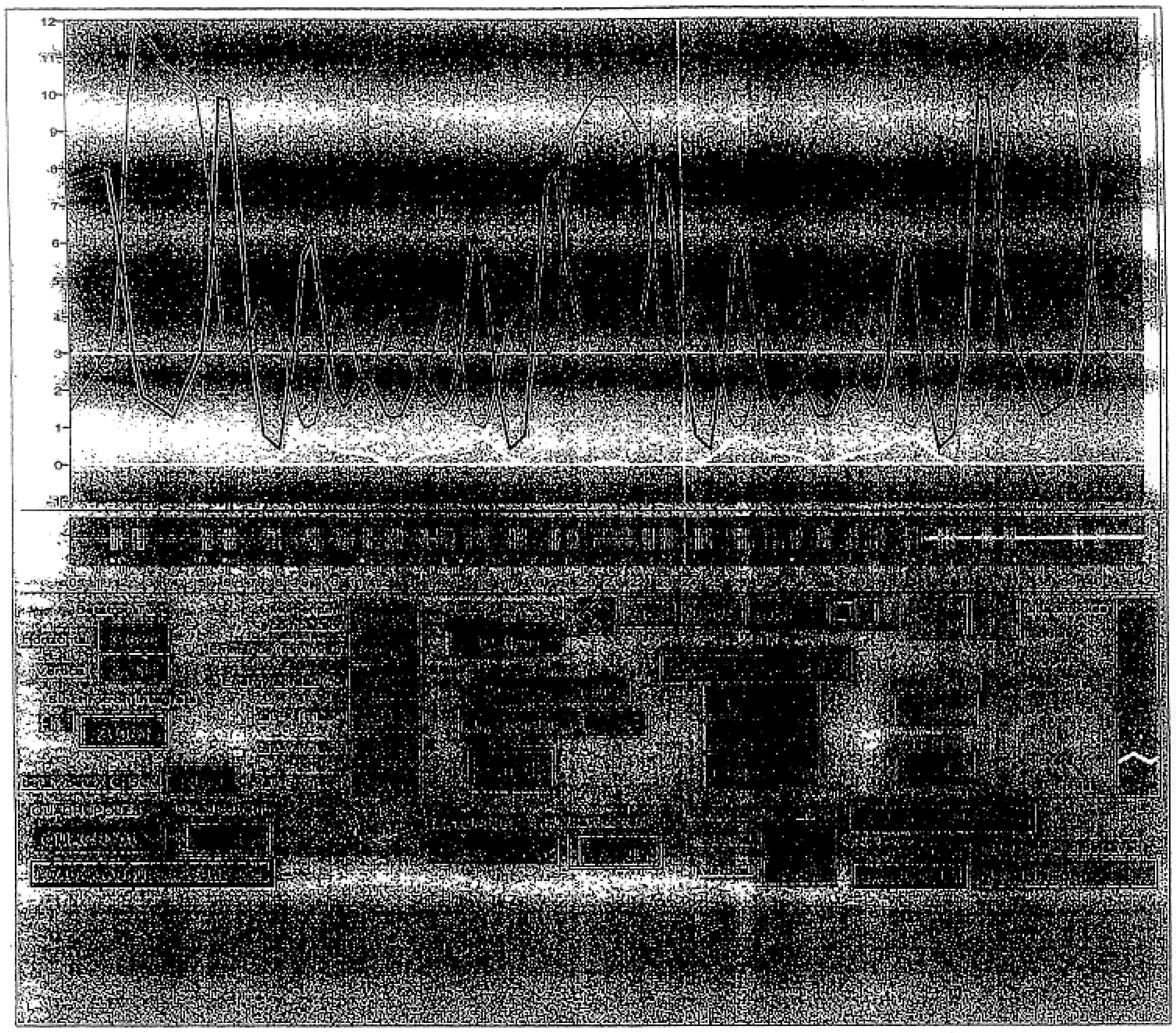
The RF system design is based on a **single-cell cavity** already available at LNF. In order to contain cost and complexity of the system, a moderate gradient is foreseen, obtainable with a simple (and cheap) RF power source (such as solid state amplifier).

It can be installed in the extraction region, symmetric to the extraction kicker.

RF System

Parameter	Symbol	Value
Frequency	f_0	**356.8 MHz**
Harmonic number	h	**100**
Voltage	V_{RF}	**≈ 70 kV**
Shunt impedance	R_S	**≈ 2.5 MΩ**
RF power	P_{RF}	**≈ 1 kW**
Beam current (s.b.)	I_b	**≈ 3.5 mA**

MainRingFunctions.vi
/u1/dafne/offLineTools/MainRingFunctions.vi
Last modified on 09/27/2001 at 04:40 PM
Printed on 10/01/2001 at 02:50 PM



$E = 350$ MeV

$\alpha_c = 0.0025$

$\frac{\Delta E}{E} = 2.9\ 10^{-4}$

$\varepsilon = 5.3\ 10^{-9}$ m.rad

$\sigma_L = 4$ mm

$V_{Loss} < 40$ keV

$\tau_T \approx 100$ sec

(10% coupling)

