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OPTIONS AND CONSTRAINTS IN THE DESIGN OF FUTURE CERN STORAGE-RING FACILITIES

by

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1. INTRODUCTION

The purpose of this report is to summarize briefly the present status of our studies on large proton storage rings which have been under way for a few months. In particular we want to indicate possibilities, limitations and compromises of interaction region layout, to outline some examples for further discussion, and to disseminate quickly some of our ideas on future CERN colliding-beam facilities. Since the studies will continue, it will be necessary to revise the contents of this report from time to time.

We are at present studying two models of a future CERN colliding-beam p-p project, viz:

(A) 400 GeV rings using normal iron magnets

(B) 400 GeV rings using superconducting magnets

As a sideline, we have given some thought to a superconducting conversion of the ISR in the existing tunnel. At field levels achieved in superconducting magnets at present of about 4 T, and with reasonable lengths of intersection regions, the maximum energy in this machine would be about 100 GeV or a little higher. This energy seems rather low at CERN where 28 GeV storage rings already exist, and where a 400 GeV injector synchrotron, the SPS, will soon become available.

The maximum energy of the storage rings is chosen within the energy range of the SPS, because it permits the energy stacking method to be used, as in the ISR, and avoids the acceleration of the stacked beam to a higher energy. The energy reached with this assumption, 400 GeV, appears to be high enough that a detailed examination of accelerating storage rings need not be undertaken at this moment.

Model (A) has been our main preoccupation during the last few months, chiefly because it became clear last year, as a result of work at BNL by M. Month, that the performance limitations of large-circumference storage rings were not adequately understood. This situation has now largely been rectified, and we are confident that storage rings with normal magnets and good performance can actually be built. The most important parameters of this machine are shown in Table I. In order to achieve a luminosity of 10^{33} cm^{-2} s^{-1}, a minimum current of 5 A is needed. The resulting problem of dumping a beam with that stored energy must be solved. First indications from an engineering study are that this can be done with an external beam dump.

Model (B) has so far been looked at only superficially though we are following closely the considerable effort in other laboratories, and in particular at BNL. We shall turn our attention in this direction much more in the coming months, since superconducting machines offer better performance prospects than normal ones.

Much of the thought given to the problems of a normal-magnet design is applicable to a superconducting machine. Furthermore, the constraints imposed by rings of large circumference on the CERN site highlight the problems of designing interaction regions. We are therefore using model (A) in this report as a "guinea pig" for resolving the conflicting requirements of machine design and physics experiments, with full confidence that the main conclusions to be drawn from this exercise will be applicable to both normal-magnet and superconducting-magnet machines.

2. SITING AND SYMMETRY

The normal-magnet storage rings we are discussing here would be roughly concentric with the SPS and about the same circumference. In principle they could be either above or below the level of the SPS. To be at the same level would require a reduction of energy below 400 GeV and would bring little, if any, advantage. The storage ring and SPS tunnels would in any case have to be separated by at least 10 to 20 m at all points for civil engineering reasons.

Below the SPS, because of the anticlinal structure of the molasse, there is considerable freedom in choosing the radius and shape of the rings, and the number of regularly spaced and separated interaction regions. However, the tunnel would lie between about 40 and 80 m below surface level. The advantages of dispersed interaction regions would be offset by the problems of access, cable lengths, need for underground counting rooms, installation of large and heavy detectors, safety requirements and all the economic and operational consequences of doing high-energy physics deep underground.

Above the SPS, respecting the 10 m minimum tunnel separation, the design of the machine and its interaction regions is strongly constrained because of the need to keep the tunnel below the surface of the molasse almost everywhere. For 400 GeV the rings must then have a race-track shape with two groups of contiguous interaction regions as shown in Fig. 1. One group, near SS5 of the SPS (on Swiss territory) would be near the surface, and the experimental halls would probably break through the molasse. Access here would be straightforward, even for the largest equipment. The other group of interaction regions near SS2 of the SPS would be about 20 m underground.

