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PROPOSAL FOR

THE FINAL LAYOUT OF THE CONTINUOUS TRANSFER SYSTEM

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1. Introduction

From 1976 onwards the CPS will serve as an injector for the 300 GeV SPS. After appropriate theoretical and experimental studies it was decided to adopt a CPS extraction scheme which is known as the continuous transfer system (CT)[1),2)].

This scheme consists of a multiturn (10 or 11 turns) shaving ejection using an electrostatic septum (ES) as peeling device. Tests with an experimental set-up have shown that the originally proposed system works satisfactorily and that there is no need for a change of the principle[3)]. The aim of this report is therefore only to study the final system layout. The system elements are specified in view of the future high intensity operation of the CPS and an attempt is made to find an optimized location for the system in the ring.

Several types of arrangements are discussed and for the favoured ones the elements are specified for a transfer momentum of 12 GeV/c and the largest anticipated beam emittances[5)].

Some hardware aspects of the system are outlined and a first price estimate is given.

2. Basic Arrangement and Design Principles

The basic arrangement of the elements for CT is :

FB1-Q1-B1-ES-B2-Q2-FB2————SM16,

where : FB 1,2 : fast bumpers, programmable in up to 11 steps

Q 1,2 : quadrupoles

B 1,2 : slow bumpers

ES : electrostatic septum

SM16 : septum magnet 16

B1 and B2 allow the beam to be placed near to the ES, Q1 and Q2 produce a local blow up of the beam and FB1 and FB2 shift the beam progressively into the ES which kicks the shaved part via SM16 out of the ring. It can be shown that quadrupoles with opposite sign must be located apart[4)2)] an integer number of betatron oscillation wave lengths, in order to conserve the beam properties outside the quadrupole region. Furthermore the ES should be placed in a position where the β-function is high and $\alpha_p \approx 0$ at the same time[2)]. This arrangement reduces particle losses at the ES and avoids momentum drift during ejection. These specific assumptions define the phase relations between the various elements and possible locations in the ring. Restrictions are introduced by the demand for the smallest possible deflection power of the FB's and the ES.

Naturally the (estimated) properties of the future high intensity beam have to be considered.

The following calculations are made with a linear model of the CPS having 50 periods and a Q-value equal to 6,25. Without discussing details the ES, FB's and Q's will be located only in focusing straight sections of the machine where their effect is enhanced by the higher β-value.

2.1 Possible Arrangements of the ES between the Quadrupoles

In the arrangement

Fig. 1 :

Q1	–	ES –		Q2 –		SM16		
	m		n		s			
α_p, β_1, K_1		β_1		β_1, K_2		β_3		$(K_1 = - K_2)$

m and n are the phase advance (or number of straight sections) between the elements, K_1 and K_2 the quadrupole strength (in m^{-1})*).

Then the momentum compaction between the quadrupoles transforms as

$$\bar{\alpha}_p = \alpha_p \; (1 + K_1 \cdot \beta_1 \cdot \sin m) \qquad (1)$$

and

$$\bar{\beta} = \beta_1 \; (1 + K_1 \beta_1 \sin 2 m + K_1^2 \; \beta_1^2 \sin^2 m) \qquad (2)$$

(see appendix A)

The functions are shown in Fig. 2 for the two quadrupole configurations. It is easy to see that there are 4 possibilities where $\bar{\alpha}_p \simeq 0$ and $\bar{\beta}$ high at the same time, namely after m = 10 or 6 s.s. and (with reduced quadrupole strength) m = 12 or 4 s.s.. Solving for $\bar{\alpha}_p = 0$ we get then the normalized quadrupole strength for the different cases :

$$K_1 \beta_1 = - \frac{1}{\sin m}$$

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* m,n,s, etc. represent a phase difference and at the same time a difference in the straight section number.

β_1, β_2, α_p are the values of the "clean" machine.

1. $m = 225^\circ \rightarrow K_1\beta_1 = \sqrt{2}$
2. $m = 135^\circ \rightarrow K_1\beta_1 = -\sqrt{2}$

$\bar{\beta}_{ES} = 3,414 \cdot \beta_1 = 75$ m

3. $m = 270^\circ \rightarrow K_1\beta_1 = 1$
4. $m = 90^\circ \rightarrow K_1\beta_1 = -1$

$\bar{\beta}_{ES} = 2 \cdot \beta_1 = 44$ m

Thus the possible locations of the ES between the quadrupoles are determined and the normalized quadrupole strength as well.

2.2 Possible Locations of the ES in the CPS

The transfer matrix between the ES and the extractor magnet is given by

$$M = M_s \cdot Q \cdot M_n$$

following the notation in Fig. 1.

The displacement at SM16 due to the deflection θ of the ES is then

$$y = \theta_{ES} \cdot \sqrt{\beta_1 \beta_3} \left[\sin (s + n) + K_2\beta_1 \sin s \cdot \sin n\right] \qquad (3)$$

(see appendix B)

The displacement should be maximized for a given deflection and quadrupole strength. Because n is no longer a free parameter, the maximum is determined by

$$\frac{dy}{ds} \equiv 0,$$

which leads to $\quad s = \text{arc tg } (K_2\beta_1 + \text{ctg } n)$

The best location for the ES is then

$$L_{ES} = 116 - (n + s) = 116 - n - \text{arc tg } (K_2\beta_1 + \text{ctg } n)$$

(The SM16 location is here called 116) and for the different cases we get :

1. $m = 10$ ss $\rightarrow n = 6$ ss; $K_2\beta_1 = -\sqrt{2}$ $\quad$ $L_{ES} = (105 - c \cdot 8)$ss
2. $m = 6$ ss $\rightarrow n = 10$ ss; $K_2\beta_1 = \sqrt{2}$ $\quad$ $L_{ES} = (103 - c \cdot 8)$ss
3. $m = 12$ ss $\rightarrow n = 4$ ss; $K_2\beta_1 = -1$ $\quad$ $L_{ES} = (106 - c \cdot 8 \pm 1)$ss
4. $m = 4$ ss $\rightarrow n = 12$ ss; $K_2\beta_1 = 1$ $\quad$ $L_{ES} = (102 - c \cdot 8 \pm 1)$ss

where $c = 0,1,2,3,...$

In case 1 and 2 the displacement at septum 16 is :

$$|y_{16}| = \theta_{ES} \cdot \sqrt{\beta_1 \beta_3} \cdot 1{,}847$$

In case 3 and 4

$$|y_{16}| = \theta_{ES} \cdot \sqrt{\beta_1 \beta_3} \cdot 1{,}306$$

In the cases 3 and 4 the best place is a D-straight section because only the phase advance between the ES and SM16 was considered, but the biggest beam displacement is achieved when taking the neighbouring F-ss. If one thinks in terms of highest displacement per deflection θ_{ES}, the cases 1. and 2. describe the most favourable locations (MFL).

Due to the smaller quadrupole strength the beam blow-up at the ES is smaller in cases 3 and 4 and the ES deflection power must be higher in order to obtain the same beam displacement at SM 16. In the following case 3 and 4 are referenced as type A locations (AL).

In order to complete the list of possibilities, the F-straight sections next to the MFL are also considered and called type B locations (BL)*). They show the same properties as MFL, except that the required ES deflection needs to be higher.

*) The experimental CT set-up is in fact of this type.

2.3 Best Locations of FB1 and FB2

The fast bump FB1 - FB2 produces a beam displacement in the region between the quadrupoles where the beam dimension is blown up. Therefore not only the displacement must be optimized but the ratio x/w, where x is the displacement and w the beam width.

In the arrangement

$$\begin{array}{ccccccccc} FB1 & - & Q1 & - & ES & - & Q2 & - & FB2 \\ & f & & m & & n & & & \\ | & & | & & | & & | & & \\ \beta_1 & & \beta_1 & & \beta_1 & & & & \end{array}$$

the beam width between the quadrupoles is $w \sim \sqrt{\varepsilon\,\bar{\beta}}$, where

$$\varepsilon = \text{horizontal emittance}$$
$$\bar{\beta} = \beta_1\,(1 + K_1\beta_1\,\sin^2 m + K_1^2\,\beta_1^2\,\sin^2 m).$$

The deflection at a place between Q1 and Q2 is

$$x = \theta \cdot \beta_1 \cdot \left[\sin\,(f + m) + K_1\beta_1 \sin f \cdot \sin m\right]. \qquad (4)$$

Introducing in $w \sim \sqrt{\varepsilon\,\bar{\beta}}$ the expression for the transformed β-function, one gets :

$$\frac{x}{w} \sim \frac{\sin\,(f + m) + K_1\beta_1\,\sin f \cdot \sin m}{(1 + K_1\beta_1\,\sin^2 m + K_1^2\beta_1^2\,\sin^2 m)^{\frac{1}{2}}}$$

which has to be optimized. Remembering that K_1 and m are no longer free parameters, the problem is reduced to the one treated in the paragraph above with the solution

$$f = \text{arc tg}\,(K_1\beta_1 + \text{ctg}\, m)$$

So, for the different cases :

1. $m = 10$ ss; $K_1\beta_1 = -\sqrt{2} \rightarrow f = (3 + c \cdot 8) \pm 1$ ss
2. $m = 6$ ss; $K_1\beta_1 = \sqrt{2} \rightarrow f = (5 + c \cdot 8) \pm 1$ ss
3. $m = 12$ ss; $K_1\beta_1 = -1 \rightarrow f = (2 + c \cdot 8)$ ss
4. $m = 4$ ss; $K_1\beta_1 = 1 \rightarrow f = (6 + c \cdot 8)$ ss

where $c = 0,1,2,3...$

In case of 1 and 2 the best choice falls into a D-ss. Therefore, the neighbouring F-sections have to be choosen.

2.4 Anticipated Beam Properties of the Future CPS

The high intensity CPS is expected to work with practically constant normalized emittance. The minimum and maximum estimates of horizontal emittance[5)] are sketched in Fig. 3. It is sufficient to work in linear approximation within the interesting momentum region (10 to 14 GeV/c). The maximum momentum spread after adiabatic debunching is assumed to be :

$$\frac{\Delta p}{p} = \pm 10^{-3}$$

and constant within the above mentioned range.

2.5 Definition of Beam Width

Recent measurements of the vertical and horizontal beam profiles[6)] confirmed their gaussian distribution. All calculations will be based on the assumption of a gaussian beam profile without cut off tails.

The beam emittance is normally defined as the area in the phase plane which contains 86,5% of all particles, that means usually a circle with a radius of 2σ as demonstrated in Fig. 4.

A circulating beam placed at a distance r from an obstacle looses all particles outside the circle with radius r. The percentage of lost particles for a two-dimensional gaussian distribution in terms of σ is shown in Fig.4. The beam width of the circulating beam is now defined by the losses which are considered to be acceptable.

In view of the high intensity operation of the CPS it is felt that systematic losses should be kept as low as possible. Therefore, in a somewhat arbitrary way, the full width of the circulating beam was defined as $w = 7\sigma$, which means ~ 0,2% systematic losses. Anyhow, with say 0,5% accepted losses, the results would not change drastically.

This consideration does not apply to the ejected beam. As the ejected beam normally traverses the obstacle (septum) only once the losses are now represented by the number of particles contained in the cut piece of the circle (see Fig. 5). The losses calculated for a one dimensional gaussian distribution are given in the same figure. Choosing ~ 0,25% as acceptable losses, the full width of the ejected beam is $v_o = 5{,}5\sigma$.

So the "visible" beam width of the circulating and the ejected beam is different.

2.6 Beam Displacement at a Septum Magnet

Referring to Fig. 7, the displacement is :

$$D = \frac{w}{2} + \frac{v}{2} + d + c_p + c_1 + c_2$$

where w, v = beam width of circulating and extracted beam

d = septum thickness

c_p = clearance for effect of synchrotron oscillations
c_1, c_2 = clearance

The beam width of the extracted beam includes the effect of momentum spread which can be added quadratically. In the case of the circulating beam the particles follow the synchrotron oscillation, which means that the effect of momentum spread must be added linearily [6].

