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Non-Isochronism of CTF 5 MeV Beam Line

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The first part of the CTF beam line (Fig. 1) has been designed[1]. H. Kugler raised the question whether the longitudinal particle distribution does not get too much deformed by the first dipole magnet before reaching the foil creating radiation for the streak camera. Indeed, the beam line mainly conceived as a spectrometer is weakly non-isochronous. This feature inherent to the design is discussed in this note.

The non-isochronism of the beam line makes two particles with different moment $p = p_{11}$ arrive at different times at a point downstream, though they started at the gun at the same time.

We consider the chromatic effects:

i) particles have different velocities owing to Δp;

ii) particles travel on a path with different length in the dipoles as $\Delta p \neq 0$.

We neglect the bunch deformation by longitudinal space charge or wake-fields, though this is certainly not admissible in reality.

1. Velocity difference

A particle with a momentum deviation dp/p relative to the reference particle comes earlier by dt to a point downstream s from the gun. The first order

$$dt / t = d\beta$$

leading to an advance *ds*

$$\frac{ds}{dp / p} = \frac{s}{\gamma^2} \qquad (1)$$

2. Path length difference

In a dipole field

$$\frac{ds}{dp / p} = -\int_1^2 \frac{D_x}{\rho(s)} ds \qquad (2)$$

The dispersion function at the end of magnet (D_{x2}, $D_x'{}_2$) is determined by the transfer matrix M and the values at input (D_{x1}, $D_x'{}_1$) according to

$$\begin{pmatrix} D_x \\ D_x \\ 1 \end{pmatrix}_2 = M \begin{pmatrix} D_x \\ D_x \\ 1 \end{pmatrix}_1$$

Using (D_{x1}, $D_x'{}_1$) = 0 and the matrix of a sector magnet that bends by $\phi = \frac{\pi}{2}$ we get after integration using the hard-edge model where $\rho(s) = \rho_o$

$$\frac{ds}{dp\,/\,p} = -\rho_o(\frac{\pi}{2} - 1) \qquad (3)$$

for the first dipole. Inspection of D_x (s) in Fig. 7[1)] shows that D_x (s) is antisymmetric in the second dipole so that the effect after the two dipoles will be doubled.

3. Total effect

Combining (1) and (3) yields

$$\frac{ds}{dp\,/\,p} = \frac{s}{\gamma^2} - n\rho_o(\frac{\pi}{2} - 1)$$

where n = 1,2 is the number of dipoles upstream of s.

With ρ_o = 0.127 m and the nominal momentum P = 4.6 MeV/c (see case q = 9.4 nC, ϕ = 30° in ref. 2) we get with ds and s in mm

$$\frac{ds}{dp\,/\,p} = \frac{s}{82} - n \quad x \quad 72.5 \qquad (4)$$

Table I, Non-isochronism in bunch at 4.6 MeV/c

s m	ds/(dp/p) mm	
1.57	+ 19	at deflecting cavity
2.09	- 47	at foil of streak camera
7.23	- 57	at entry LIL ACS (advanced position)
10.1	- 22	at entry LIL ACS

Fig,.2 gives the result in graphical form distinguishing the three regions: between gun and 1st dipole; between the dipoles; between 2nd dipole and LIL ACS. The parameter is the momentum of the beam.

The point s = 0 is at the cathode of the rf gun. It can be seen that the effect of D_x in the dipoles dominates at higher energy. In principle, the two effects could be made to cancel each other at the entrance of LIL ACS by a proper choice of a lower than nominal energy.

4. Discussion

To get a feeling for the influence of this effect, we examine by how much the bunch in the nominal case (9.4 nC) gets lengthened or compressed on its way down the beam line until certain points of interest, where we either measure its length (deflecting cavity, foil) or where its length gets frozen by acceleration (entrance of LIL section). Fig. 3 shows the distributions after the gun as obtained with TBCI-SF[2]. Full momentum spread and full bunch length are marked in each case.

Table II gives the rms values of these distributions[3] showing that the bunch at the gun exit nearly has the length ($<s> = 1$ mm) we aim at.

Table II, RMS values of particle distribution in long phase space at gun output

Φ	$<s>$ mm	$<\Delta p/p>$ %
10°	1.4	1.8
20°	1.6	1.2
30°	1.8	0.4
40°	2.0	1.6
50°	2.1	3.5

Since the momentum acceptance of the line is limited, the tails of some distributions wll be cut producing a shortening of the bunch with concomitant particle loss.

The relevant momentum acceptances are obtained from

$$\frac{\Delta p}{p} = \frac{r - \Delta x}{Dx}$$

where r = pipe radius (20 mm) and Δx the beam size[1] owing to emittance; the latter is determined by the aperture limits after the gun.

