TS/LI' Note 94-55 1 (Min)

CLIC BEAM DYNAMICS MEETING No 2

Chairman: G. Guignard
Secretary: A. Riche

Minutes of the CLIC Beam Dynamics Meeting hold on Thursday, November 17th, 14.h

Subjects:

ALTERNATE DESIGN FOR ISOCHRONOUS ARCS	T.E. D' AMICO
DRIVE BEAM WITH MAXIMUM TRANSFER EFFICIENCY: LONGITUDINAL AND TRANSVERSE DYNAMICS: PROPOSAL FOR THE FOCUSING	J.A. RICHE

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G. Guignard	SL	W. Remmer	PS
A. Mikhailichenko	PS	W. Schnell	SL
G. Parisi	SL	L. Thorndahl	SL
J.P. Potier	PS	I. Wilson	SL
J.A. Riche	PS		
L. Rinolfi	PS		

Next meeting forseen on Thursday 8 December
Tentative agenda :
Non dispersive bumps in the main linac G. Parisi
Corrections of geometric aberrations in an isochronous ring B. Autin

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T.E. D'AMICO 17-11.94

ALTERNATE DESIGN OF ISOCHRONOUS ARCS

1. AIMS

To find an insertion that can be used as a building block for the many arcs of the main injection system that requires isochronicity to preserve bunch length while at the same time minimising the growth of the normalised horizontal emittance due to synchrotron radiation.

2. APPROACH

Analytical study of an isochronous insertion consisting of a minimum number of deflecting magnets. To provide expressions for the parameters of such insertions in order to simplify the design of isochronous insertions satisfying special constraints such as minimisation of the emittance growth, arc's length, phase advance etc.

3. NORMALISED HORIZONTAL EMITTANCE GROWTH

$$\Delta\gamma\varepsilon_x[m_*rad] \approx 4_*10^{-8} E^6[GeV] I_5[m^{-1}]$$

$$I_5 = \sum_i \frac{l_i}{|\rho_i|^3}\langle H\rangle_i$$

where $l_i, \rho_i, \langle H\rangle_i$ are respectively for the i-th magnetic segment, the length, the radius of curvature and the mean value of

$$H = \frac{1}{\beta_x}\left[D_x^2 + \left(\beta_x D_x' - \frac{1}{2}\beta_x' D_x\right)^2\right]$$

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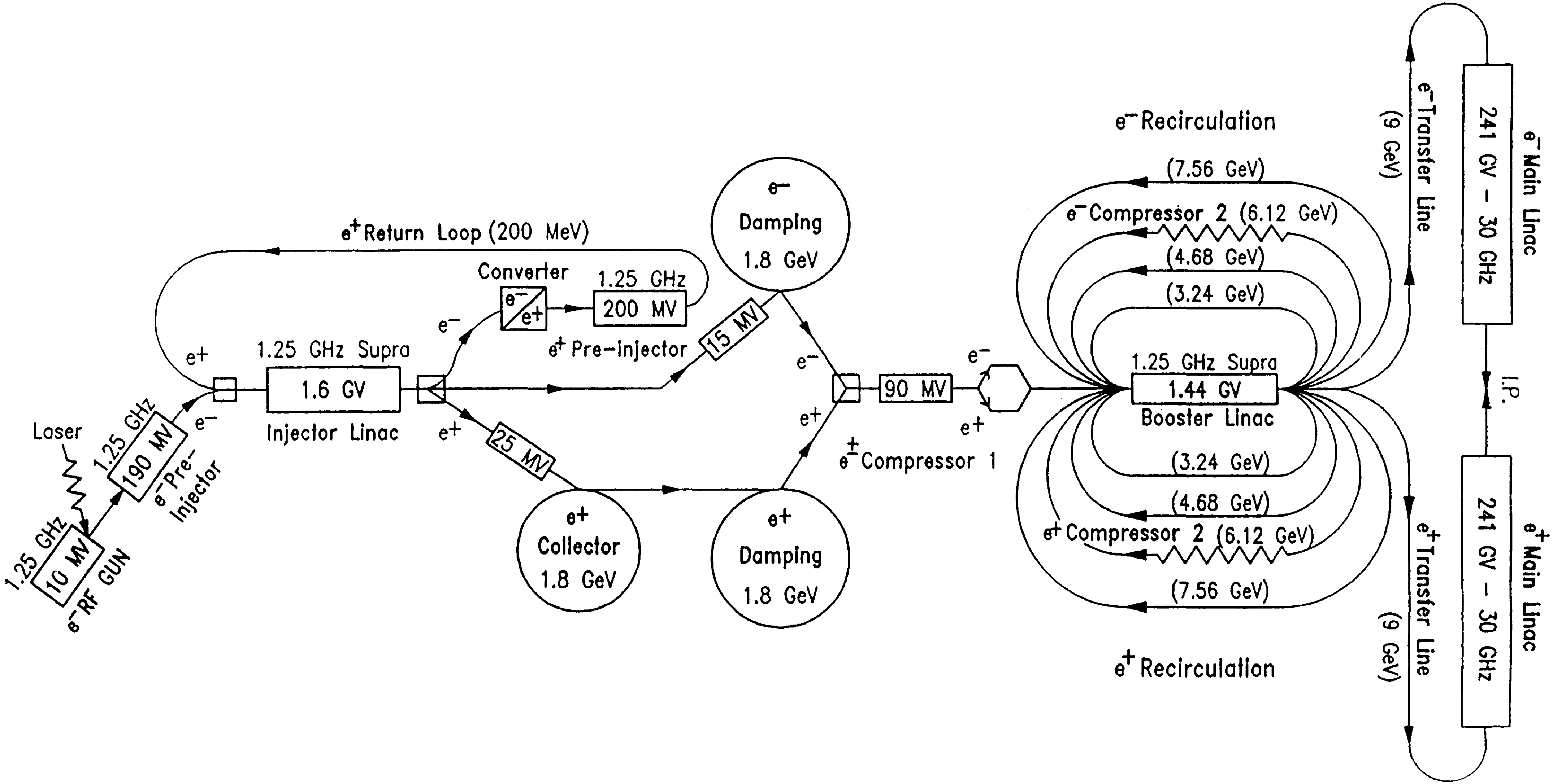


INJECTOR COMPLEX FOR THE e^+ and e^- CLIC MAIN BEAMS

ISOCHRONICITY

2. **MINIMUM NUMBER OF DEFLECTING MAGNETS IN AN ISOCHRONOUS INSERTION**
   K. G. Steffen in his book "High Energy Beam Optics" proved that the minimum number is three.
   Choice of sector magnets and symmetry about the middle plane of the central deflecting magnet to simplify the problem.

3. **FIRST ORDER ISOCHRONICITY CONDITION**

$$\int_0^{s1} D/\rho \; ds = 0$$

the integral extending to half insertion because of the symmetry. The dispersion and its derivative are supposed to be zero at the entrance of the insertion. When this condition is satisfied the insertion is of course also nondispersive.

LAYOUT OF THE INSERTION

1. PERIODICITY CONSTRAINT

The derivatives of the beta function at both ends of the insertion are of opposite sign for symmetry reasons. Unfortunately it will be shown later that it is practically impossible to impose that they are zero in both planes. To link together several insertions in order to build the desired arc, it is necessary to add a matching insertion.