With $c_p = \frac{\Delta p}{p} \cdot \alpha_p \cdot R$ and $v = \sqrt{v_o^2 + c_p^2}$, where

$w = 7\sigma$; $v_o = 5{,}5\sigma$ and $2\sigma = \sqrt{\varepsilon_H \cdot \beta}$ we get

$$D = 1{,}75 \cdot \sqrt{\varepsilon_H \cdot \beta} + 0{,}5 \sqrt{7{,}56 \cdot \varepsilon_H \cdot \beta + \left(R\alpha_p \cdot \frac{\Delta p}{p}\right)^2} + R\alpha p \cdot \frac{\Delta p}{p} + C_1 + C_2 + d$$

The displacement requirements at SM16 for the future CPS beam are shown in Fig. 8, based on the given emittance estimates.

2.7 Deflection Requirements of ES and FB

ES :

The first slice of the beam cut by the ES has the biggest emittance. Its position in the phase plane at SM16 is such that the horizontal beam width is nearly as large as a fast extracted complete beam (this has been confirmed by tests with an experimental set up). This justifies the treatment of the multiturn ejected beam in the same manner as for a complete one. The deflection angle of the ES is then determined by

$$\theta_{ES} = \frac{D}{1{,}847\sqrt{\beta_1 \beta_3}}$$

when locating the ES in a most favourable location (MFL) and

$$\theta_{ES} = \frac{D}{1{,}306\sqrt{\beta_1 \beta_3}}$$

in case of B.L. and A.L.

The requirements for the future CPS beam are given in Fig. 9.

FB :

The deflection power of the fast bumpers needs two specifications : the initial step value and the maximum deflection needed to make the last beam piece jump into the ES.

Assuming a circulating beam of width w to be placed at ½ w distance from the ES, then the displacement $\Delta x_1 = 0{,}5w - x_{10}$ is required in order to bring 10% of the beam into the ES (refer to Fig. 6). (Only a 10 turn ejection is considered because both the first and last step are higher than for 11 turn ejection.)

With the definition $w = 7\sigma$ we find from Fig. 6

$$\Delta x_1 = 3{,}5\sigma - 1{,}23\sigma \approx 2{,}3\sigma$$

From tests one knows that for a good 10 turns ejection the last step must be approximately 2 times higher (see i.e. ref. [3], Fig. 4c).

Therefore, $\Delta x_{10} = 4{,}6\sigma$

Remembering that $\sigma = 0{,}5 \sqrt{\varepsilon_H \cdot \bar{\beta}}$

where $\bar{\beta}$ is the same as in formula (2) we get the deflection angle of the FB from formula (4)

$$\theta_1 = 1{,}15 \cdot \sqrt{\frac{\varepsilon_H}{\beta_o}} \cdot \frac{(1 + K_1\beta_1 \sin^2 m + K_1^2\beta_1^2 \sin^2 m)^{\frac{1}{2}}}{\sin (f + m) + K_1\beta_1 \sin f \sin m}$$

and twice as much for the highest step. The results are shown in Fig. 10.

3. Selection of Feasible Arrangements

Most of the possible locations for the ES are short straight sections where only a 0,8 m long ES can be housed. The field strength of the ES is calculated as

$$E = \frac{p \cdot \beta}{\ell} \quad tg\ \theta_{ES} \cdot \left[10^{9} \ \frac{v}{cm} \right]$$

where β = ratio of particle velocity to that of light

ℓ = septum length (cm)
p = particle momentum (GeV/c)

The result is given in Fig. 11. Even for the lowest emittance estimates the field strength is above the operational limit if one takes into account the unknown influence of a high intensity beam and also a rather wide gap width.

<u>Therefore : The ES must be housed in a long straight section</u>

This eliminates most of the theoretically possible arrangements. The remaining locations to house the ES are :

1) FB1 ——— Q1 —— ES —— Q2 ——— FFB2 ; $|K\beta| = \sqrt{2}$
| ←2 or 4ss→ | ←10ss→ | ←6ss→ | ←6 or 4→ |

ES in MFL : ss 81; ss 41
ES in BL : ss 91; 71; 51; 31

2) FB1 ——— Q1 —— ES —— Q2 ——— FB2
| ←4 or 6→ | ←6ss→ | ←10ss→ | ←4 or 2→ | $|K\beta| = \sqrt{2}$

ES in MFL : ss 71; ss 31
ES in BL : ss 1; 81; 61; 41; 21

3) FB1 —— Q1 —— ES—— Q2 ——FB2

|← 2ss →|← 12ss→|←4ss→|← 6ss→| |Kβ| = 1

ES in AL : ss 91; 81; 51; 41

4) FB1 —— Q1 —— ES —— Q2 —— FB2

|← 6ss→|← 4ss→|← 12ss→|← 2ss →| |Kβ| = 1

ES in AL = ss 1; 71; 61; 31; 21

Therefore, in principle all long F-straight sections could house the septum. It should be remembered that the distance between the quadrupoles can only be increased in full betatron wavelength steps (16 magnet units) and the distance between the fast bumpers in steps of 8 magnet units. However, most of the above arrangements interfere strongly with other machine elements which are phase sensitive or nearly impossible to move. Moreover, one is interested to adopt a MFL arrangement for the following reasons: The AL arrangement produces less beam blow-up which means that particle losses at the ES are approximately 1.3 times higher than in MFL. In case of the BL arrangement the beam excursions are $\sqrt{2}$ higher than necessary and in both cases the electrical field strength of the ES must be increased by a factor of $\sqrt{2}$ as compared to the MFL.

Therefore, only feasible MFL arrangements are discussed below without justification for abandoning the other possibilities.

<u>Arrangement with ES in ss 81</u>

	FB1	Q1	B1	ES	B2	Q2	FB2
ss	53	55	77	81	85	87	93

This scheme is only feasible if the present slow extraction 62 (SE 62) equipment moves, and this, in turn, is only possible if SE 16 is stopped (which will be the case[7]) and at the same time 3 γ-transition quadrupoles are shifted. For the moment the slow ejection elements are optimized for alternate operation of SE16 and SE62 and the installation of the above CT scheme could be a good opportunity to optimize the layout for slow extraction from ss 62, because SE16 will not be used after 1975. In case of realization mainly the following work needs to be executed at practically the same time :

1) Move γ-transition quadrupoles 49, 69, 79 to ss 73, 85, 95;

2) Move pick-up 87 and wide band pick-up 93;

3) Transformation of SE16/62 to SE62 :
   SQUARE 53 ⟶ ss 33 (move knock-out kicker)
   Booster quadrupole 23 ⟶ ss 19 or 27
   ES 83 ⟶ ss 47 (move IBS)
   TSM 85 ⟶ ss 49
   Slow bump ⟶ ss 44 + 52

Considering all details of the installation work one finds that the realization of this scheme involves interventions in 37 straight sections and 8 magnet vacuum chambers and requires a special shut-down of about 3 weeks in September/October 1975[12].

Fig. 12 shows the calculated worst case trajectories and beam envelopes under the assumption of an ideal closed orbit. Although there is theoretically ample clearance, experience with a high intensity beam might show that there is not enough margin for random closed orbit deviations. Then the maximum beam excursions can be reduced by a controlled deformation of the closed orbit which can be achieved by radial adjustment of the quadrupoles or by a correction dipole, located for example in ss 89.

Calculations with the help of the SYNCH programme show that the phase advance between both the quadrupoles and the fast bumpers is far from being an exact multiple of $\lambda/2$ and there are differences in the local β-functions. This leads to strong coherent oscillations after excitation of the fast bumpers as demonstrated in Fig. 15.

After appropriate matching of the elements the oscillations can be avoided, but unfortunately the required difference in element strength is considerable (Fig. 15).

Arrangement with ES in ss 31

	FB1	Q1	B1	ES	B2	Q2	FB2
ss	21	25	27	31	35	5 or 57 or 89	9 or 93

A certain disadvantage of this scheme is that FB1 occupies a part of a long straight section, but in the present situation of the CPS it seems nevertheless tolerable.

The above arrangement is compatible with the present slow ejection 62/16 and will not interfere with a possible future optimized SE62.

It involves interventions in 18 straight sections and 6 magnet vacuum chambers. No special shut-down is required for installation[12].

The calculated worst case trajectories and beam envelopes are shown in Fig. 13.

Again the beam excursions can be reduced by an appropriate closed orbit deformation, if required. Useful locations to place a correction dipole are ss 35 or 37.

The calculated phase advance between quadrupoles and fast bumpers is nearly ideal, so that matching of the elements for zero coherent oscillations may be unnecessary or only a question of a few percent. On the other hand this scheme shows beam sausaging around most of the ring which might lead to troublesome beam dynamic effects at high intensity. For the moment, there is no practical evidence for such a danger, but appropriate tests in the forthcoming months could be advisable.

4. Final Specification of Elements

It is evident that the properties of the future high intensity beam and the choice of the transfer energy influence strongly the element specifications. Knowing neither the first nor the second, it is proposed to specify for 12 GeV/c and the highest emittance estimate at this momentum. The values given below hold for an MFL arrangement and are taken from figures 9 and 10 or calculated in the appendix C.

Fast Bumpers FB1 and FB2

1st step deflection angle	: $\theta_1 = 0{,}6$ mrad
highest step deflection angle	: $\theta_{11} = 1{,}2$ mrad
stability of deflection	: $\Delta\theta/\theta \leqslant 1$ %
rise time of steps	: $t_r \sim 300$ ns
uniform field region (within ~ 2%)	: 136 mm
maximum space occupation	: 1 short straight section

Electrostatic Septum ES

deflection angle	θ_{ES}	=	1,06 mrad
gap width	g	=	18 mm
gap height	h	=	20 mm
stability	$\Delta\theta/\theta$	$\leqslant$	1%

septum : wire + foil as thin as possible

Quadrupoles Q1, Q2

Short PS standard elements

required current : 441 A

stability $\Delta I/_I$: $\leqslant$ 0,5%

If powered with a capacitive discharge power supply, the base width of the half sine must be longer than 2,6 ms.

Slow Bumpers B1, B2

Short PS standard elements

required current : ∿ 265 A ± 30%

stability : $\Delta I/_I \leqslant 10^{-3}$

If powered with a capacitive discharge power supply, the base width of the half sine must be longer than 2,6 ms.

Septum Magnet 16

Deflection requirements are unchanged

Septum thickness d = 3 mm

Gap height : > 30 mm

Gap width : > 31 mm

Stability : $\frac{\Delta\theta}{\theta} \leqslant 4,6 \cdot 10^{-4}$

Half sine discharge length = $T_B \geqslant 1,3$ ms

Alternate operation between 2 different current levels required

Bump 16

Deflection requirements are unchanged;

Stability $\frac{\Delta\theta}{\theta} \leqslant 10^{-3}$

Half sine discharge length = $T_B \geqslant 2,6$ ms

Alternate operation between 2 different current levels required

5. Some System and Hardware Aspects

All the specifications have been discussed with the specialists concerned in order to make shure that they are well within technical reach [9]. The aim of this chapter is just to give a rough outline of the hardware design principles and system components which have not been mentioned yet.

It is suggested to have full computer control over all parts of the system. Due to the remarkable stability of the operation as observed during the tests with an experimental set-up, only one servo loop is proposed to counteract a slow drift of the beam position at the ES which results in an unequal intensity distribution over the duration of the ejected beam. The rather delicate settings of the individual program steps of FB1 and FB2 should be made by hand and are expected to stay constant over periods of hours.

At present, efforts are made to get all existing and planned ejection equipment under computer control[10]. Most of the continuous transfer system equipment will have similar or even identical components. The ejection computer will anyway be less occupied during the acceleration cycle dedicated to SPS injection. Therefore it is preferable to use the existing ejection system computer rather than to install a new one.

One determinating factor for the beam losses during CT is the electrostatic septum thickness. Its installation in a long straight section will give flexibility for further improvements (like use of wires). The fast programmed bumpers may be split up into one dipole providing a simple 23 μs flat top pulse and another the programmed part. Thus, the current load for the thyratrons in the complicated 11 steps high voltage generator could be reduced and a part of the experimental set-up equipment could be reused.