~1 nC (3.5 mA

MainRingFunctions.vi
/u1/dafne/offLineTools/MainRingFunctions.vi
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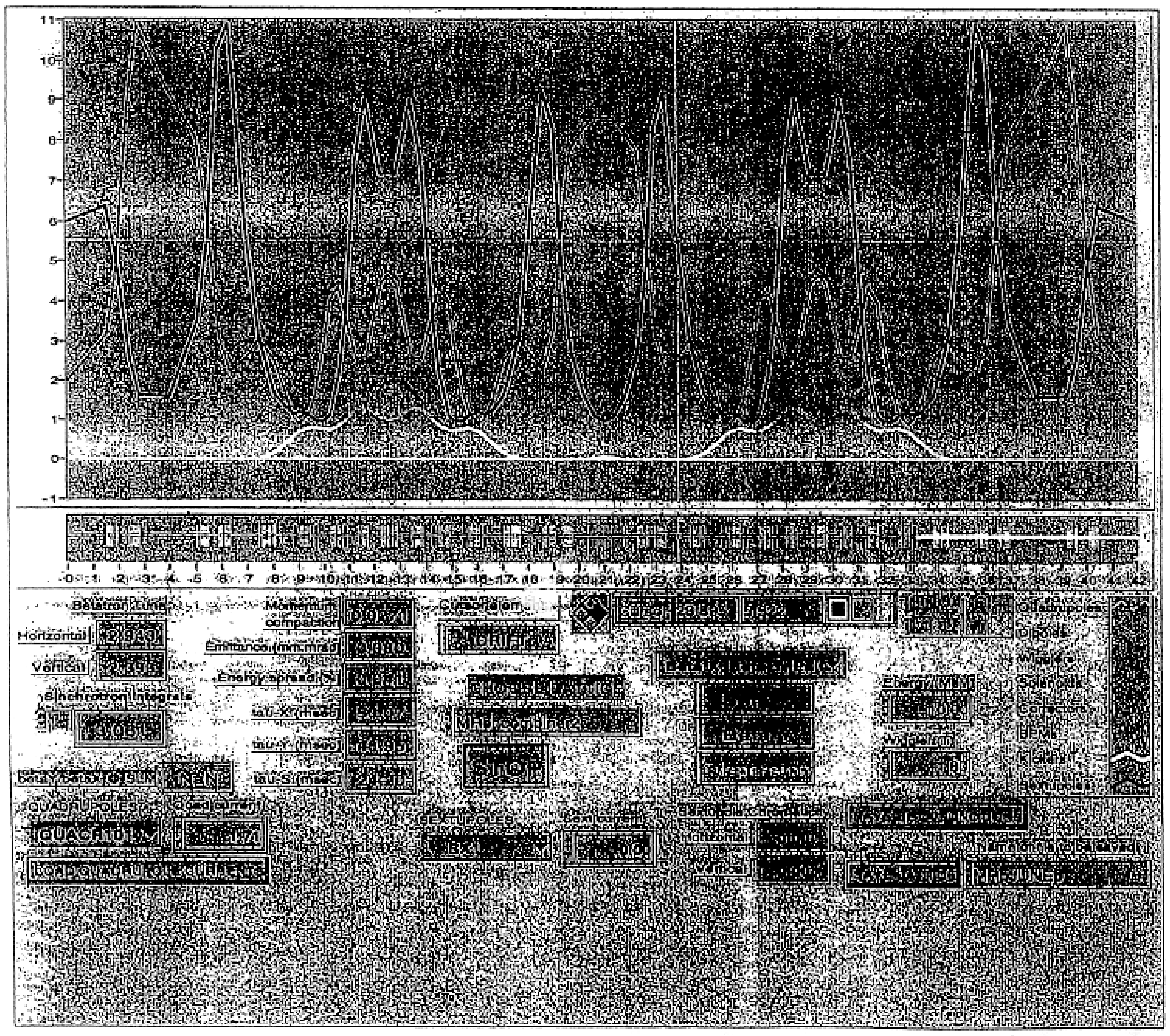

$E = 350$ MeV

$\alpha_c = 0.027$

$\frac{\Delta E}{E} = 2.9\ 10^{-4}$

$\varepsilon = 3.8\ 10^{-8}$ m.rad

$\sigma_L = 12$ mm

$V_{Loss} < 17$ keV

$\tau_T \approx 1000$ sec

(10% coupling)

High momentum compaction lattice

Parameter	Symbol	Value
Energy	E	350 MeV
Momentum compaction	α_c	$2.7\ 10^{-2}$
Energy spread	σ_E/E	$2.9\ 10^{-4}$
Emittance	ε	$3.8\ 10^{-8}$ m rad
Bunch length	σ_z	12 mm
Beam losses (@$q_b \approx 1$ nC)	V_{loss}	< 17 keV
Touschek lifetime	τ_T	≈ 1000 s

Low momentum compaction lattice

Parameter	Symbol	Value
Energy	E	350 MeV
Momentum compaction	α_c	$2.5\ 10^{-3}$
Energy spread	σ_E/E	$2.9\ 10^{-4}$
Emittance	ε	$5.3\ 10^{-9}$ m rad
Bunch length	σ_z	4 mm
Beam losses (@$q_b \approx 1$ nC)	V_{loss}	< 40 keV
Touschek lifetime	τ_T	≈ 100 s