2. SCHEMATICS OF HALF ISOCHRONE INSERTION

Thus the isochrone insertion consists of two insertions:

a) half matching section obtained with two quadrupoles, one defocusing and the other focusing.

b) half bending section also consisting of two quadrupoles, one focusing and one defocusing framed by two deflecting magnets, the second having half the length of the first.

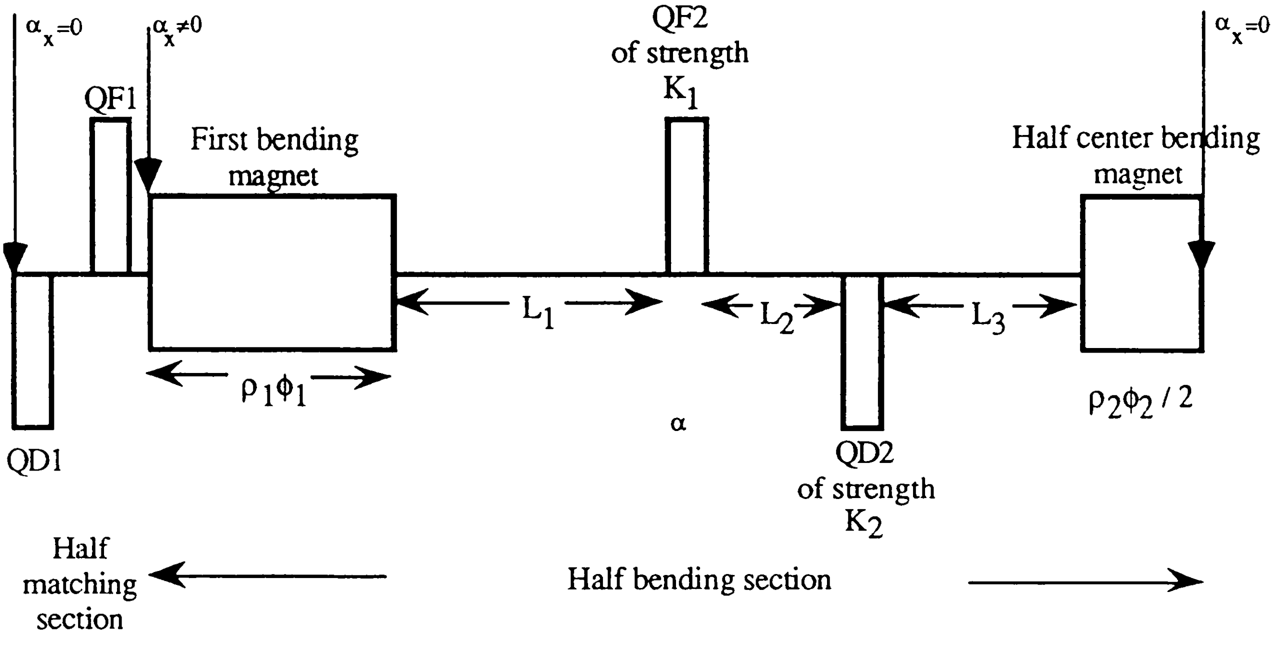


Fig 1

Half isochrone insertion

THE DISPERSION AND ITS DERIVATIVE AT THE ENTRANCE OF THE SECOND DEFLECTING MAGNET

1. **Notation**

   Following K. G. Steffen, the dispersion and its derivative at the entrance of the second deflecting magnet are called D_j and D'_j respectively

2. **Isochronicity condition**

$$\rho_1(\phi_1 - \sin\phi_1) +$$
$$D_j \sin(\phi_2/2) - \rho_2 D'_j[\cos(\phi_2/2) - 1] + \rho_2[\phi_2/2 - \sin(\phi_2/2)] = 0$$

3. **Symmetry condition**

The derivative of the dispersion in the centre of the second magnet should be zero, that is:

$$-\frac{\sin(\phi_2/2)}{\rho_2} D_j + \cos(\phi_2/2) D'_j + \sin(\phi_2/2) = 0$$

4. **Expressions for D_j and D'_j**

   Assuming that the deflecting magnets have the same length $(\rho_1\phi_1 = \rho_2\phi_2)$:

$$D'_j = -\frac{\rho_1}{\rho_2}(\frac{3}{2}\phi_1 - \sin\phi_1)$$

$$D_j = \rho_2[D'_j ctn(\phi_2/2) + 1]$$

EXPRESSIONS FOR THE DRIFT SPACES L_1, L_2, L_3

1. Notations

$$C = \cos(\phi_1) \quad , \quad S = \sin(\phi_1)$$
$$C_1 = \cos(L_q\sqrt{k_1}) \quad , \quad S_1 = \sin(L_q\sqrt{k_1})$$
$$C_2 = \cosh(L_q\sqrt{k_2}) \quad , \quad S_2 = \sinh(L_q\sqrt{k_2})$$
$$q_1 = \frac{C_1}{S_1\sqrt{k_1}} \quad \text{and} \quad q_2 = \frac{C_2}{S_2\sqrt{k_2}}$$
$$a = \frac{SC_1}{-D_j'C_2q_1}\left[\rho_1\frac{1-C}{S} - q_1\right]$$
$$b = -q_2\left(1 - \frac{1}{C_2}\frac{q_1\frac{S}{D_j'C_1} - q_2\frac{1}{C_2}}{(q_1 - q_2)}\right)$$

2. L_1, L_2, L_3

$$L_1 = -\frac{D_j'C_2q_1}{SC_1q_2}\left[\Delta L_3 - q_2(a-1)\right]$$
$$L_2 = (q_1 - q_2)\frac{\Delta L_3 - b}{q_2 + \Delta L_3}$$
$$L_3 = D_j/D_j' + \Delta L_3$$

where ΔL_3 is a free parameter on the longitudinal position of the defocusing quadrupole which can be adjusted to obtain the required isochronous insertion which best meet the required constraints on such parameters as normalised emittance growth, arc radius, maximum dispersion, maximum beta function values or total phase advance.

CONSTRAINTS ON ΔL_3 FOR L_1, L_2, L_3 TO BE POSITIVE

	$a > 0$ i.e. $q_1 < \rho_1 \frac{1-C}{S}$	$a < 0$ i.e. $q_1 > \rho_1 \frac{1-C}{S}$
$\frac{D_j}{D'_j} < q_2 < q_1$		$\Delta L_3 > -\frac{D_j}{D'_j}$
$q_2 < q_1$ and $q_2 < \frac{D_j}{D'_j}$		$\Delta L_3 > -q_2$
$q_2 > q_1$ and $-q_2 < -\frac{D_j}{D'_j} < \text{b}$		$-\frac{D_j}{D'_j} < \Delta L_3 < b$
$q_2 > q_1$ and $-\frac{D_j}{D'_j} < -q_2$		$-q_2 < \Delta L_3 < b$
$q_2 < q_1$ and $q_2(a-1) < -\frac{D_j}{D'_j}$	$\Delta L_3 > -\frac{D_j}{D'_j}$	
$q_2 < q_1$ and $q_2(a-1) > -\frac{D_j}{D'_j}$	$\Delta L_3 > q_2(a-1)$	