The racetrack configuration with grouped interaction regions brings two types of problems, both tractable we believe. Firstly, the low superperiodicity of two already makes the machine rather sensitive to perturbations arising both from structure imperfections and from beam-beam effects. Some care is needed to avoid further asymmetries which could produce appreciable disturbances with a superperiodicity of unity. All intersections are strong potential sources of perturbations and must be arranged symmetrically between the two groups of interaction regions. An example with suitable topology is shown in Fig. 2.

The second problem is to prevent the large flux of particles scattered at small angles in a high-luminosity region from generating background in neighbouring interaction regions. In the absence of a long piece of machine lattice between intersections the layout must be chosen to minimize such background.

3. TYPES OF INTERACTION REGION

For given energy and stacked current, the maximum design luminosity of an interaction region is limited mainly by two factors, viz. the non-linear electromagnetic beam-beam interaction, and the maximum acceptable values of betatron function in the neighbouring quadrupoles. The first is fundamental but not well quantified, and the second is limited by chromaticity and tolerances. Both factors lead to a situation of compromise between luminosity and field-free length around the interaction region.

One is therefore led to consider a machine with two or more types of interaction region, each designed to be suitable for a particular class of experiment. We have so far considered three types of interaction region. The numbers mentioned for luminosity, field-free space etc. are approximate and should only be taken as an indication of what could be achieved, since they depend on many factors as yet undetermined.

In discussing lengths of interaction regions it is necessary to distinguish between the total length of the insertion and the length of field-free space around the interaction volume unencumbered by machine elements. In some configurations there may be useful space available for detectors outside the vicinity of the interaction volume, between quadrupoles for example, where the beam transport properties of the insertion could be usefully employed in the design of the detector arrangement for small angles.

All types of intersection region are designed to the limits of the beam-beam effect or other beam-dynamics phenomena, as well as technical feasibility.

3.1. High-Luminosity Regions

This type would typically give a luminosity around 10^{33} cm^{-2} s^{-1} for stacks of 5 A and a field-free length of 10 - 20 m. This would be changed if engineering work on the beam-dumping problem yielded a different maximum current, or if the beam-beam limit were to correspond to a linear ΔQ different from the 0.005 we assume at present.

A typical layout of such a region is shown in Fig. 3, and the betatron functions and dispersion in Fig. 4. There is nearly 20 m length of field-free region available between the separating magnets for a large-angle detector system. The use of superconducting magnets here would permit a somewhat greater field-free length.

3.2. General-Purpose Regions

These would have a crossing angle of a few milliradians, a luminosity in the range of 10^{31} - 10^{32} cm^{-2} s^{-1} and about 50 - 100 m of unobstructed space around the interaction region.

3.3. High-β Regions

Here the beam optics would be arranged to achieve spatial separation of particles at very small angles to the beam without excessively long drift spaces. High betas of 100 - 400 m in both planes would permit scattering angles down to ∿ 20 μrad to be measured by devices similar to Roman pots. These high-β regions might have a similar length and crossing angle to the general-purpose regions, and could even be special cases of these. Although there would be extra quadrupoles near the crossing point, a large fraction of the total length of the region would be free for installing detectors. The luminosity would be in the range of 10^{30} - 10^{31} cm^{-2} s^{-1}. Fig. 5 shows one such arrangement, and Fig. 6 the betatron functions and dispersion.

4. HORIZONTAL OR VERTICAL CROSSINGS?

From the machine point of view opinions are divided on this issue. In general it appears that the design of interaction regions is more difficult and constrained for vertical crossings than for horizontal, the weights of the arguments depending on the machine parameters. It is important at this stage to have a clear idea of the experimental physics requirements which might favour one or other type of crossing. In order to be definite, the examples here all assume horizontal crossings.

5. NUMBER OF INSERTIONS

The number of insertions is determined by the scale and scope of the physics programme which the storage rings are supposed to support. In addition, special insertions will be required for injection and beam dumping. It seems likely that a minimum of six interaction regions will be required for physics experimentation, especially if more than one type is necessary, as we believe.