The beam diagnostic should comprise besides the standard digital data acquisition (efficiency, surveillance of uniform ejected intensity, integrated losses at ES and SM16) a powerful analog signal observation system with steady display on a storage scope. Proposed detectors in addition to the CPS equipment are :

- fast beam current transformer for observation of the internal and external beam;
- fast beam loss monitor at the ES and SM16 position;
- an electrostatic pick-up in front of the ES;
- a medium fast beam current transformer between SM16 and first beam dump and another near the beam switch ISR's - SPS;

further a miniscanner at the ES might be useful and fast sampling equipment in connection with the mini-toposcope in front of SM16 or in the external beam.

The operation will be combined with an adiabatic debunching procedure which is part of another study still under way (D. Boussard).

6. System Cost Estimate and Tentative Time Schedule

A cost estimate of the CT system has been carried out on a preliminary base and the parts covered by Lab. I and Lab. II are given separately.

The following list indicates the hardware and the person taking the technical responsibility. The time schedule given in Fig. 16 is based on the present staff situation and work load in the CPS. The system should be ready by September/October 1975.

Persons in charge	Hardware	Covered by Lab. II
D. Fiander	Programmable high voltage pulse generator; pulsed HV power supplies; pulse forming networks; controls, cable work, dipoles, spare parts	700 kfrs.

Persons in charge	Hardware	Costs covered by Lab. II
C. Germain	Electrostatic septum, HV supply, controls, spare unit	250 kfrs.
F. Rohner	Quadrupoles, dipole bumpers, pulsed power supplies, cable work, controls	310 kfrs.
D. Bloess	Computer controls	190 kfrs.
A. Krusche	Timing, beam diagnostics	100 kfrs.
	Lab. II Total	1'600 kfrs.

Persons in charge	Hardware	Costs covered by Lab. I
F. Rohner	Power supply for bump 16, cable work, controls	110 kfrs.
D. Bloess	Septum magnet 16, power supply, cables, interlocks + controls	630 kfrs.
Coordination U. Jacob	installation costs	∿ 250 kfrs.
	Lab. I Total	990 kfrs.

7. Summary

The installation possibilities of an optimized continuous transfer system (CT) in the CPS have been studied and two solutions are found which both represent the theoretically most favourable arrangement. The first scheme is grouped around an electrostatic septum (ES) in straight section 81 and the second groups around an ES in ss 31.

The first solution interferes mainly with the present layout of the slow extraction scheme and requires therefore a considerable installation effort concentrated in a special shut-down in 1975.

The second solution shows no installation difficulties but requires some experience in the behaviour of a high intensity beam under conditions where the beam is sausaged around most of the ring.

It is proposed to try to get this experience in the forthcoming months and decide for the second solution (ES31) provided there is no evidence for unwanted side effects. The given element specifications hold for both solutions and have been worked out on the basis of emittance estimates for the future high intensity beam and a transfer momentum of 12 GeV/c.

8. Acknowledgements

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D. Fiander	H. Riege
C. Germain	F. Rohner
W. Hardt	J.C. Soulié
L. Henny	P.H. Standley
U. Jacob	Ch. Steinbach
K.H. Kissler	R. Tinguely
W. Kubischta	E. Weisse
H. Kugler	C.J. Zilverschoon
J.H.B. Madsen	

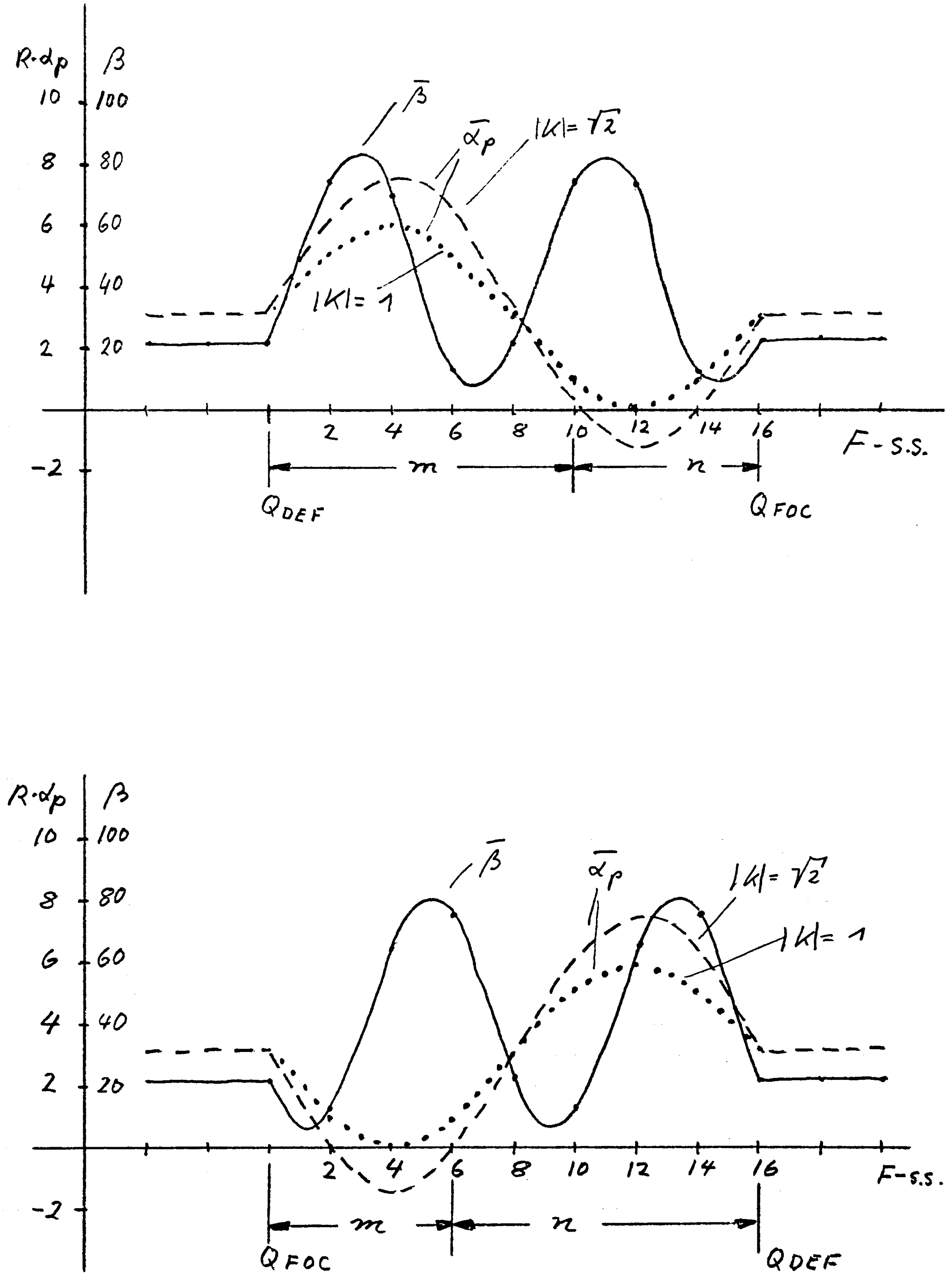


Fig. 2: Momentum compaction and betatron amplitude function between quadrupoles in λ distance

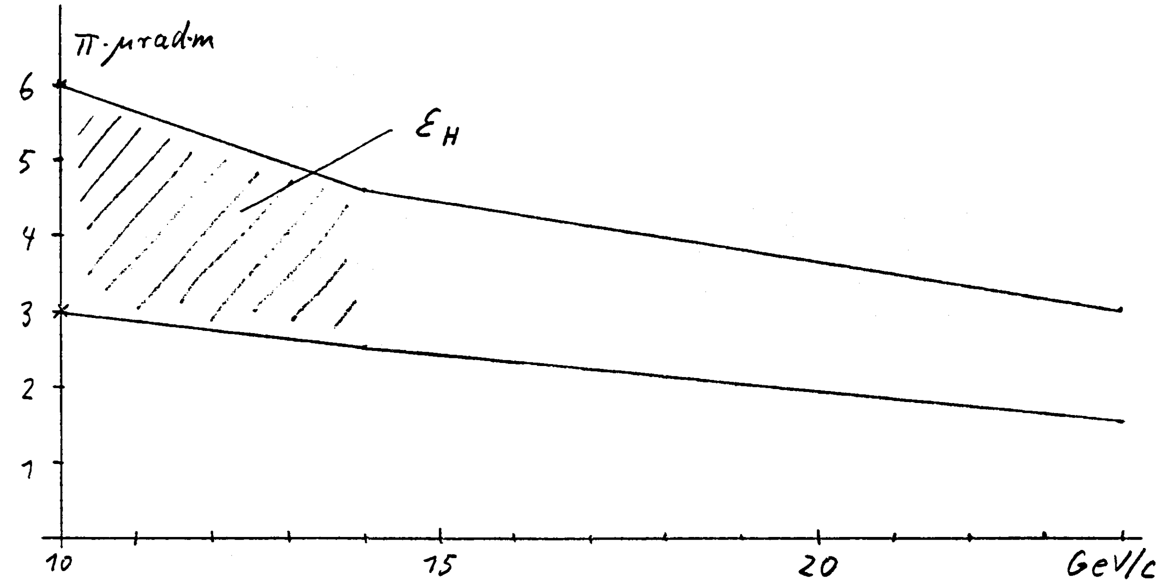
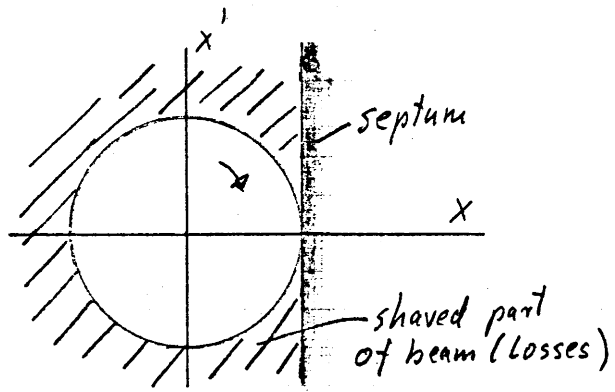


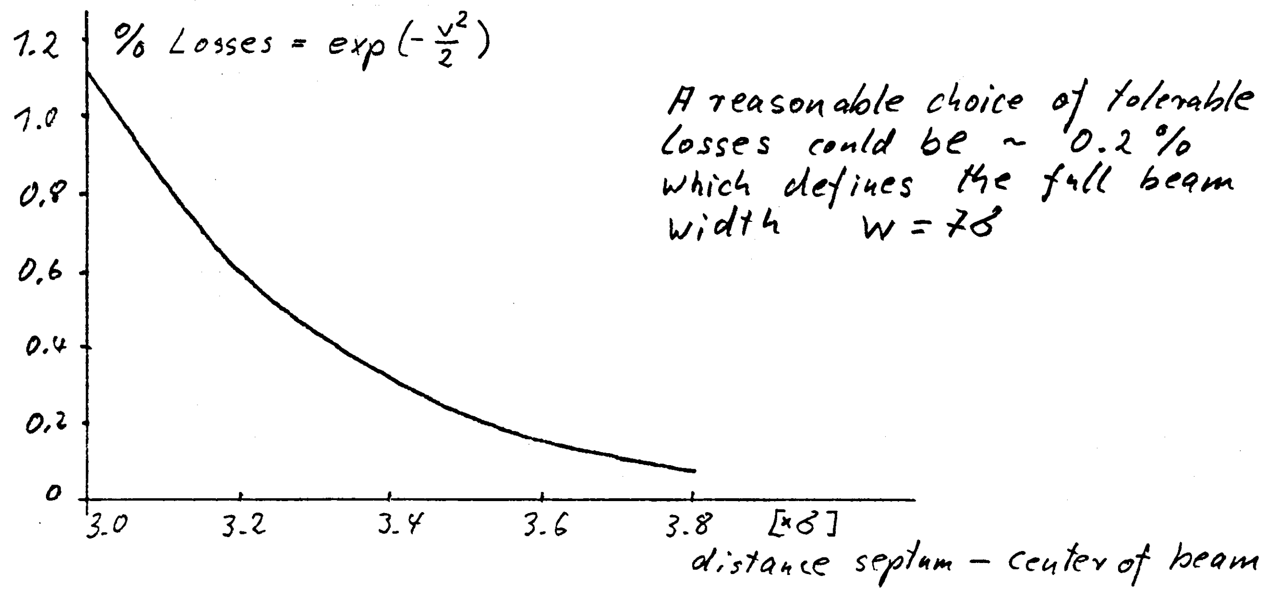
Fig. 3 : Estimated horizontal beam emittance of high intensity CPS [5)]