$q_2 > q_1$ and $q_2(a-1) < -\frac{D_j}{D'_j} < b$ for $a \le \frac{1}{C_2^2}$ or for $a > \frac{1}{C_2^2}$ with $q_1 < q_2$	$-\frac{D_j}{D'_j} < \Delta L_3 < b$	
$q_2 > q_1$ and $q_2(a-1) > -\frac{D_j}{D'_j}$ for $a \le \frac{1}{C_2^2}$ or for $a > \frac{1}{C_2^2}$ with $q_1 < q_2$	$q_2(a-1) < \Delta L_3 < b$	

DESIGN OF AN ISOCHRONOUS INSERTION

A simple interactive program written in the Microsoft Spreadsheet application Excel gives the possibility of exploring the behaviour of the insertions obtained by different values of the following parameters :

1) **Total deflecting angle of the arc.**
2) **Ratio between the radii of curvature of the first to the second deflecting magnets.**
3) **Gradient of the focusing quadrupole.**
4) **Focusing strength k_2 of the defocusing quadrupole.**
5) ΔL_3

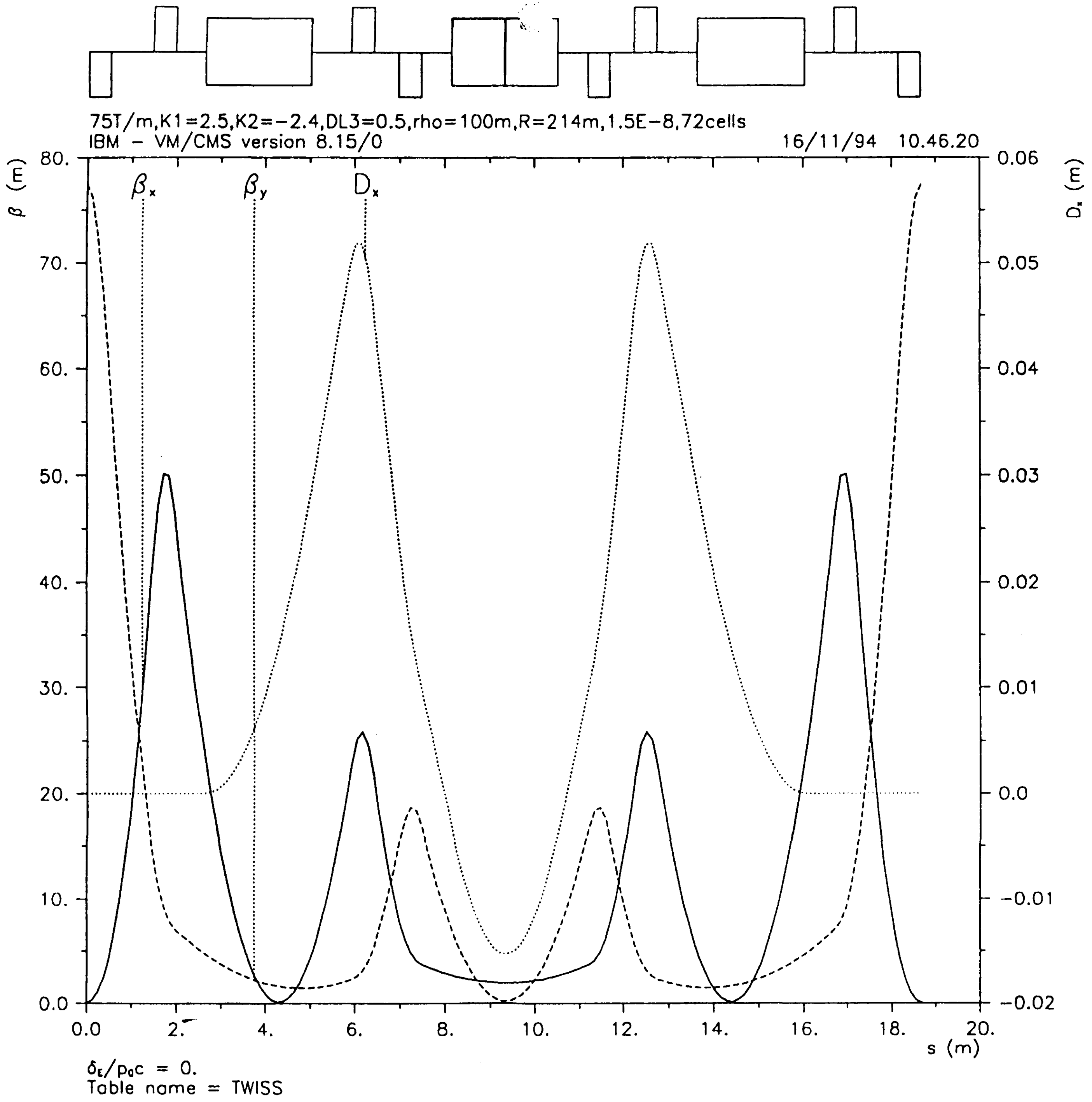
Taking advantage of the insertion symmetry, the program can easily compute the minimum value of the alpha function and the corresponding beta function at the entrance of the first bending magnet:

$$\alpha_0 = 2\sqrt{a_{12}a_{21}(1+a_{12}a_{21})}$$

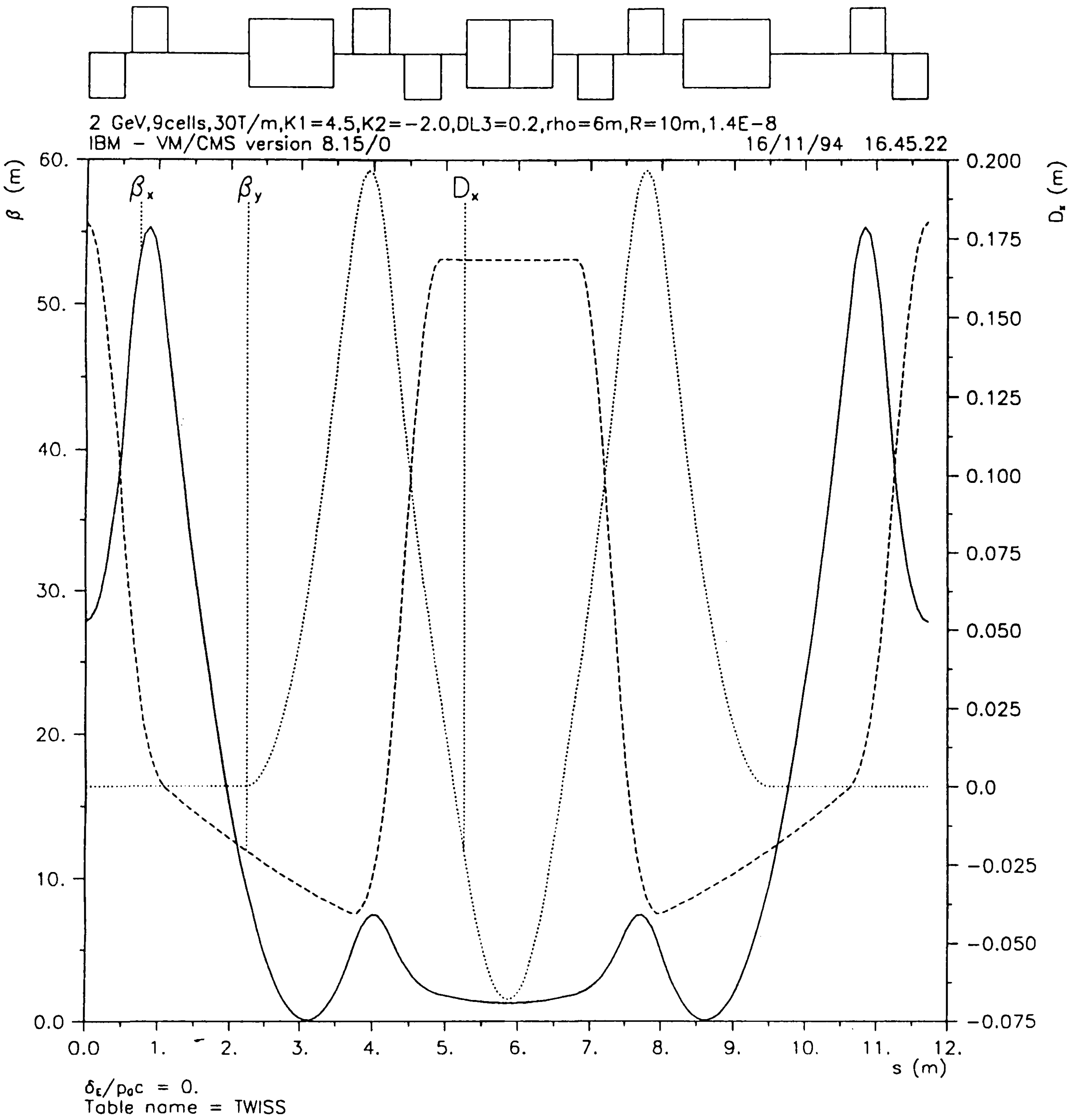
$$\beta_0 = \frac{(1+2a_{12}a_{21})\sqrt{a_{12}a_{21}(1+a_{12}a_{21})}}{a_{11}a_{21}}$$

where a_{11}, a_{12}, a_{21} are the elements of the transfer matrix for half the bending section which are easily obtained in the Excel program. This also provides the maximum values of the horizontal and vertical beta function inside the insertion, the growth of the normalised horizontal emittance due to synchrotron radiation and the effective insertion radius.

To compute the parameters of the half matching section, a MAD program has been written to obtain a periodic insertion.


75T/m,K1=2.5,K2=-2.4,DL3=0.5,rho=100m,R=214m,1.5E-8,72cells
IBM - VM/CMS version 8.15/0
16/11/94 10.46.20
β (m)
D_x (m)
β_x
β_y
D_x
0.0
10.
20.
30.
40.
50.
60.
70.
80.
-0.02
-0.01
0.0
0.01
0.02
0.03
0.04
0.05
0.06
0.0
2.
4.
6.
8.
10.
12.
14.
16.
18.
20.
s (m)
δ_E/p_0c = 0.
Table name = TWISS

13


2 GeV,9cells,30T/m,K1=4.5,K2=-2.0,DL3=0.2,rho=6m,R=10m,1.4E-8
IBM - VM/CMS version 8.15/0
16/11/94 16.45.22
β (m)
D_x (m)
β_x
β_y
D_x
60.
50.
40.
30.
20.
10.
0.0
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.0
-0.025
-0.050
-0.075
0.0
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
s (m)
δε/p₀c = 0.
Table name = TWISS

CONCLUSIONS

It has been shown the existence of a family of isochronous insertions and how it is possible to design them.

The first order anisochronicity is fully eliminated and the low values of the dispersion contribute to decrease the second order effects, as well as the emittance blow-up in the injection system.

On the other hand it makes more difficult the compensation of the chromaticity although first computations show that it requires sextupole strengths comparable with those in damping rings. This however deserves more analysis when the insertion is part of a ring through which the beam passes several times.

Further investigations should study the energy spread acceptance and the way to control second-order effects. Tracking should provide results about the behaviour of this family of isochronous insertions when higher orders are taken in account.

DRIVE BEAM WITH MAXIMUM TRANSFER EFFICIENCY. LONGITUDINAL AND TRANSVERSE DYNAMICS STUDY AND PROPOSAL

J. A. Riche 17-11-94

Some references:

W. Schnell 1992 workshop on e^+e^- colliders
CLIC Note 184

G. GUIGNARD CLIC Note 157
" " 172 (HEA Int. Conf. 92)

L. Thorndahl [Transfer structure]
Transverse wake fields in CLIC CTS
(with G. Guignard, G. Carron, A. Millich)

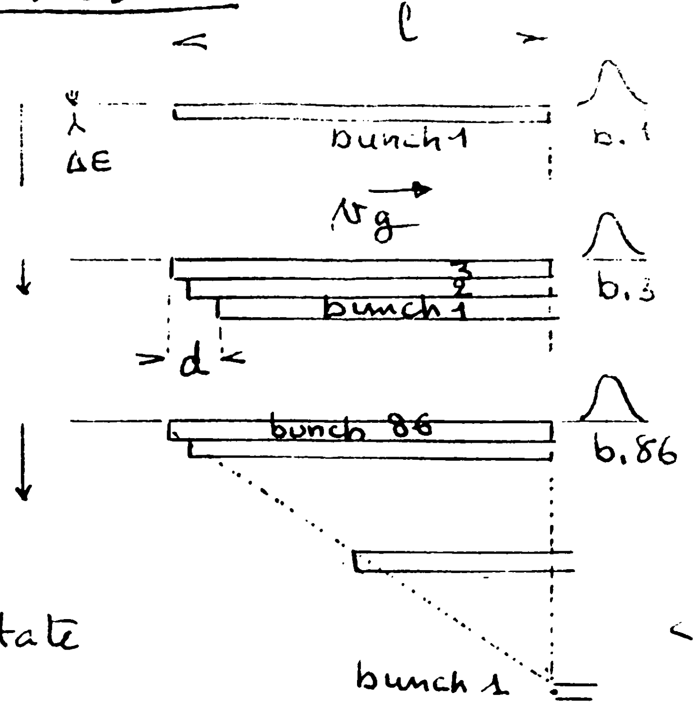
Recent proposals from J.P. Delahaye for
- a reduction of power
- a reduction of charge / bunch
Clic drive beam as continuous train of bunches 06/94
Clic drive beam revisited
drive beam forum 23/09/94
An "After Burner" for C.D.B 30/09/94

In the frame of these new proposals,
- a verification that ultimate limit is 100 MeV at the end of the drive linac. Consequences.
- A proposal for a <u>new focusing principle</u> adapted to a very large energy acceptance.