The configuration of the crossing regions must be chosen to avoid systematic effects of unit periodicity, either from the structure or from the beam-beam forces.

Taking into account the various constraints of symmetry, topology, injection and beam dumping, a reasonable example with six interaction regions would have two of them for high luminosity. The remaining four could either be all general-purpose or two g-p and two high-β corresponding to Fig. 2. Without further study it is not sure whether such arrangements would be acceptable for reasons of superperiodicity.

In the model ilustrated in Fig. 1, the injection and dumping insertions would be at the ends of the major axis of the racetrack configuration. Symmetry requires that the beams cross in these regions though they might be separated to avoid unnecessary beam-beam effects. The beam geometry would be similar to that of the general-purpose interaction regions. Injection from the SPS would be in the SW insertion branching from the SPS tunnels T60 (ejection) and T10 (injection). Acceleration in both directions in the SPS would be necessary, requiring a short extra injection tunnel in addition to modifications to the RF and magnet power supply systems. Dumping would be in the NE insertion which would be $\sim$ 50 m below surface level.

The beams move outwards in the high-luminosity interaction regions and in the injection/dumping insertions, and move inwards in the other four interaction regions. This provides the maximum straight-flight path, interrupted only by quadrupoles, for the latter regions, and may help to reduce the background there coming from interactions in the neighbouring high-luminosity regions. It is also a favourable arrangement for injection and dumping.

TABLE I

Parameter list for large storage ring lattice

Maximum momentum	400 GeV/c
Maximum bending field	1.8 T
Machine radius *)	964 m
Stored current	5 A
Stored energy in beam *)	40 MJ
Maximum single beam tune shift	0.02
Maximum tune spread	0.02
Vacuum chamber aperture radius	30 mm
Betatron wavenumber *)	26.25
Period length	57.2 m
Quadrupole length	3.3 m
Low beta insertions:	
Free space	20 m
Maximum beam-beam tune shift	0.005
Amplitude function at crossings, vert.	1.4 m
Amplitude function at crossings, horiz.	5.0 m
Crossing angle	∿ 1 mrad
Luminosity	$\sim 1.0 \times 10^{33}$ cm^{-2} s^{-1}