The momentum acceptance at the foil

$$\frac{\Delta p}{p} = \frac{20 - 3.3}{0.31} = \pm 5.4\%$$

Inspection of Fig. 3 shows that at the foil no cut should occur for the range of Φ considered.

The momentum acceptance in the straight section between the dipoles (relevant for measurement with deflecting cavity and for conditions at LIL section) is

$$\frac{\Delta p}{p} = \frac{20 - 2.4}{0.6} = \pm 2.9\%$$

Table III gives the initial bunch lengths and the resulting full bunch lengths using ds/(dp/p) from table I. We restrict ourselves to the cases Φ = 20°, 30° and 40°. The low-energy tail in case Φ = 40° is cut away.

Table III, Initial and effective full bunch length in mm

Φ	initial at gun	at foil	initial after Δp cut ± 2.9%	at deflector	at LIL advanced	at LIL
20°	± 2.8	± 3.9	± 2.8	±2.3	± 4.2	± 3.3
30°	± 3.8	no change	± 3.8	no change, but deformation		
40°	± 3.8	±2.0	± 2.8	± 3.4	±1.2	±2.2

Shortened bunches are underlined.

The table corroborates that the bunch length at the monitors can be quite different from the length at the gun exit as suspected by H. Kugler. One could, if required, move the deflecting cavity closer to the gun by designing a different beam line. Whether the radiation monitor could be moved close to the gun is doubtful because of the high background radiation produced by the gun. It is recommended to start up the line with the monitors in the present position.

A bunch compressor will produce a large absolute ds(dp/p) with the sign determined by its design. In order to become independent of the Φ (gun), it should be preceded by a small 3 GHz section which would allow to appropriately prepare the particle distribution in longitudinal phase space for the bunch compressor for all reasonable Φ (gun). Although no bunch compressor will be installed until we have not obtained the first results with the synchro-laser, we should design one to get an idea on space requirements after we also understood the wakefield and space charge effects.

References

1) A.J. Riche, "The proposed beam optics for the CTF and the Instrumentation Layout", CERN internal note PS LP(CTF) 90-29

2) H. Kugler, A. Pisent, A.J. Riche, J. Ströde, "Beam dynamics simulations of the RF gun, particle source of the CTF", Cern Divisional Report PS 90-23 (LP)

3) J. Ströde, "Catalogue of simulations of the CRF Rf gun", CERN internal note PS-LP (CTF) 90-35

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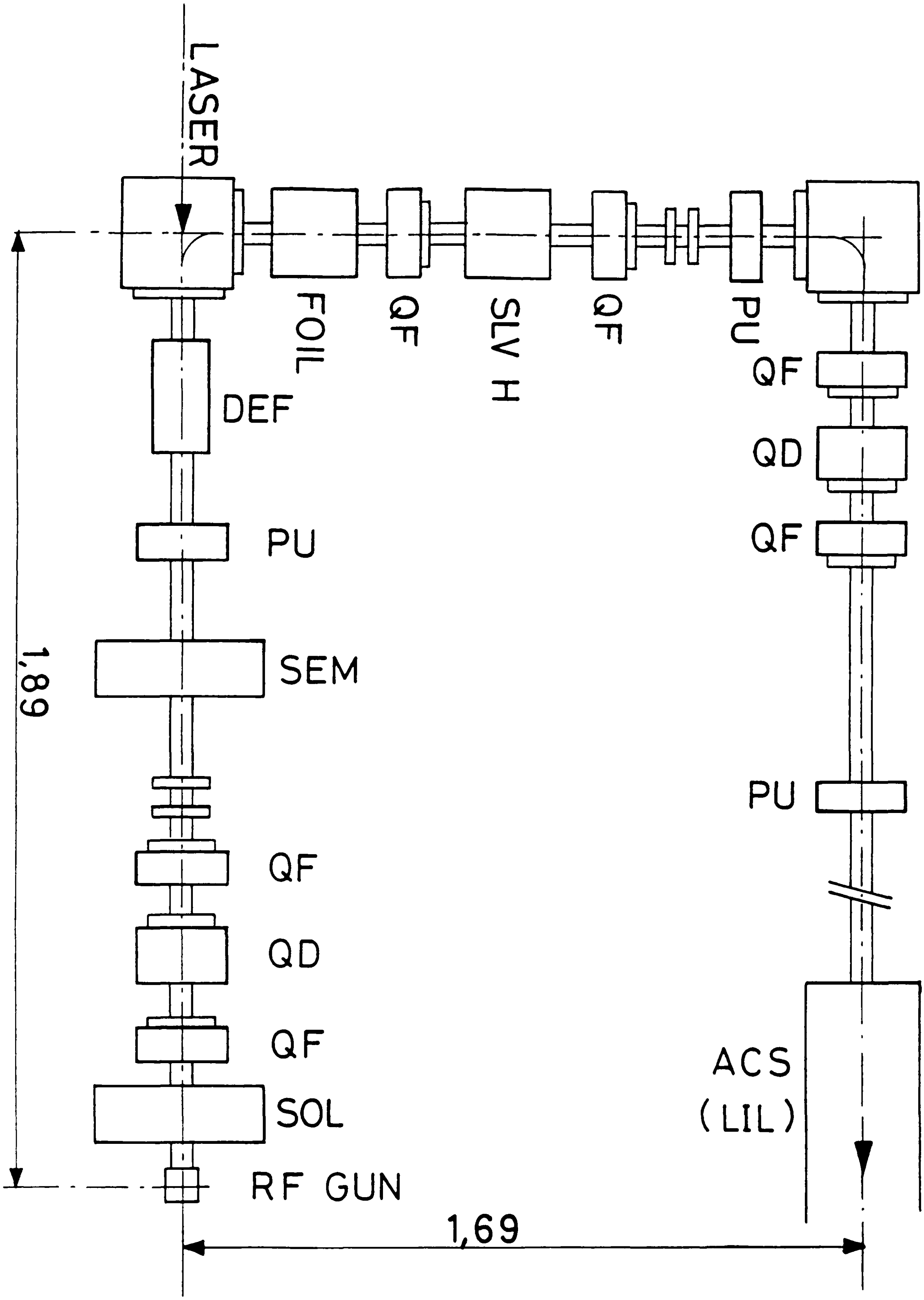