LONGITUDINAL

$\langle \hat{E} \rangle$

w. large in Rs



$n_b \sim 86$

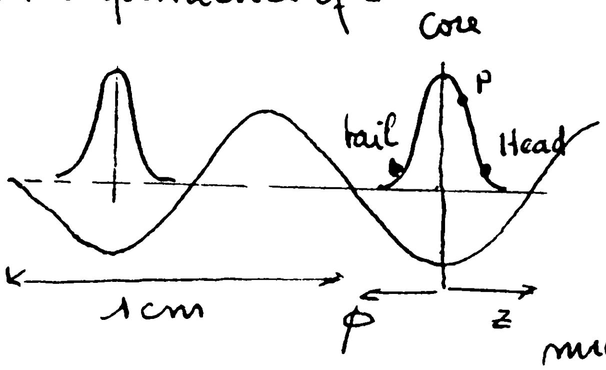
$\langle \hat{E} \rangle l = f(n_b)$

$n_b \geq 86$

$\langle \hat{E}_{st} \rangle l = Cte$

$n_b \geq 86$
steady state

time dependence of E



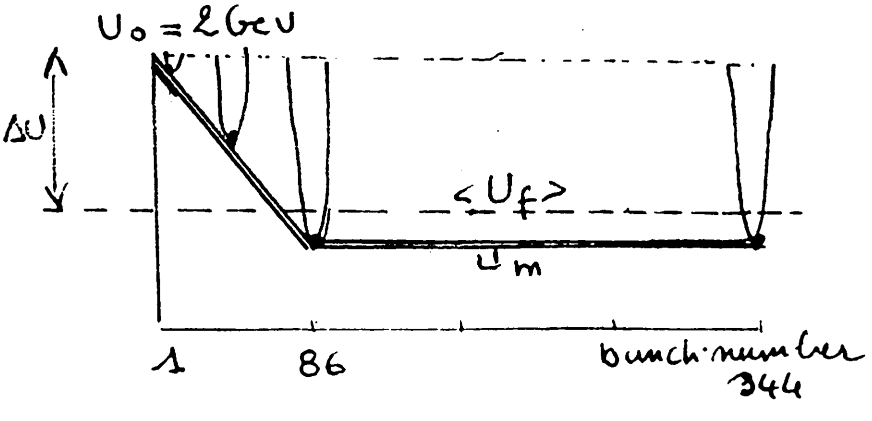
longitudinal wake
with fundamental f 30GHz

energy of bunch core ↘
much more than head and tail

Charge efficiency $f(\sigma_b)$: 0.85 $\sigma_b = 1mm$
0.92 $\sigma_b = 0.7\ mm$

J.P.D. drive beam forum
12-09-94.

After n_c cavities ($c\alpha$, at linac end)



$U_m = n_c l \langle \hat{E} \rangle (n_b)$
if $n_b \leq 86$

$U_m = n_c l \langle E_{st} \rangle$
if $n_b \geq 86$

ΔU can be used for the transfer

Can be used for the transfer:

$\Delta U = U_0 - \langle U_f \rangle$

$= (2\,GV - 0.1\,GV)\,\frac{7}{8} = 1.66\,GV$

if $U_m = 100\,MV$

J.P.D drive beam forum.

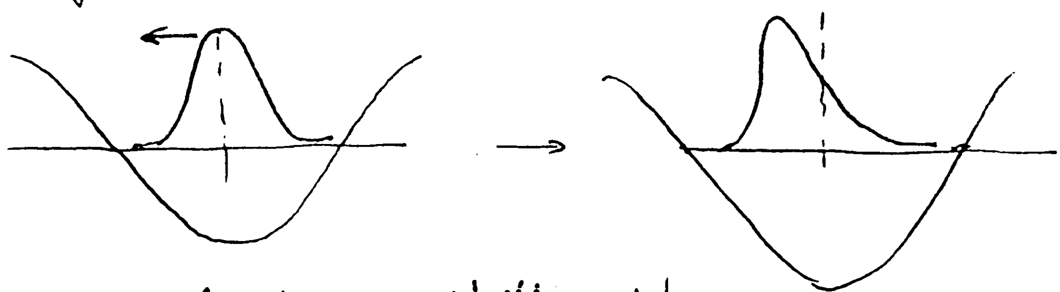
for 80 MV/m 250 MeV 30 GHz main linac

$q_1 \quad \Delta U = 5.92\,GV\,\mu C$

ex 3.5 μC 1.69 GV

ex 344 bunches, 10 nC / b

Why a limit at 100 MeV ?



mainly from shift in phase

J.P.D. "an After Burner"

Verified by solving

$$\begin{cases} \varphi = \varphi_0 + (1-\beta)\, 2\pi c t / \lambda \\ d(\beta\gamma)/dt = e/mc\; E \cos\varphi \end{cases}$$

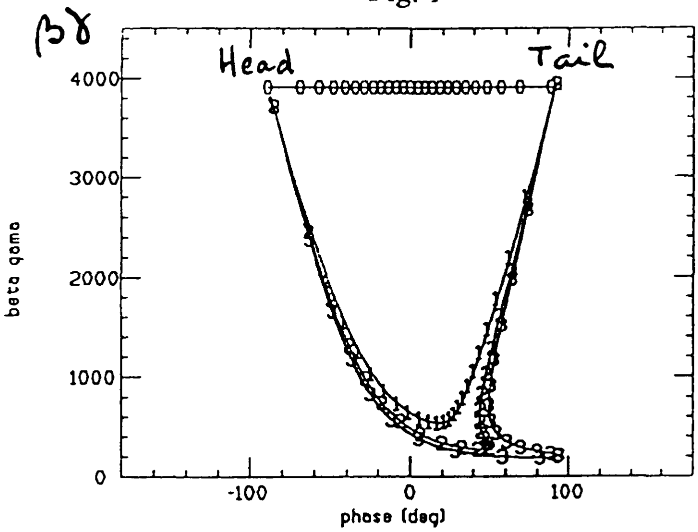
for a gaussian initial charge distribution