The ellipse contains $\iint \rho \, dx\,dx' = 1 - e^{-\frac{v^2}{2}}$ of all particles [11)], where

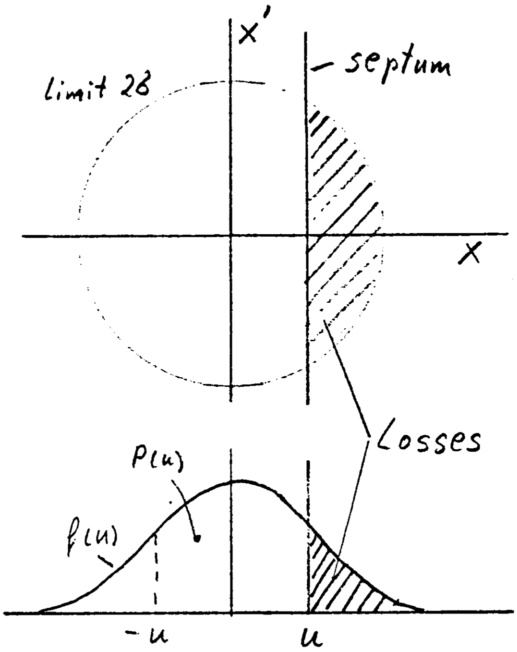
$\rho = \frac{1}{2\pi\sigma_1\sigma_2} \exp(-\frac{v^2}{2})$

and $v^2 = \frac{x^2}{\sigma_1^2} + \frac{x'^2}{\sigma_2^2} = (\frac{x}{\sigma})^2$



A reasonable choice of tolerable losses could be ~ 0.2 % which defines the full beam width $W = 7\sigma$

Fig. 4 : Definition of beam width of the circulatin beam

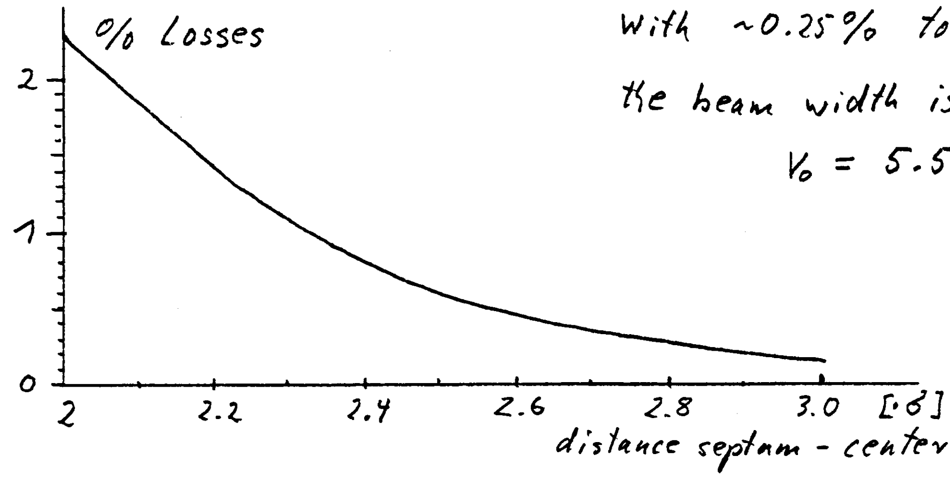


A fast extracted beam meets an obstacle only once; therefore only the shaded part in the phase plane (or profile) is lost.

With $P(u) = \int_{-u}^{+u} f(u)\,du$ 11)

the losses become

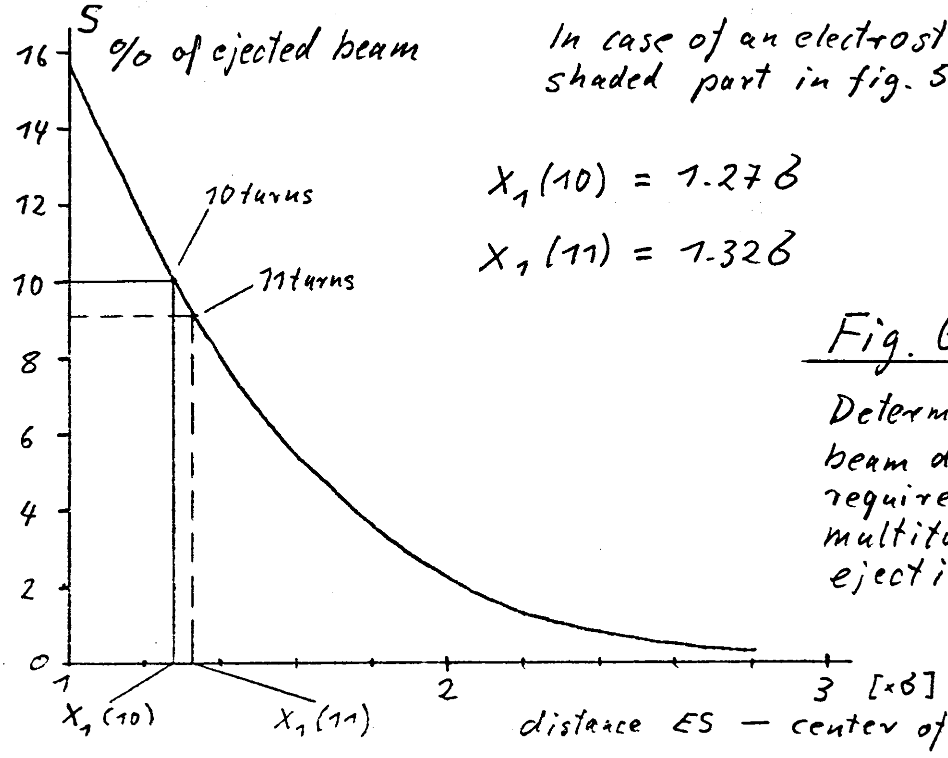
$$L = 0.5\,[1 - P(u)]$$



With ~0.25% tolerated losses the beam width is defined as

$$V_0 = 5.5\,\sigma$$

Fig. 5: Definition of beam width of a fast extracted beam



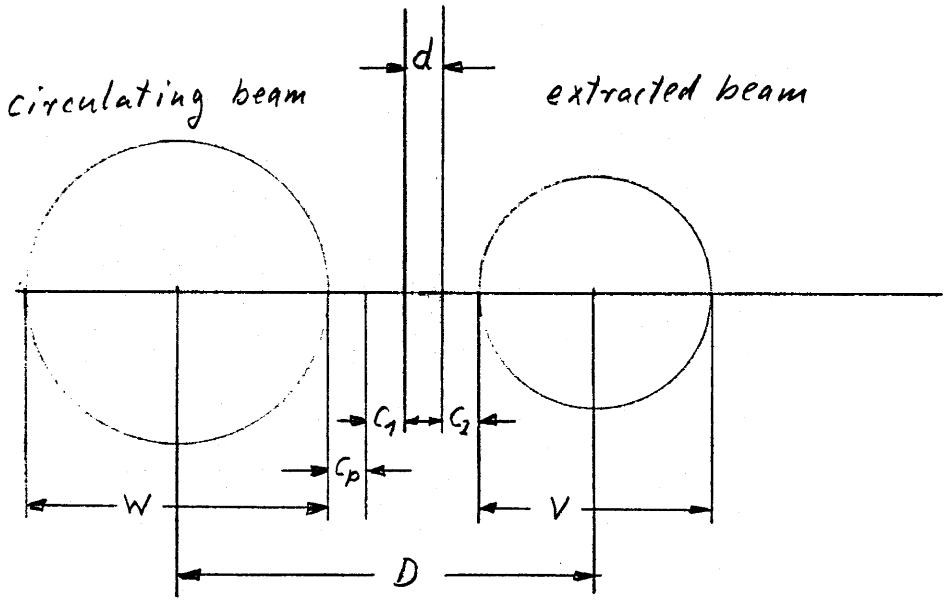
In case of an electrostatic septum the shaded part in fig. 5 is ejected

$$X_1(10) = 1.27\,\sigma$$

$$X_1(11) = 1.32\,\sigma$$

Fig. 6:

Determination of 1. step beam displacement requirements for a multiturn shaving ejection



Required beam diplacement at extractor magnet:

$$D = \frac{W}{2} + \frac{V}{2} + d + C_p + C_1 + C_2$$

W : width of circulating beam

V : width of extracted beam *)

d : septum thickness

C_p : clearance for effect of momentum spread

C_1, C_2: clearance

*) the effect of momentum spread is included, so:

$$V = \sqrt{V_0^2 + \left(k\alpha_p \cdot \frac{\Delta p}{p}\right)^2}$$

Fig 7: Definition of beam displacement requirement at a septum

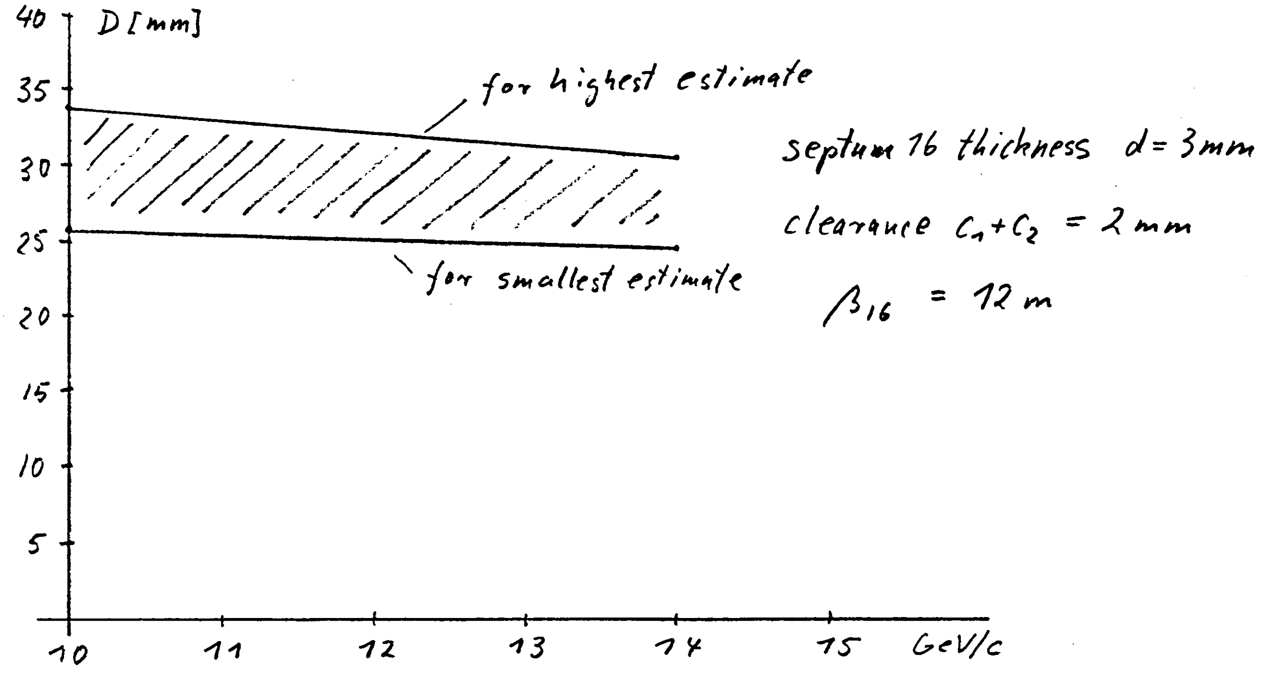


Fig. 8 : Anticipated displacement requirements for the high intensity beam at SM16