Fig. 1 Layout of first part of CTF beam line

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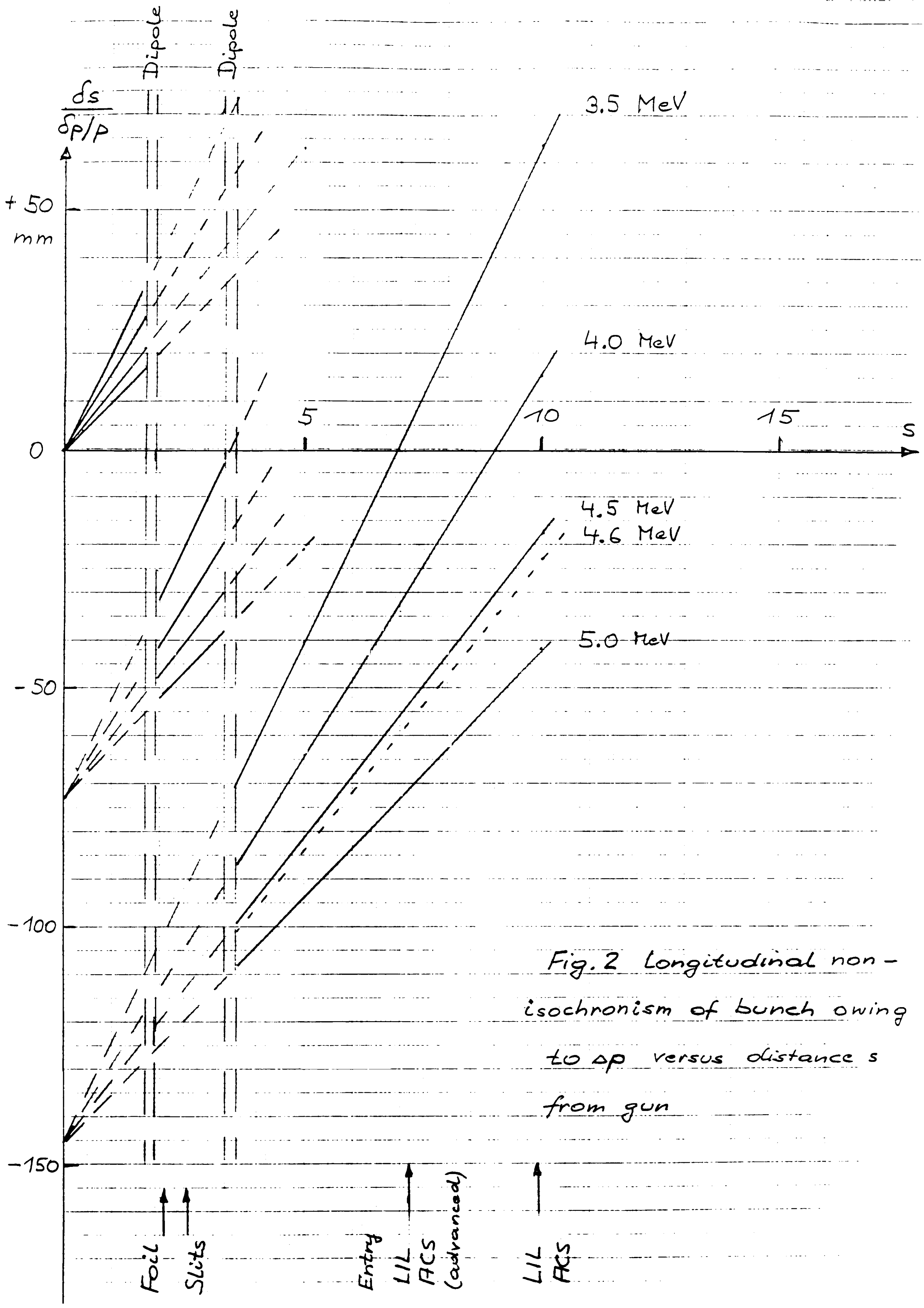