φ : phase relative to a ligth particle

E from ΔU

3000 m linac

Fig. 1



0 2 GeV
1 266 MeV
2 134 -
3 94 -

Fig. 2

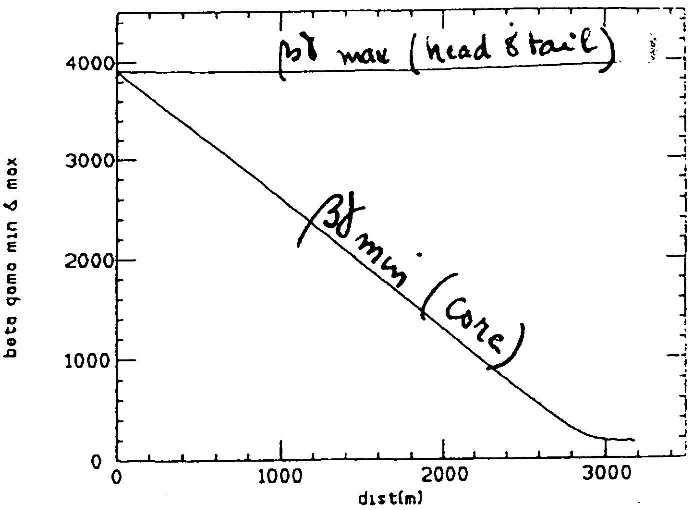
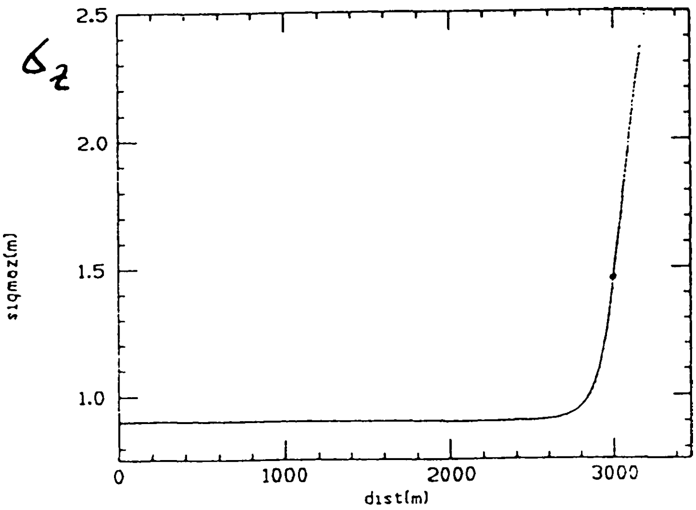
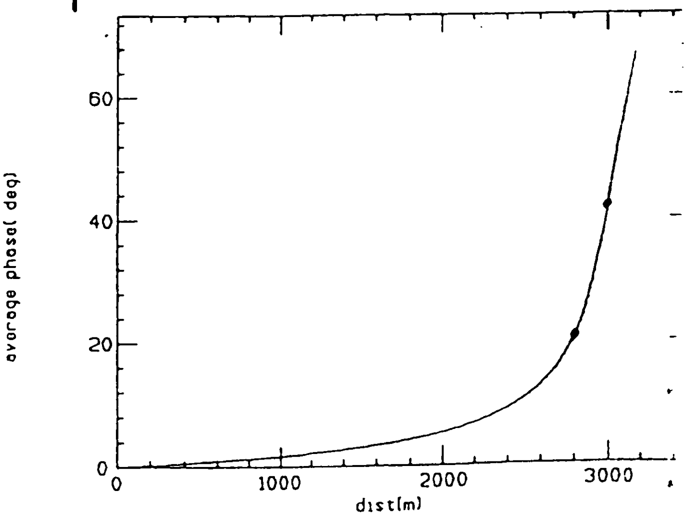


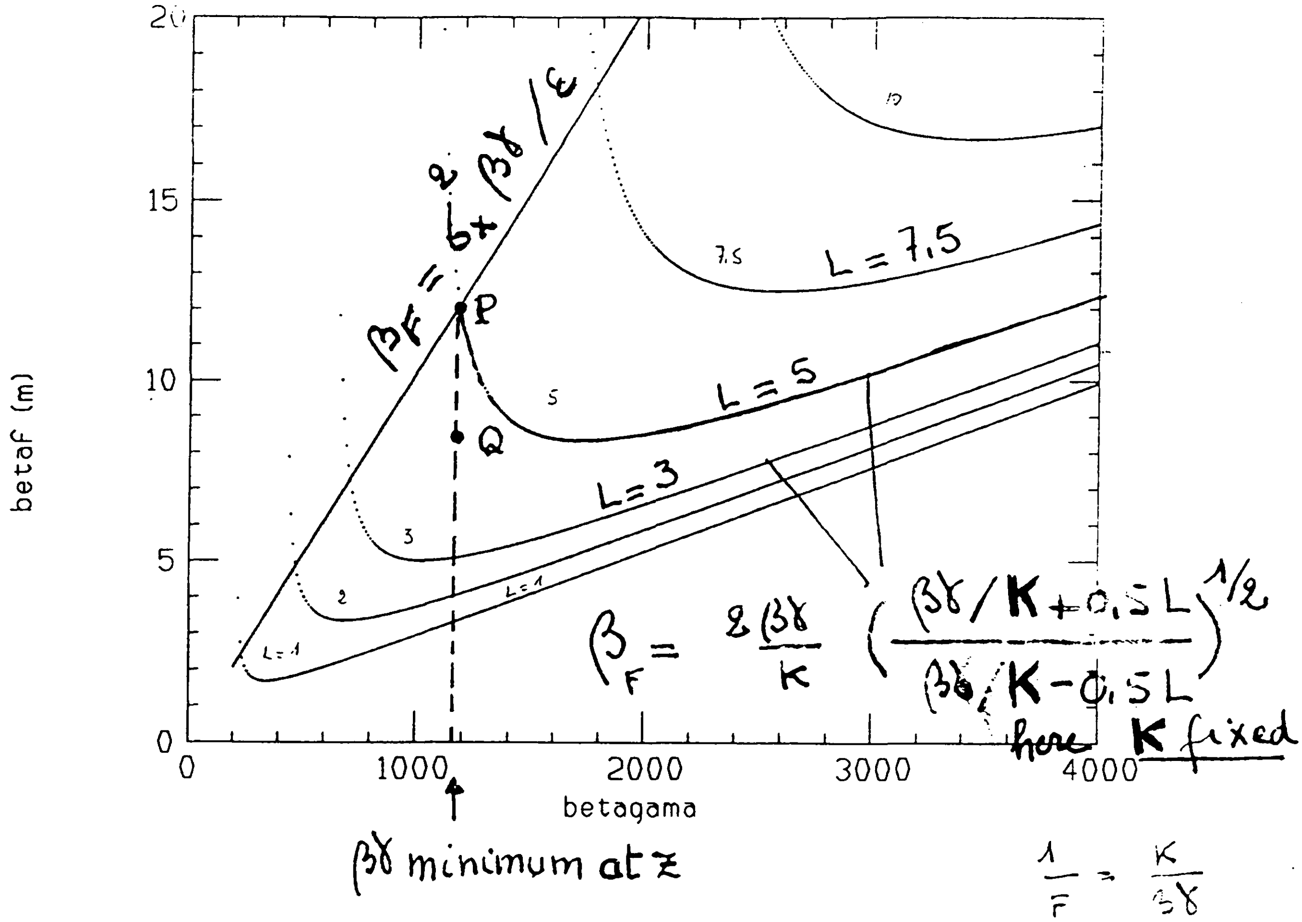
Fig. 3



<φ> over 1 bunch Fig. 4



TRANSVERSE



1. Consider $\beta\gamma_{min}$ at z

2. $\beta_F \leq \sigma_x^2 \; \beta\gamma / \epsilon$ $\quad$ σ_x fraction iris radius

   at z β_F max determined by $\beta\gamma_{min}$

3. take $\beta_F \max = \sigma_x^2 \; \beta\gamma_{mini} / \epsilon$ (point P)