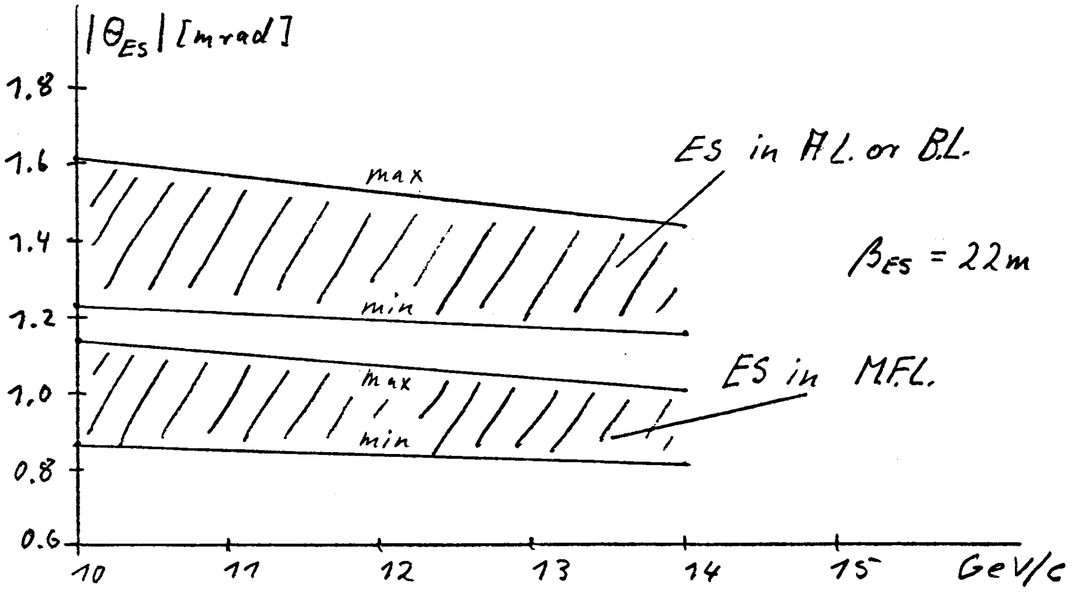


Fig. 9 : Deflection angle requirements of electrostatic septum

(M.F.L. = Most Favourable Location)

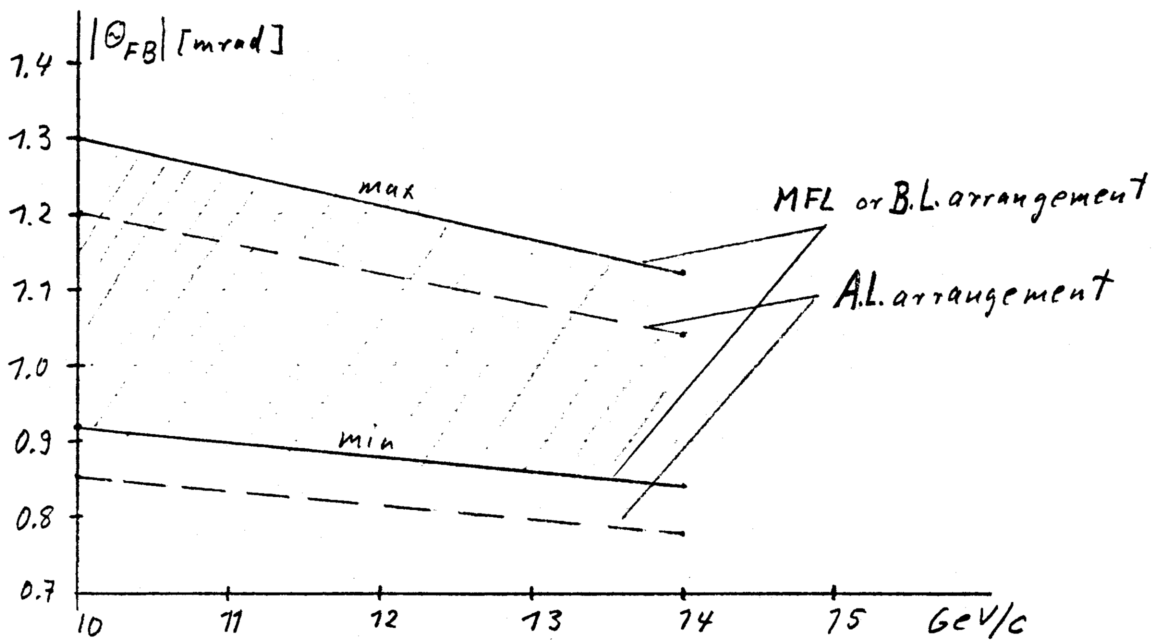


Fig. 10 : Fast bump deflection angle (highest step of 10 turns ejection)

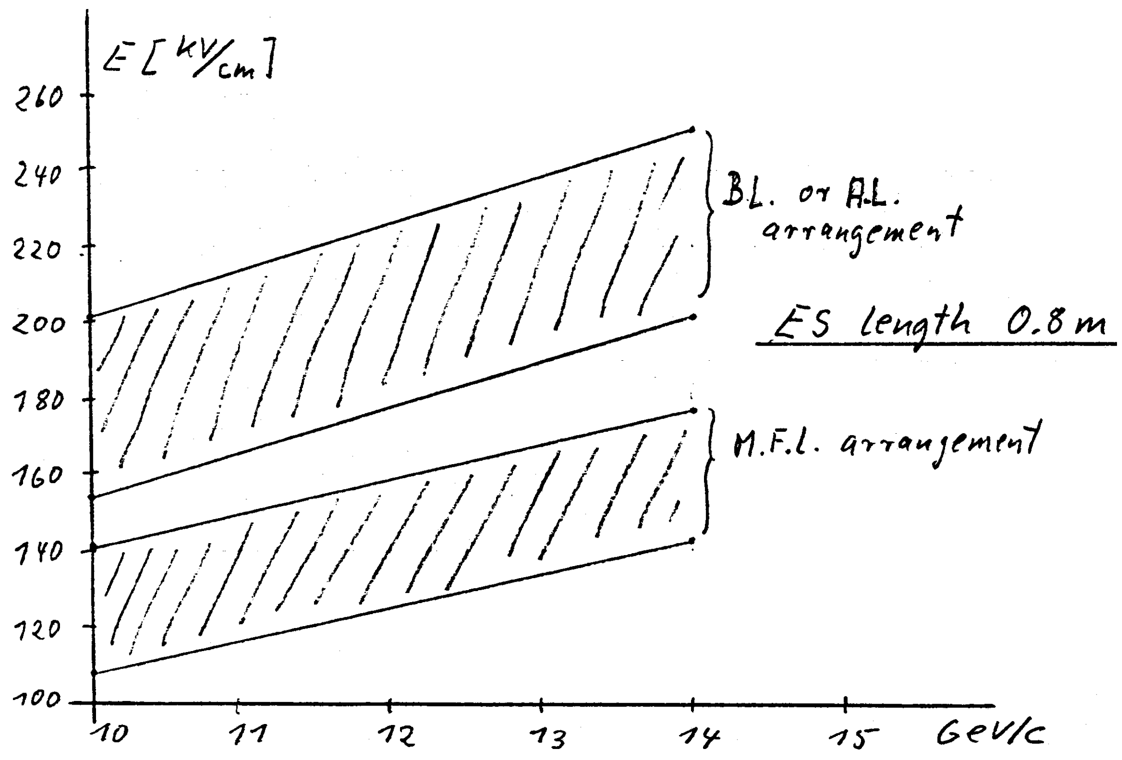


Fig. 11 : Field strength requirement of a 80 cm long electrostatic septum (possible length when housed in a short straight section)

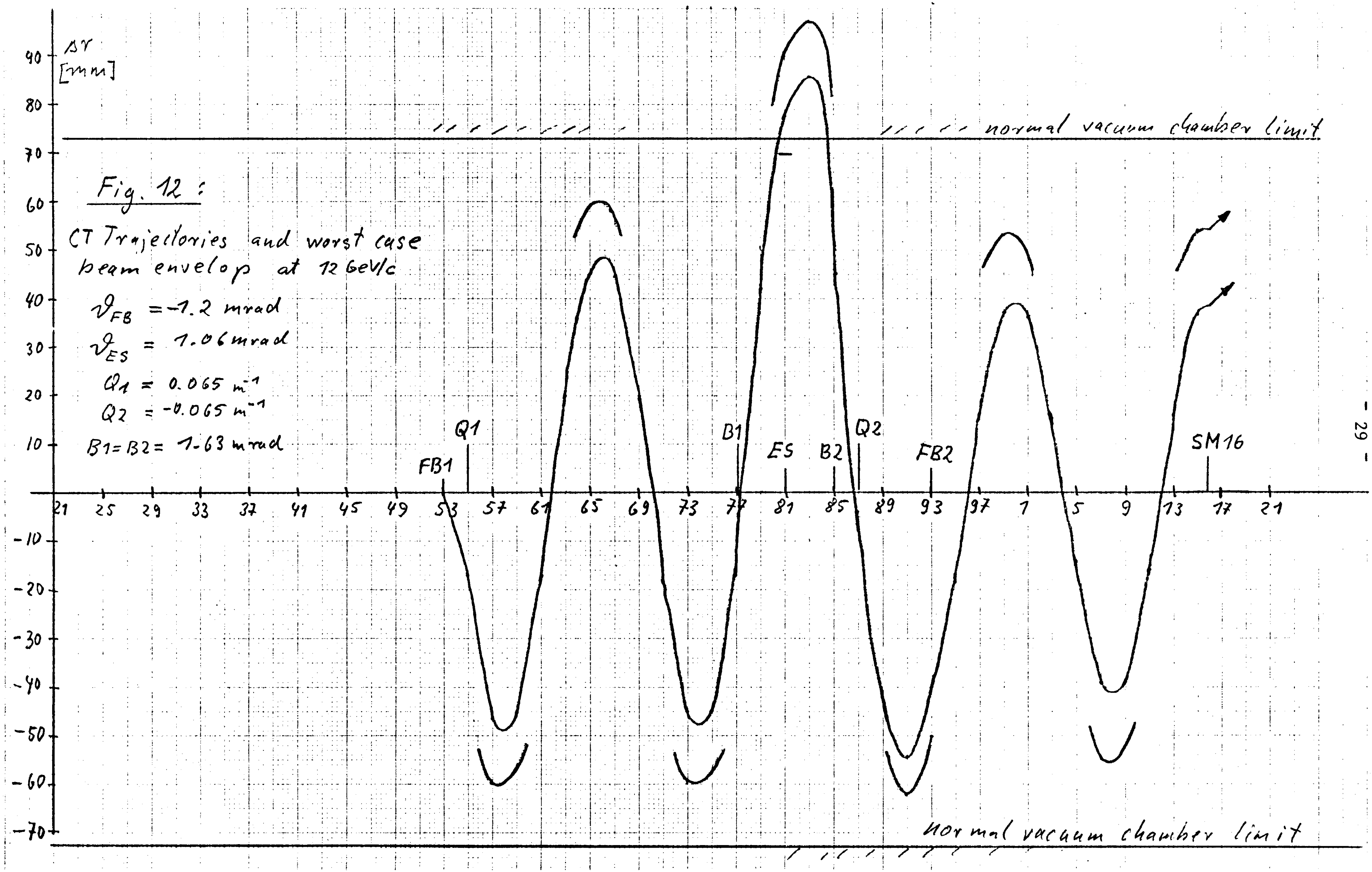


Fig. 12 :