Fig. 2 Longitudinal non-isochronism of bunch owing to Δp versus distance s from gun

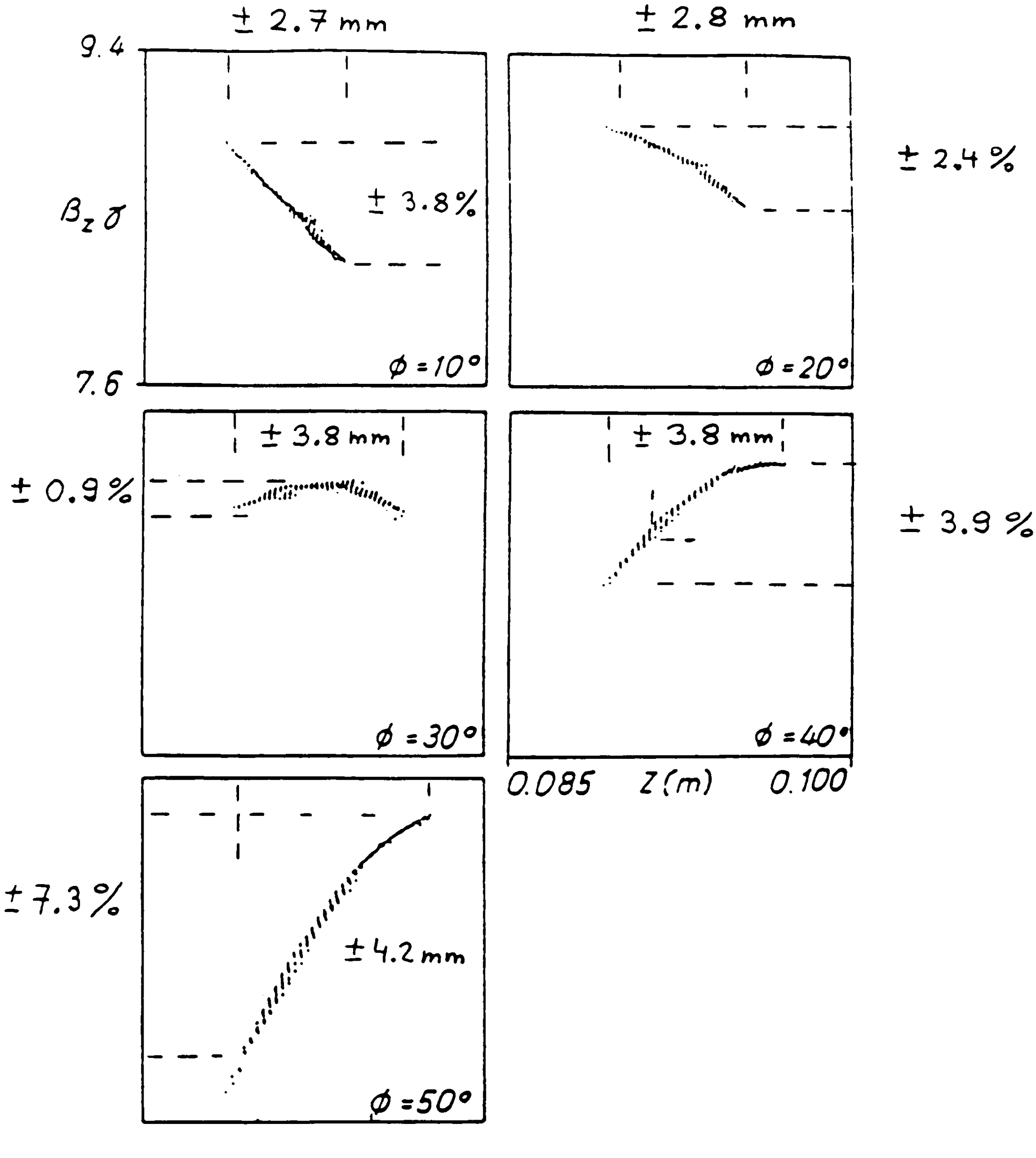

Fig. 3 *Longitudinal phase space diagrams for a 9.4 nC bunch (r = 5 mm, t = 30 ps) at the outlet of the rf-gun. Parameter of the curves is the rf-phase at the laser pulse.* (from ref. 2)