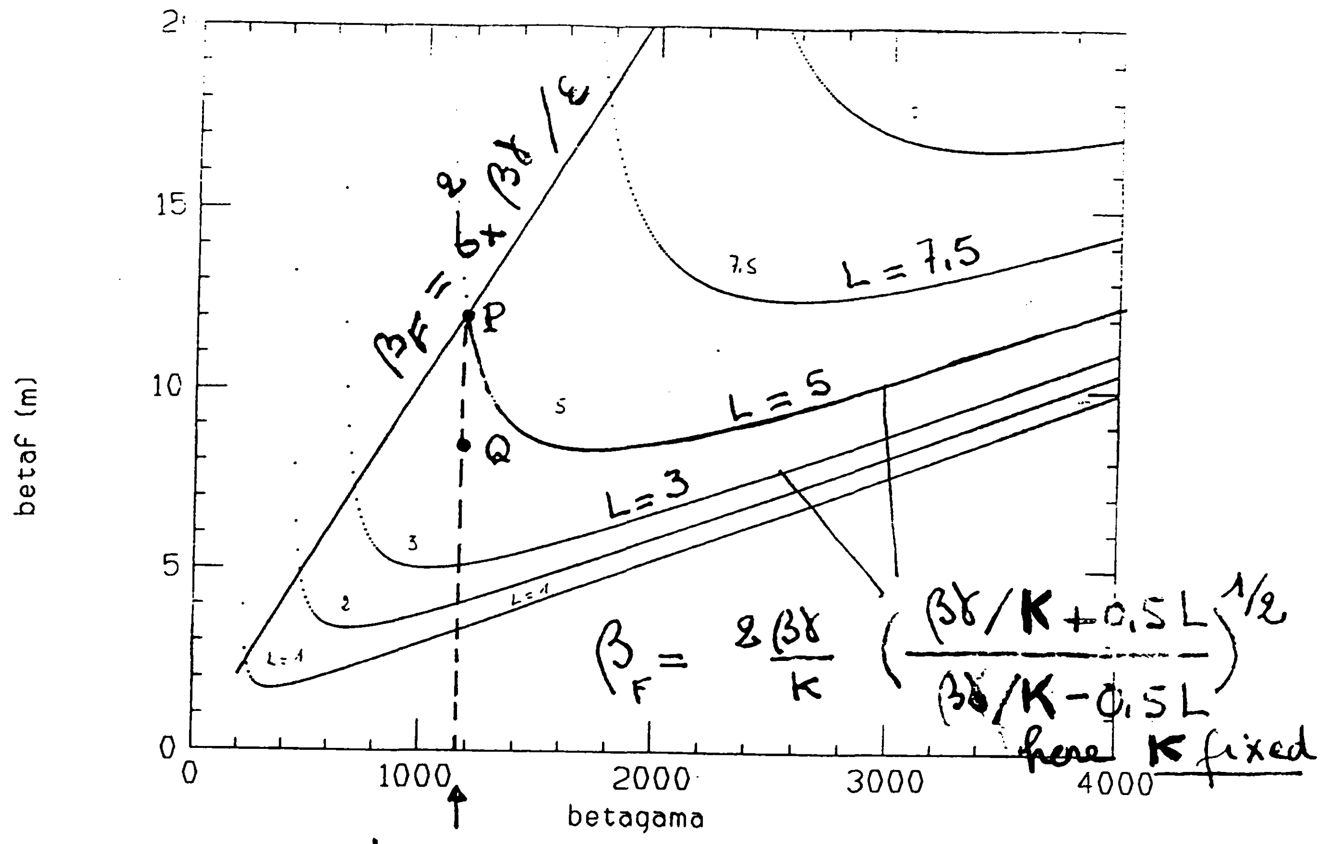
   and not $\beta_{F\,max} <$ ...... (point Q)

   because, from $L = \dfrac{2\beta\gamma}{K} \; \dfrac{(\sigma_x^2 K / 2\epsilon)^2 - 1}{(\sigma_x^2 K / 2\epsilon)^2 + 1}$

   same as formula in the graph, with β_F as in 2-

   $L_P > L_Q$ → decrease nb quadrupoles

4. L read at point P, for z, and for $\beta\gamma_{mini}$ at z. The other particles at z, with $\beta\gamma > \beta\gamma_{min}$ <u>are on the line $L = L_P$</u>, all under $\beta_F = \sigma_x^2 \beta\gamma / \epsilon$ (only 1 cross at P) → 2 - verified

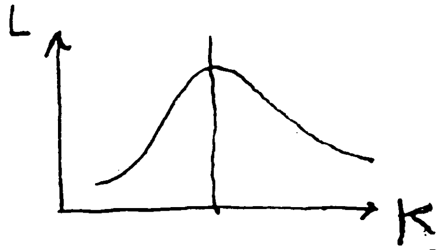


βγ minimum at z

$$\frac{1}{F} = \frac{K}{\beta\gamma}$$

5/ at P it may be that the selected value for K doesnt give the maximum value for L

$$L = \frac{2\beta\gamma}{K} \frac{(6_x^2 K / 2\epsilon)^2 - 1}{(6_x^2 K / 2\epsilon)^2 + 1}$$



$$K = \sqrt{2 + \sqrt{5}}\ 2\epsilon / 6_x^2$$

This K gives L_{max} → minimum number of quadrupoles

Conclusion → minimum number of quadrupoles

→ acceptance for all energies over $\beta\gamma_{min}$

3000 m linac

Fig.5

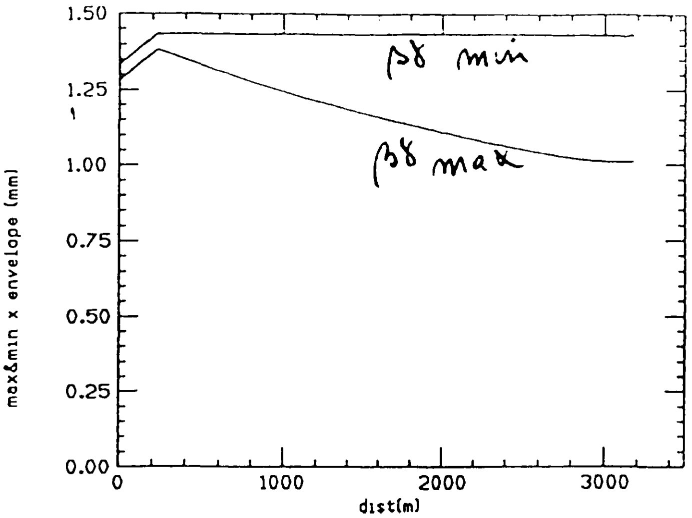
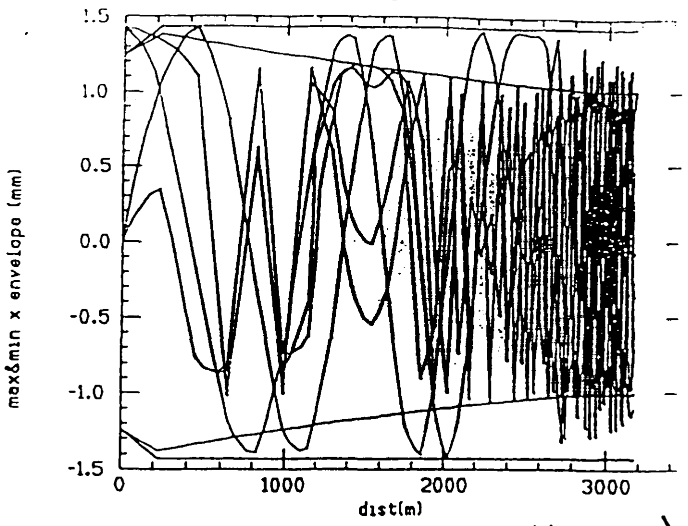


Fig. 5a



trajectories with: and $(\sqrt{\varepsilon\beta_F}, 0)$
- max energy loss $(0, \sqrt{\varepsilon/\beta_F})$
- minimum energy loss
- intermediate energy loss