CT Trajectories and worst case beam envelop at 12 GeV/c

$\vartheta_{FB} = -1.2$ mrad

$\vartheta_{ES} = 1.06$ mrad

$Q_1 = 0.065\ m^{-1}$

$Q_2 = -0.065\ m^{-1}$

$B1 = B2 = 1.63$ mrad

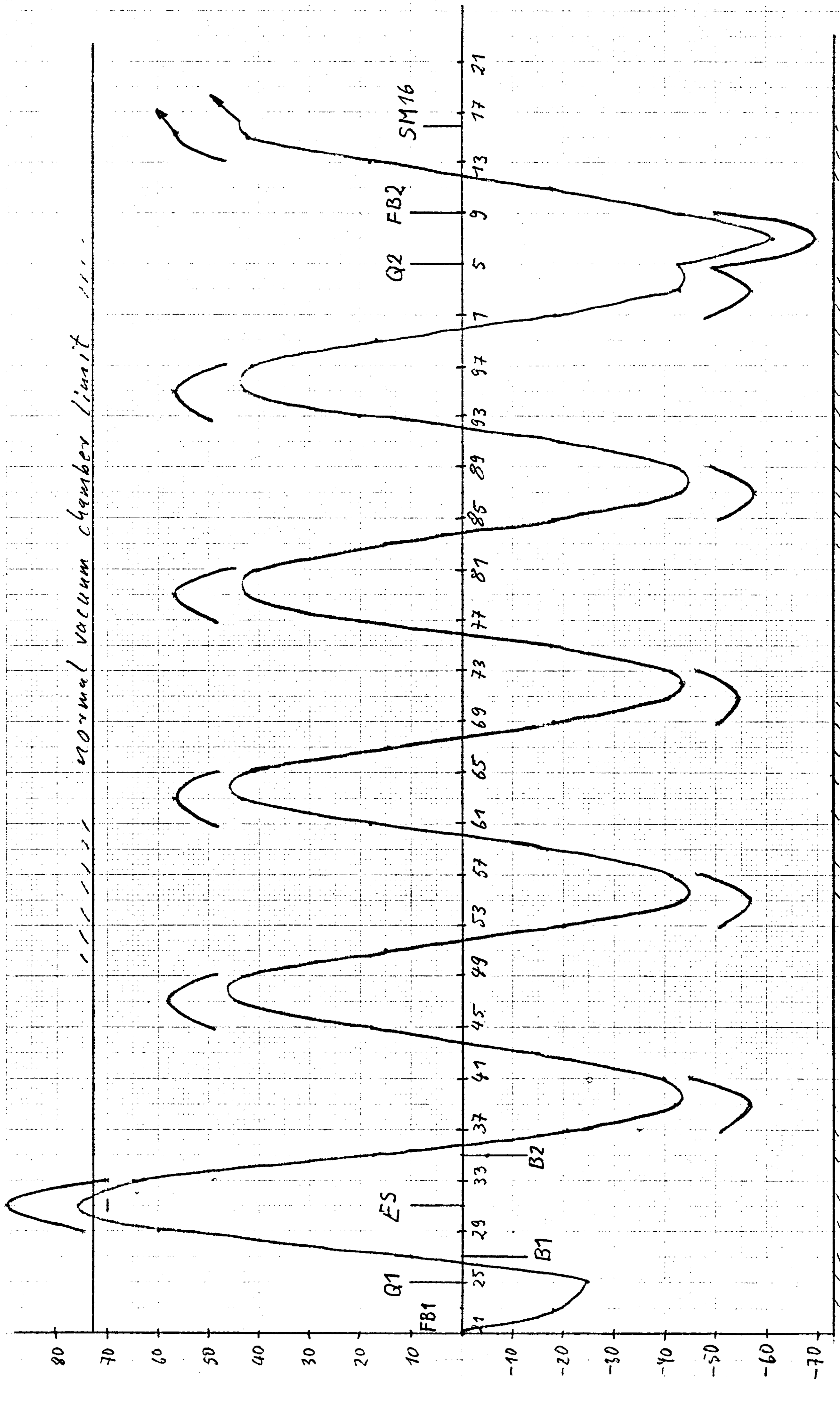


Fig. 13: CT Trajectories and worst case beamenvelop

$\vartheta_{FB} = -1.2$ mrad B1 = B2 = 1.63 mrad

$\vartheta_{ES} = 1.06$ mrad Q1 = −Q2 = $-0.065\ m^{-1}$

Phase plots

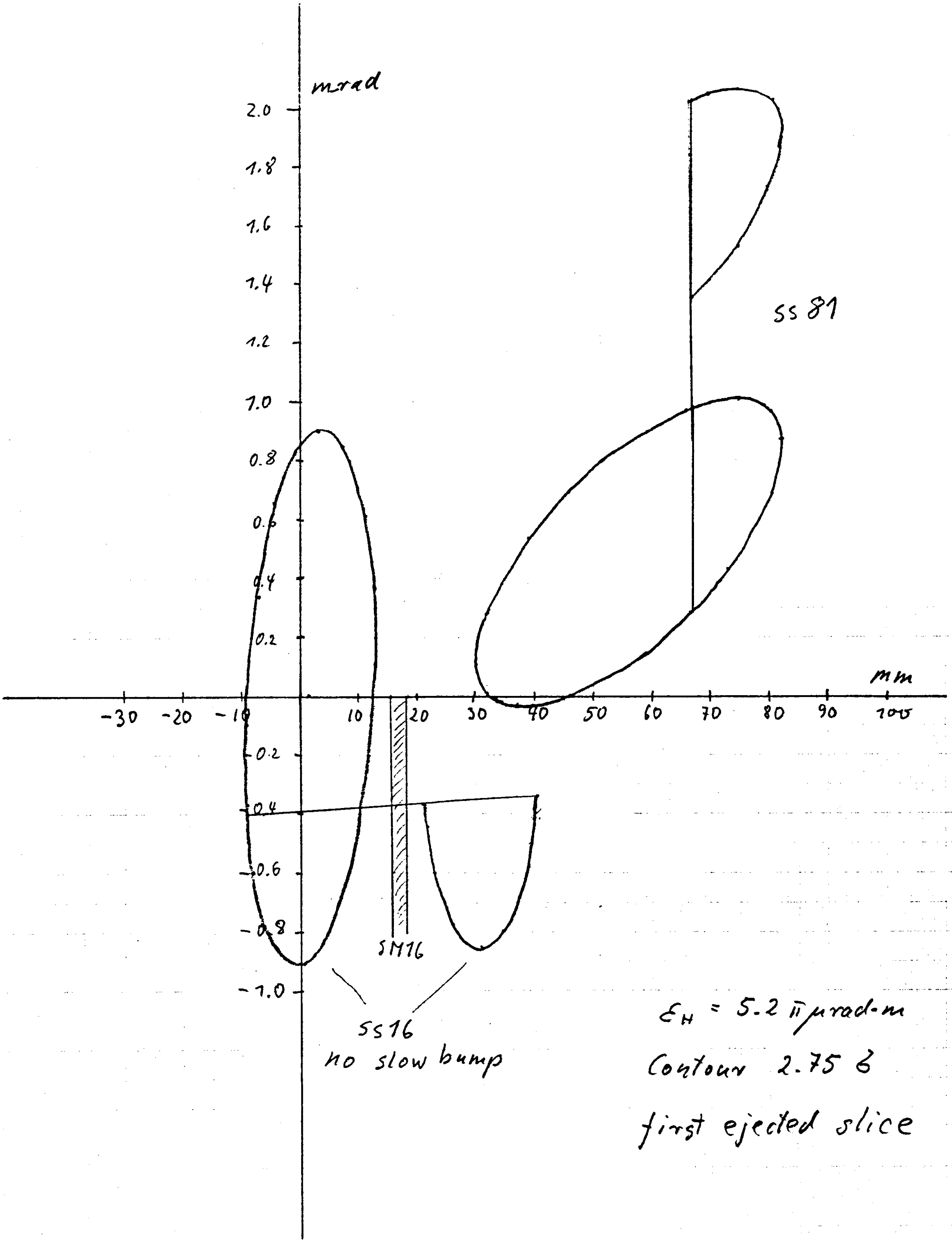
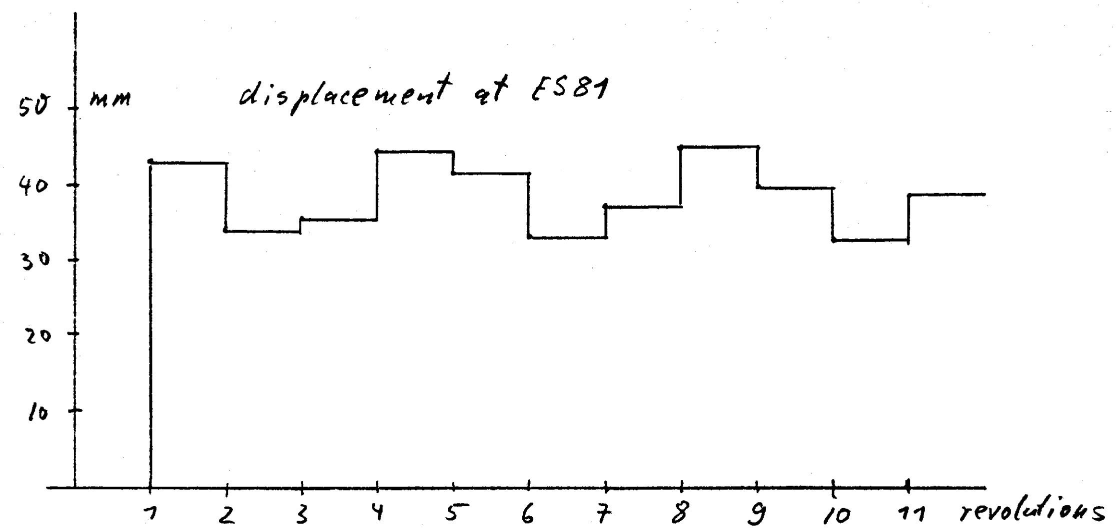
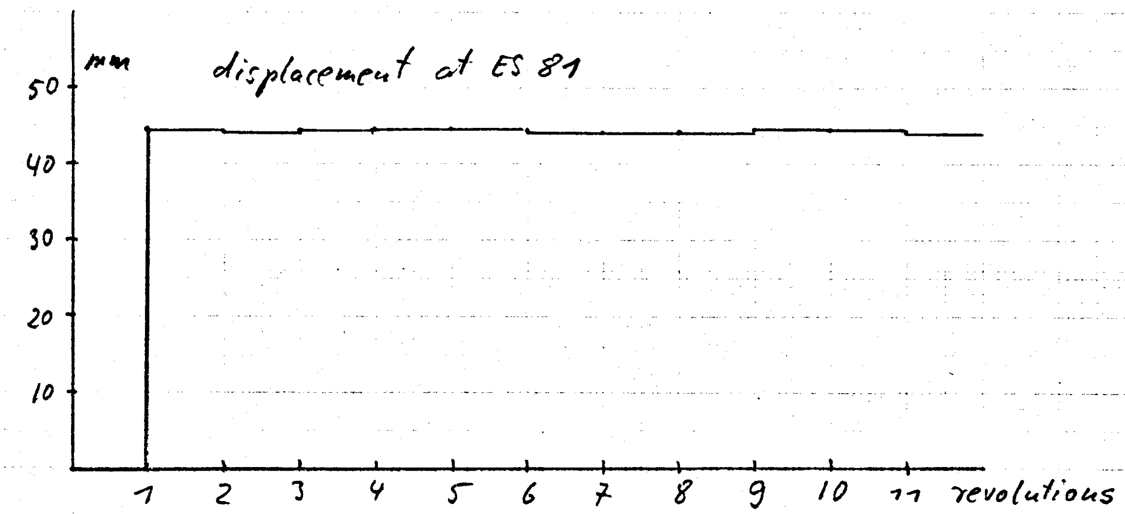