*) Excluding insertions

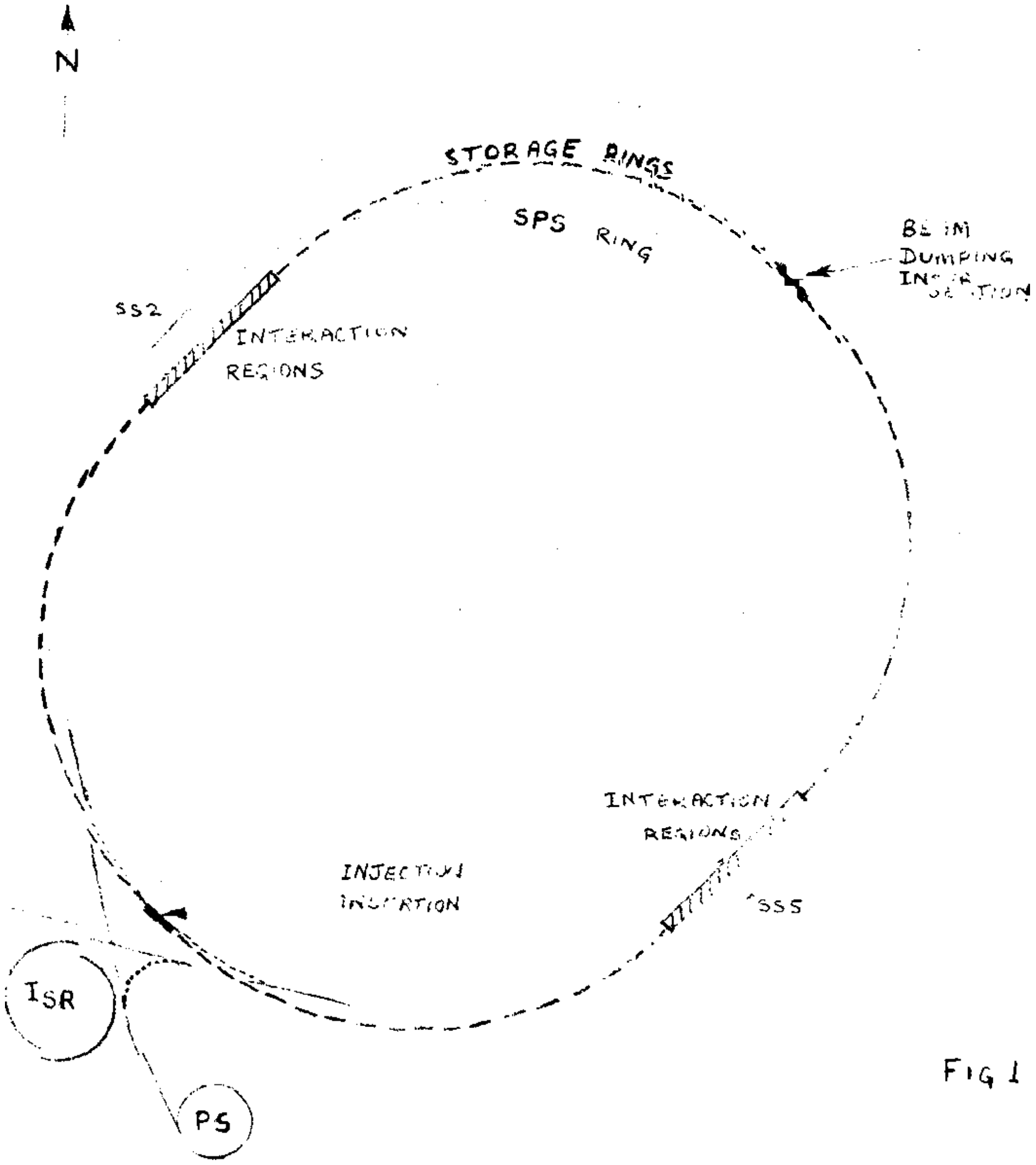
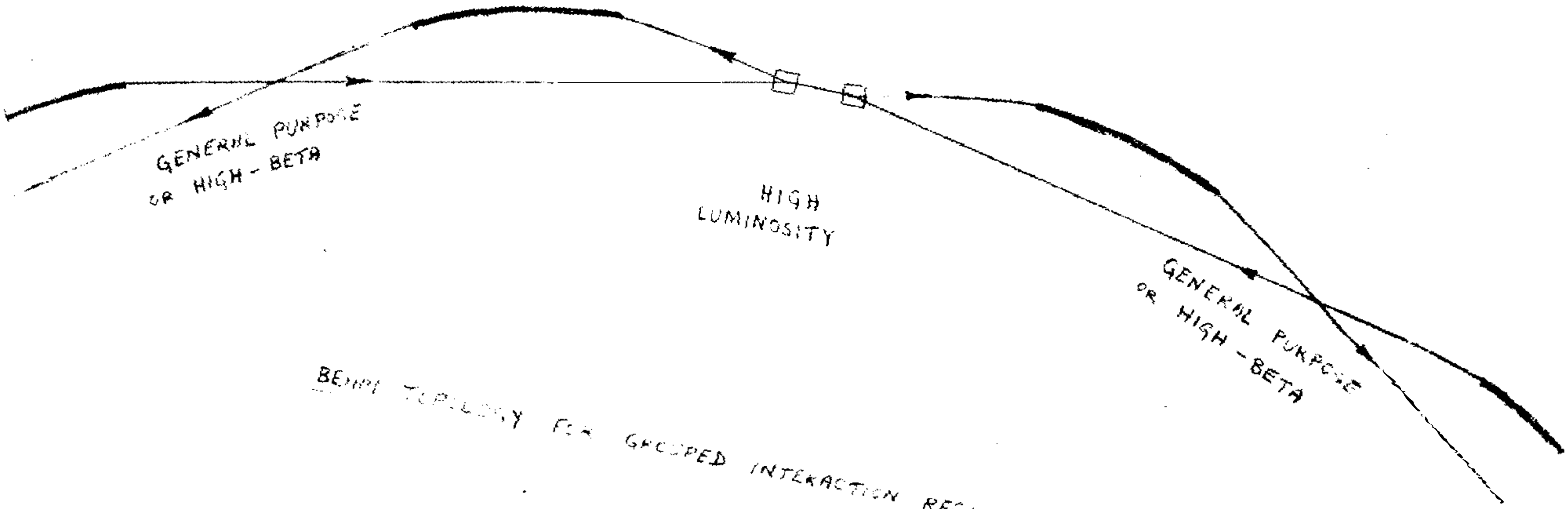