Fig. 6

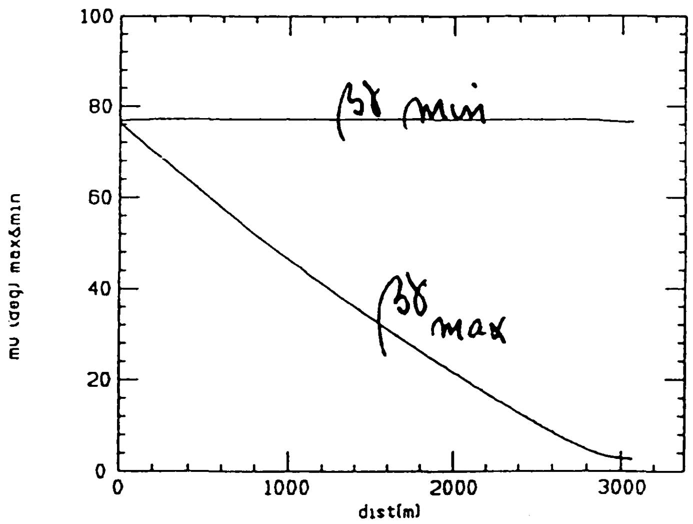


Fig. 7

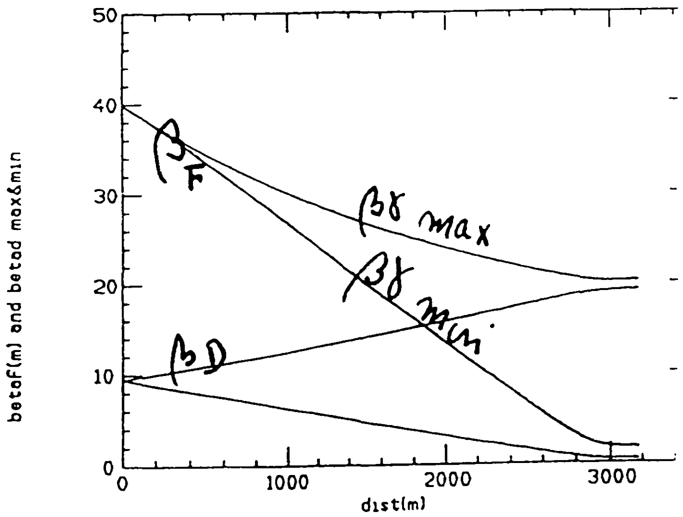


Fig. 8

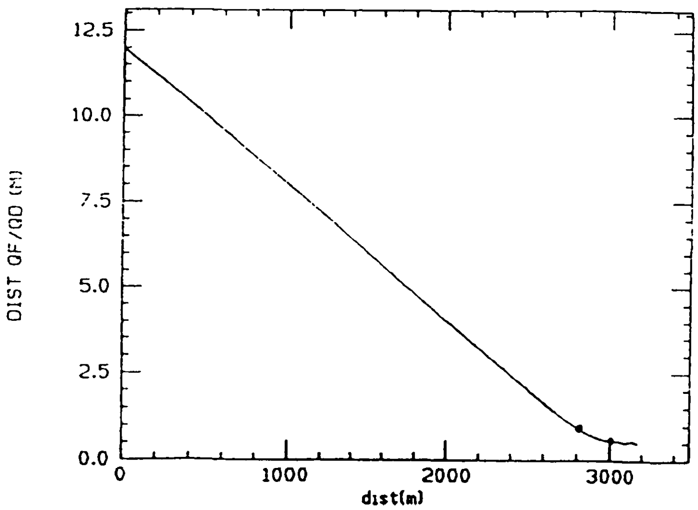
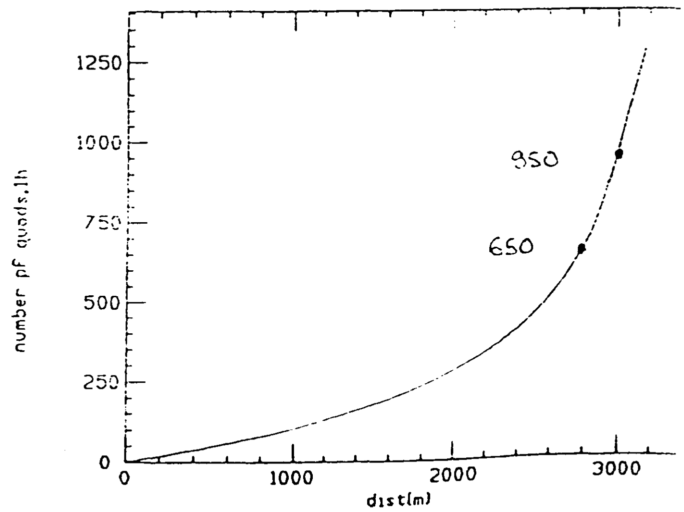


Fig. 9



Force of the quadrupole.

The initial dispersion is neglected, when compared with the one induced by the wake. The initial parameters are the same as in III.1[1]. The rms radial displacement available is 1.33 mm (chosen as a fraction of the iris of transfer structure a = 5 mm). The rms normalized emittance is 2 10^{-4} (m rad). For these values, K= 403. The corresponding integrated gradient is G ds = 0.688 T m / m. To have an idea of the compactness and the complexity of the design of a quadrupole with this gradient, we compare with the values for the quadrupoles of LIL:

	QL1	QL2	QN
integrated gradient (T m / m)	0.55	1.23	1.3
gradient (T/m)	2.5	5.6	4
core length (m)	0.2	0.2	0.26
Φ(mm)	58	58	157
cooling	air	water	water

1) II.1 : initial energy 2 GeV
initial bunch length : 0.9 mm

III. COMPARISON OF THE RESULTS OBTAINED WITH 3000 M DRIVE BEAM, 4400 M DRIVE BEAM, FED WITH TRAINS AT 2 GeV, OR 2 *2200 DRIVE BEAM FED WITH TRAINS WITH HALF THE CHARGE.

The bunch initial rms length 'l' of 0.9 mm, and the initial phase advance μ of 77 deg. are common to all examples.

	"3000m linac"		"4400m linac"		half the charge 2x2100m linac	
W_0 (MeV)	2000	2000	2000	2000	2000	2000
W_f (MeV)	200	100	200	125	200	100
Length (m)	2850	3000	4000	4400	2000	2100
final. bunch length σ_z(mm)	0.9	1.42	0.95	>1.4	0.9	1.0
final μ (deg)	6<<77	3<<77	6<<77	4<<77	5.5<<77	3<<77
initial β (m)	40	40	40	40	10	40
final β (m)	4<<20.5	2<<20	4<<20	2.5<<20	4<<24	2<<23
initial distance QF/QD (m)	12	12	12	12	12	12
final distance(m)	1.0	0.5	1.65	0.8	1.0	0.75
total nb of quad.	570	950	860	1300	450	560
Figures with plotted results	1 to 9		11 to 19		21 to 29	

The total number of quadrupoles for a 2*2100 m linac is therefore 1120, if going down to 100 MeV, and 900 if going down to 200 MeV (2*2000 m linac in this case). One can see that the total number of quadrupoles is about the same as the one for the 4000 m long linac fed with one beam of twice the charge used for each of the 2000 m linacs.