Fig. 14

Coherent oscillations

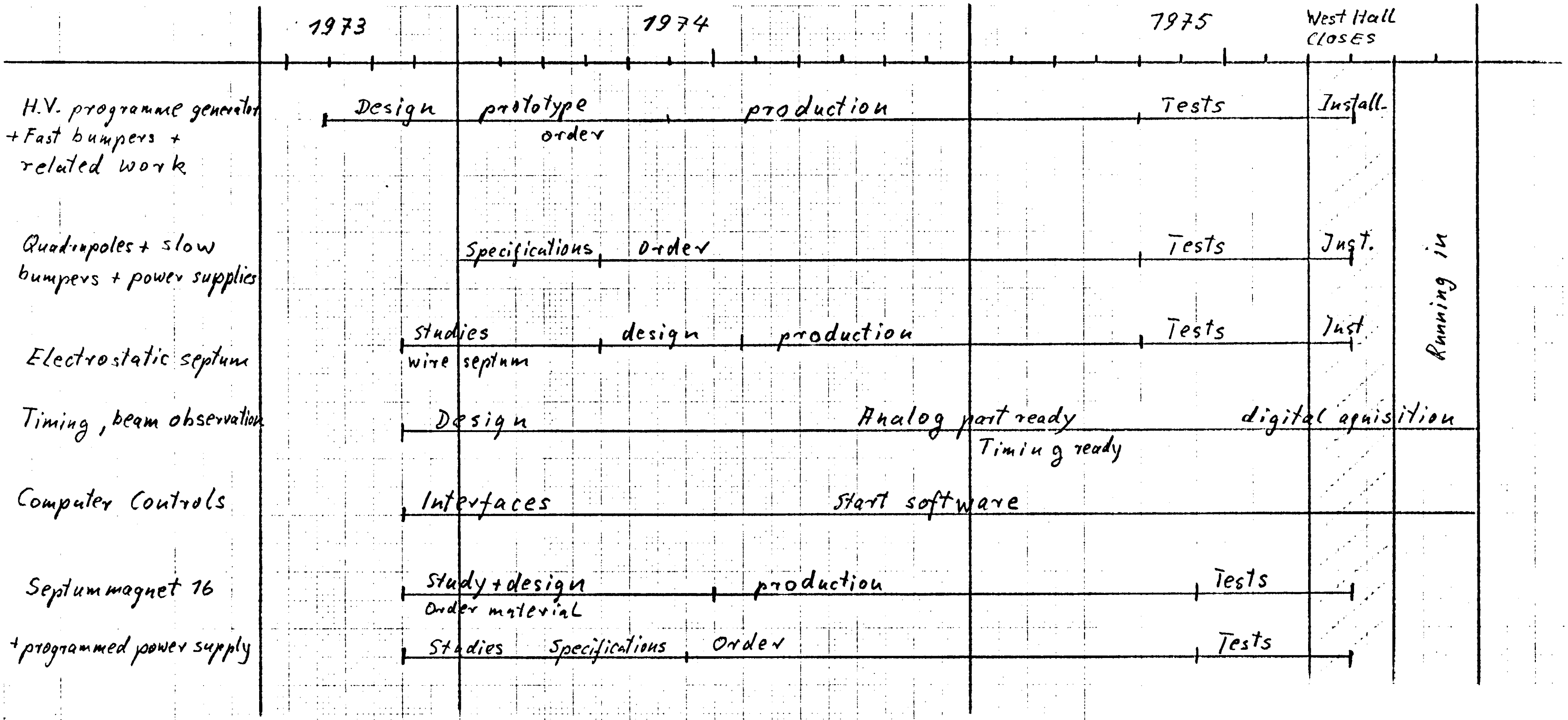


Example of coherent oscillations after excitation of fast bump with long flat top pulse [-1.2 mrad).
Conditions: $Q_H = 6.25$ (clean machine)
$K_{55} = - K_{87} = 0.065\,m^{-1}$ (then $Q_H = 6.26$)
$\vartheta_{53} = \vartheta_{93} = -1.2$ mrad



Coherent oscillations after matching of quadrupoles and fast bumpers.
Conditions: $Q_H = 6.25$ (clean machine)
$K_{55} = 0.07\,m^{-1}$; $K_{87} = -0.055\,m^{-1}$ ($Q_H = 6.234$)
$\vartheta_{53} = -1.2$ mrad; $\vartheta_{93} = -1.32$ mrad

Fig. 15



Tentative Time Schedule for CPS-SPS Continous Transfer Project

Fig. 16

APPENDIX A

In the arrangement

$$\begin{array}{ccc} S_1/Q & \text{———} & S_2 \\ | & \Delta\psi & | \\ \alpha_p, \alpha'_p, \beta_1 & & \beta_1 \end{array}$$

the simplified transfer matric between points S_1 and S_2 without quadrupole Q be :

$$M_1 = \begin{pmatrix} \cos\Delta\psi & \beta_1 \cdot \sin\Delta\psi \\ -\dfrac{\sin\Delta\psi}{\beta_1} & \cos\Delta\psi \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}$$

where $\Delta\psi$ is a multiple of the phase advance between equal cells. Then after insertion of the quadrupole with its strength k, α_p transforms as

$$\begin{pmatrix} \bar{\alpha}_p \\ \bar{\alpha}'_p \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} 1 & 0 \\ k & 1 \end{pmatrix} \begin{pmatrix} \alpha_p \\ \alpha'_p \end{pmatrix} = \begin{pmatrix} a_{11} + k \cdot a_{12} & a_{12} \\ a_{21} + k \cdot a_{22} & a_{22} \end{pmatrix} \begin{pmatrix} \alpha_p \\ \alpha'_p \end{pmatrix}$$

or

$$\bar{\alpha}_p = (a_{11} + k \cdot a_{12})\, \alpha_p + a_{12} \cdot \alpha'_p$$

for k = 0 we have $\alpha_p = \bar{\alpha}_p \rightarrow \alpha'_p = \alpha_p \dfrac{(1 - n_{11})}{n_{12}}$

then $\bar{\alpha}_p = \alpha_p\,(1 + k \cdot n_{12})$

or $\underline{\bar{\alpha}_p = \alpha_p\,(1 + k\beta_1 \sin\Delta\psi)}$ (11)

The betatron amplitude function transforms in this approximation as :

$$\bar{\beta} = \beta_1 \, (a_{11} + K a_{12})^2 + \frac{1}{\beta_1} \cdot a_{12}^2$$

or

$$\bar{\beta} = \beta_1 \, (\cos^2 \Delta\psi + 2\cos \Delta\psi \cdot K \cdot \beta_1 \sin \Delta\psi + K^2 \beta_1^{\,2} \sin^2 \Delta\psi + \sin^2 \Delta\psi)$$

$$\underline{\bar{\beta} = \beta_1 \, (1 + K\beta_1 \cdot \sin^2 \Delta\psi + K^2 \beta_1^2 \sin^2 \Delta\psi)}$$

APPENDIX B

In the configuration : S_1 — Q — S_2

$$\begin{array}{ccc} S_1 & Q & S_2 \\ | & | & | \\ \beta_1 & \beta_2 & \beta_3 \end{array}$$

be

$$M_1 = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta_2}{\beta_1}} \cos \Delta\psi_1 & \sqrt{\beta_1 \ \beta_2} \sin \Delta\psi_1 \\ -\frac{\sin \Delta\psi_1}{\sqrt{\beta_1 \ \beta_2}} & \sqrt{\frac{\beta_1}{\beta_2}} \cos \Delta\psi_1 \end{pmatrix}$$

the transfer matrix between S_1 and Q, and

$$M_2 = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} = \begin{pmatrix} \sqrt{\frac{\beta_3}{\beta_2}} \cos \Delta\psi_2 & \sqrt{\beta_2 \beta_3} \sin \Delta\psi_2 \\ -\frac{\sin \Delta\psi_2}{\sqrt{\beta_2 \ \beta_3}} & \sqrt{\frac{\beta_2}{\beta_3}} \cos \Delta\psi_2 \end{pmatrix}$$

the transfer matrix between Q and S_2.

Then the total transfer matrix between S_1 and S_2 is given by

$$M = M_2 \cdot Q \cdot M_1 \quad \text{where} \quad Q = \begin{pmatrix} 1 & 0 \\ K & 1 \end{pmatrix}$$

or

$$M = \begin{pmatrix} a_{11} (b_{11} + Kb_{12}) + b_{12} \cdot a_{21} & a_{12} (b_{11} + Kb_{11}) + b_{12} \cdot a_{22} \\ a_{11} (b_{21} + Kb_{22}) + b_{22} \cdot a_{21} & a_{12} (b_{21} + Kb_{22}) + b_{22} \cdot a_{22} \end{pmatrix}$$

and the vector

$$\begin{pmatrix} y_2 \\ y'_2 \end{pmatrix} = M \begin{pmatrix} y_1 \\ y'_1 \end{pmatrix}$$

We are only interested in the displacement y_2 which is for $y_1 = 0$:

$$y_2 = y'_1 \left[a_{12} (b_{11} + Kb_{12}) + b_{12} \cdot a_{22} \right]$$

$$y_2 = y'_1 \sqrt{\beta_1 \beta_3} (K\beta_2 \sin \Delta\psi_1 - \sin \Delta\psi_2 + \sin \Delta\psi_1 \cdot \cos \Delta\psi_2 + \sin \Delta\psi_2 \cdot \cos \Delta\psi_1)$$

$$\underline{y_2 = y'_1 \sqrt{\beta_1 \beta_3} (\sin (\Delta\psi_1 + \Delta\psi_2) + K\beta_2 \sin \Delta\psi_1 \cdot \sin \Delta\psi_2)}$$

APPENDIX C1

Required Quadrupole Current

Normalized strength $|k\beta| = \sqrt{2}$; $\beta = 22$ m

therefore $|k| = 0,0643\ m^{-1}$

where $k = \frac{G \cdot L \cdot I}{p_o} \cdot 0,2998\ [m^{-1}]$

For the short standard quadrupoles it is $g \cdot \ell = 3,5$ T at 600 A; or

$$GL = \frac{3,5}{600} = 5,83 \cdot 10^{-3}\ \frac{T}{A}$$

then $$I = \frac{k \cdot p_o}{0,2998 \cdot G \cdot L} = \frac{0,0643 \cdot 12}{0,2998 \cdot 5,83} \cdot 10^3 = \underline{441.2\ A}$$

Slow Bump Current

The electrostatic septum is normally placed at a distance of a $\approx$ 70 mm from the centre of the vacuum chamber. Taking the minimum estimated emittance at 12 GeV/c (which gives the higher displacement requirement) $\varepsilon_H = 2,8\ \pi$ µrad·m and $\beta = 75$ m (valid for the circulating beam) the displacement is $y = 70 - 3,5 \cdot \frac{1}{2} \sqrt{\varepsilon_H \cdot \beta} = 70 - 1,75 \sqrt{2,8 \cdot 75} = 45$ mm. The bump has its maximum at the ES, therefore

$$y'_{bump} = \frac{y}{\sqrt{\beta_1 \beta_2}} = \frac{45}{22} = 2,05 \text{ mrad}$$

The short CPS standard high energy dipoles have $BL = 0,31 \cdot 10^{-3}\ \frac{Tm}{A}$

then with $$y' = \frac{BL}{p_o} \cdot 0,2998 \cdot I$$

$$I = \frac{2{,}05 \cdot 12}{0{,}31 \cdot 10^{-3} \cdot 0{,}2998} = \underline{265 \text{ A}}$$

To add enough margin for a local radial orbit displacement, which can easily reach $\pm$ 10 mm. Therefore $\underline{I = 265 \text{ A} \pm 30\%.}$

APPENDIX C2

Gap Width of Electrostatic Septum

The first shaved pieces of the beam ellipse have the highest emittance and the highest horizontal dimensions. The ellipse is cut at a distance of $x = 1{,}27\ \sigma$. With a half width $\frac{v}{2} = 2{,}75\ \sigma$ as defined for a beam passing an obstacle only once the beam occupies $\Delta x = \frac{v}{2} - x \simeq 1{,}5\ \ \sigma$ between the electrodes of the ES. With $\varepsilon_H = 5{,}2\ \pi$ µrad·m and $\beta_{ES} = 75$ m we get with

$$\sigma = 0{,}5 \quad \sqrt{\varepsilon_H \cdot \beta_{ES}}$$

$$\Delta x = 0{,}75\ \sqrt{5{,}2 \cdot 75} = 15 \text{ mm}$$

With 3 mm clearance the gap width is about 18 mm.

Gap Height of ES

The betatron amplitude function behaves between the quadrupoles as

$$\bar{\beta} = \beta\ (1 + K\beta \sin^2 m + K^2\ \beta^2 \sin^2 m)$$

in sections of the same type. For the vertical plane it is simply $\beta = \beta_D$ and $K = -\frac{\sqrt{2}}{\beta_F}$ which gives at the place of the ES where m = 10 ss :

$$\bar{\beta}_v = 12 \left(1 - \sqrt{2} \cdot \frac{12}{22} \cdot \sin 450^o + 2 \cdot \left(\frac{12}{22}\right)^2 \cdot \sin^2 225^o\right)$$

$$\bar{\beta}_{v|ES} = 6{,}3 \text{ m}$$

The circulating beam has a width of $v = 5{,}5\sigma = 2{,}75 \cdot \sqrt{\varepsilon_v \cdot \beta_v}$.