N
STORAGE RINGS
SPS RING
BEAM DUMPING INSERTION
SS2
INTERACTION REGIONS
INTERACTION REGIONS
SS5
INJECTION INSERTION
ISR
PS

Fig 1



BEAM TOPOLOGY FOR GROUPED INTERACTION REGIONS

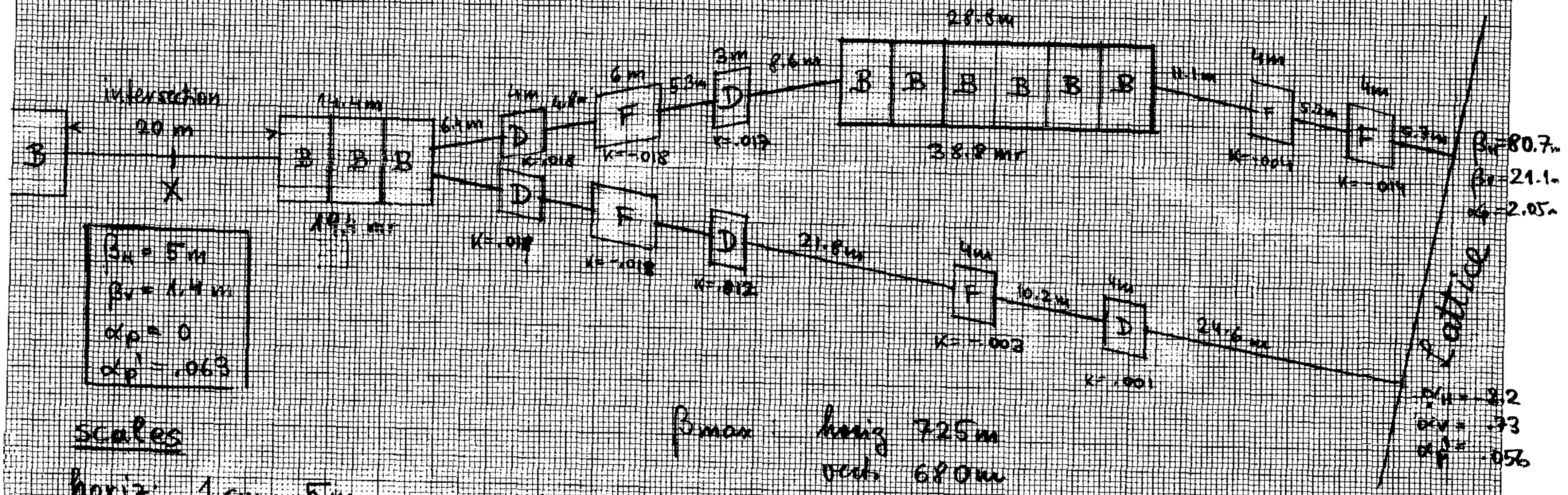
FIG 2

FIG.3: LOW-BETA INSERTION