With $\varepsilon_v = 3\ \pi$ µrad·m [5] it is

$v \simeq 12$ mm which determines the minimum septum height. Some clearance for a vertical position error should be allowed. Therefore a minimum septum height of 20 mm seems reasonable.

Stability Requirements

A. Fast Bump FB1 - FB2

It is very complicated to determine the stability requirements for all 10 or 11 steps under all circumstances. But it is rather easy for the first step which may be a good approach to the rest.

Referring to Fig. 5, the first ejected piece contains

$$S = \frac{1}{2} \left[1 - P(u) \right] \text{ of the beam.}$$

A variation of u gives $\Delta S = P(u_2) - P(u_1) = \Delta P(u)$. Because of :

$$P(u) = \int_{-u}^{+u} f(u)\, du \quad \text{it is}$$

$$\frac{\Delta P(u)}{\Delta u} = f(u) \quad \text{or} \quad \Delta u = \frac{\Delta S}{f(u)}$$

with $u = 1,27$ and $\Delta S = 0,005$ (5% variation of 10% of the beam) it is

$$f(u = 1,27) = 0,18 \quad \text{and} \quad \Delta u = \frac{0,005}{0,18} = 0,028$$

The first step produces a displacement of $x = 2,3\ \sigma$, then the stability must be $\frac{\Delta x}{x} = \frac{0,028}{2,3} = 1,2\%$ in order to obtain an intensity variation of 5%. During the tests with the experimental set-up it was found that 1,5% change of the fast bump current produced an approximate ejected beam current variation of 10% [3]. Therefore, a stability of better than 1% may be sufficient.

B. Slow Bump

A variation $\Delta u = 0{,}028$ corresponds to a displacement of $\Delta x = 0{,}028 \cdot \sigma$. With $\sigma = 0{,}5 \sqrt{\varepsilon_H \cdot \beta_{ES}}$ and $\varepsilon_H = 2{,}8\ \pi$ µrad·m, and $\beta_{ES} = 75$ m it is $\Delta x = 0{,}2$ mm which produces ~ 5% intensity variation. The bump produces a displacement around 50 mm, therefore :

$$\frac{\Delta x}{x} = \frac{0{,}2}{50} = 4 \cdot 10^{-3}$$

which is a modest requirement. But the operation should be possible with a pencil or bright beam without loosing performance. In this case the emittance is expected to be roughly four times smaller [5]. Therefore, it is proposed to specify $\frac{\Delta x}{x} < 2 \cdot 10^{-3}$.

C. Quadrupoles

A variation of the quadrupole strength influences both the fast bump displacement and beam dimension at the electrostatic septum. In addition, imperfect slow bumps 16 and 81 produce a closed orbit deformation which is a function of the quadrupole strength.

a) FB1 produces a displacement

$$y = \theta \cdot \beta \left[\sin(f+m) + K\beta \sin f \sin m\right] = 2{,}3\ \sigma$$

then $$\frac{\Delta y}{y} = \theta\beta \cdot K\beta \sin f \cdot \sin m \cdot \frac{\Delta K}{K}$$

Replacing $\theta\beta$ and substituting $\Delta u = \frac{\Delta y}{\sigma}$ gives

$$\Delta u = \frac{\Delta S_1}{f(u_1)} = \frac{2{,}3}{\frac{\sin(f+m)}{K\beta \sin f \sin m} + 1} \cdot \frac{\Delta K}{K}$$

Remembering $K\beta = \sqrt{2}$; $f = 2$ ss; $m = 10$ ss; $f(u_1 = 1{,}27) = 0{,}18$ the first ejected slice variation is :

$$\Delta S_1 = 0{,}17 \cdot \frac{\Delta K}{K}$$

b) A variation ΔK produces a change $\Delta\sigma$, or $\sigma_2 = \sigma + \Delta\sigma$. The first beam slice is cut at a constant distance $x_1 = \sigma \cdot u_1 = \sigma_2 \cdot u_2$.

With $\Delta u = u_1 - u_2 = u_1 \cdot \frac{\Delta\sigma}{\sigma} \cdot \frac{1}{1 + \frac{\Delta\sigma}{\sigma}} \approx u_1 \cdot \frac{\Delta\sigma}{\sigma}$

the variation of the first slice becomes

$$\Delta S_2 = \Delta u \cdot f(u_1) = u_1 \cdot f(u_1) \cdot \frac{\Delta\sigma}{\sigma}$$

From $\sigma = 0{,}5 \cdot \sqrt{\varepsilon \cdot \bar{\beta}} = 0{,}5 \cdot \sqrt{\varepsilon\beta} \cdot \sqrt{1 + K.\beta \sin^2 m + K.^2\beta^2 \sin^2 m}$

one finds $\frac{\Delta\sigma}{\Delta K}$ and $\frac{\Delta\sigma}{\sigma}$. Putting the values for m, $K\beta$ and with $\varepsilon = 2{,}8\ \pi$ µrad·m and $u_1 = 1{,}27$ it follows $\Delta S_2 = 0{,}114 \cdot \frac{\Delta K}{K}$.

c) A calculation with the SYNCH programme showed that under realistic conditions bump 16 and 81 together with a variation of the quadrupole strength produce a displacement variation at the ES which follows the equation

$$\Delta x = 7{,}9 \cdot \frac{\Delta K}{K}$$

The variation of the first slice is then :

$$\Delta S_3 = f(u_1) \cdot \Delta u = f(u_1) \cdot \frac{\Delta x}{\sigma} = \frac{7{,}9}{\sigma} \cdot f(u_1) \cdot \frac{\Delta K}{K}$$

With $\sigma = 0{,}5 \sqrt{\varepsilon \cdot \bar{\beta}}$ and $\varepsilon = 2{,}8\ \pi$ µrad·m; $\bar{\beta} = 75$ m it is

$$\Delta S_3 = 0{,}19 \frac{\Delta K}{K}$$

The total intensity variation of the first ejected slice is then

$$\Delta = \Delta S_1 + \Delta S_2 + \Delta S_3 = 0{,}475 \cdot \frac{\Delta K}{K}$$

If $\Delta = 0{,}005$ (5% of 10% of the beam), the allowed quadrupole strength variation is

$$\underline{\frac{\Delta K}{K} = 1\%}$$

Again it is proposed to include an operation with a pencil beam which leads to $\frac{\Delta K}{K} \leqslant 5 \cdot 10^{-3}$.

APPENDIX C3

Uniform Field Dimensions of Fast Bump Dipoles

FB1 is uncritical because the beam passes more or less through the centre. But the part of the beam which is kicked by the ES is displaced in FB2 by the amount

$$y = \theta_{ES} \cdot \beta \, (\sin (n + s) + K\beta \cdot \sin s \cdot \sin n)$$

where $\beta = 22$ m, $K\beta = -\sqrt{2}$; n = 6 ss; s = 6 ss,

$$\theta_{ES} = 1{,}1 \text{ mrad}$$

So $|y|_{FB2} = 41{,}3$ mm

The half beam width is $\frac{v}{2} = 2{,}75\ \sigma = 2{,}75 \cdot 0{,}5 \sqrt{\varepsilon_H \cdot 22}$

with $\varepsilon_H = 5{,}2\ \pi$ µrad·m : $\frac{v}{2} = 15$ mm

If one adds about 10 mm possible local closed orbit displacement and 2 mm for the effect of momentum spread, the uniform field should cover ± 68 mm. This is a large value and it may be worth envisaging an off centre installation of the dipole.

APPENDIX C4

Septum Magnet 16

a) Stability

SM16 will be used for fast extraction towards the ISR's and CT. The smallest expected horizontal emittance of a bright beam is of the order of $\varepsilon_H = 0{,}25\ \pi\ \mu\text{rad}\cdot\text{m}$. This holds for both a fast extraction at highest CPS energy and CT at a transfer momentum around 12 GeV/c [5].

The SM16 stability should be such that the emittance blow-up is small and difficult to measure. Assuming about 20% tolerable emittance blow up, the SM 16 deflection stability should be better than about 10% of half the beam size in the phase plane.

With $$y'_{max} = \sqrt{\frac{\varepsilon}{\beta}} = \sqrt{\frac{0{,}25}{12}} = 0{,}14 \text{ mrad}$$

the tolerable variation is $\Delta y' = 0{,}014$ mrad. SM 16 provides $\theta = 30$ mrad, therefore

$$\frac{\Delta\theta}{\theta} = \frac{0{,}014}{30} = 4{,}6 \cdot 10^{-4}$$

b) Discharge Length of Half Sine Excitation

One is interested to excite the septum magnet by a discharge power supply. The discharge length T_B of the half sine current should be long enough in order not to change the emittance of the ejected beam during the ejection. After simple calculation one gets

$$T_B = t_E \cdot \frac{90}{\text{arc cos } (1 - \frac{\Delta\theta}{\theta})}$$

Applying the above stability criterium and with an ejection length $t_E = 25\ \mu s$ one gets

$T_B = 1{,}3$ ms as minimum discharge length.

c) Gap Dimensions

The lowest transfer momentum for fast ejection and CT is assumed to be 10 GeV/c. Here the maximum estimated emittances are $\varepsilon_H = 6\pi$ µrad·m and $\varepsilon_v = 3\ \pi$ µrad·m, corresponding to a beam dimension of

$$v_H = 5.5\sigma = 2{,}75\ \sqrt{\varepsilon_H} \cdot \beta = 23{,}3\ \text{mm}$$

and $$v_v = 22{,}4\ \text{mm}.$$

With reasonable clearance the gap dimensions can be determined as :

gap height : $h = 30$ mm

gap width : $w = 31$ mm

Stability

Bump 16

The half beam size corresponding to the emittance $\varepsilon_H = 0{,}25\ \pi$ µrad·m is

$$2\sigma = 1{,}73\ \text{mm}.$$

Tolerating a variation $\Delta x = 0{,}17$ mm it becomes with a bump displacement of about $x = 50$ mm :

$$\frac{\Delta x}{x} = 3{,}4 \cdot 10^{-3}$$

which is a modest stability requirement. Therefore a specification of $\frac{\Delta x}{x} = 2 \cdot 10^{-3}$ is proposed.

Half Sine Discharge Length of Bumps

Slow bumps are normally not well matched, neither in amplitude nor in time. The switching-on process creates therefore coherent oscillations which may disturb a uniform shaving ejection.

Assume $\theta = \theta_o \cdot \sin \pi \cdot \frac{t}{T_B}$ with T_B = length of half sine be the description of a bump. Then the highest deflection increase seen by the particles when travelling between the bump dipoles becomes :

$$\Delta\theta = \pi \cdot \theta_o \cdot \frac{\Delta t}{T_B} \quad \text{at} \quad t = 0$$

where Δt = travelling time of particles between dipoles. The maximum displacement at a place with $\beta = \beta m$ is then

$$\Delta x = \pi \cdot \theta_o \cdot \frac{\Delta t}{T_B} \cdot \sqrt{\beta \cdot \beta m.}$$

The rest oscillation of a bump due to an amplitude or phase mismatch can roughly be described by one dipole with reduced amplitude, say by a factor of k.

Then the formula above can be applied, replacing θ_o by $k \cdot \theta_o$ and identifying Δt with the revolution time of the particles.

In the worst case all excited coherent oscillations of all bumps sum up. For two bumps one obtains

$$\Delta x_m = \frac{\pi \cdot \sqrt{\beta m}}{T_B} (\Delta t + K \cdot \Delta t_r) (\theta_1 \cdot \sqrt{\beta_1} + \theta_2 \cdot \sqrt{\beta_2})$$

With $\Delta t = 0{,}17\ \mu s$ ($\lambda/2$ bump)

$\Delta t_r = 2{,}1\ \mu s$

$k = 0{,}1$; $\beta_1 = 22$ m ; $\beta_2 = 12$ m; $\beta m = 75$ m

$\theta_1 = 2{,}3$ mrad ; $\theta_2 = 4.2$ mrad

it becomes $$T_B = \frac{260}{\Delta x_m} \ \mu s$$

Tolerating $\Delta x_m = 0{,}1$ mm at the electrostatic septum the minimum half sine discharge length becomes

$$\underline{T_B = 2{,}6 \text{ ms}}$$