GEOMETRY

outer arc – half length 121.46 m
inner arc – " " 117.07 m

total length insertion 238.53 m



scales

horiz: 1 cm – 5m
vertic: 1 cm – 50cm

βmax : horiz 725m
vert. 680m
|αp|max 4.6 m

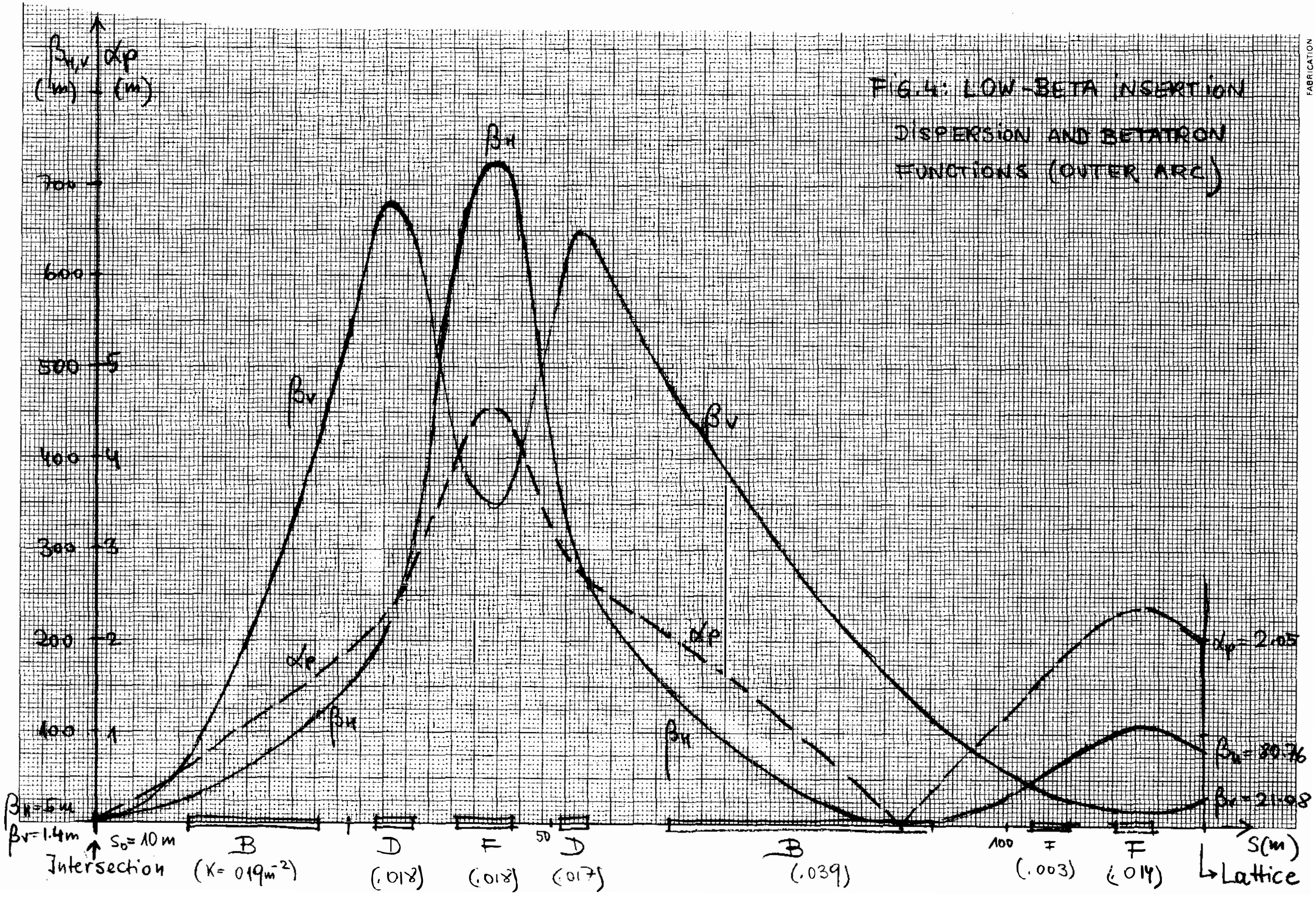
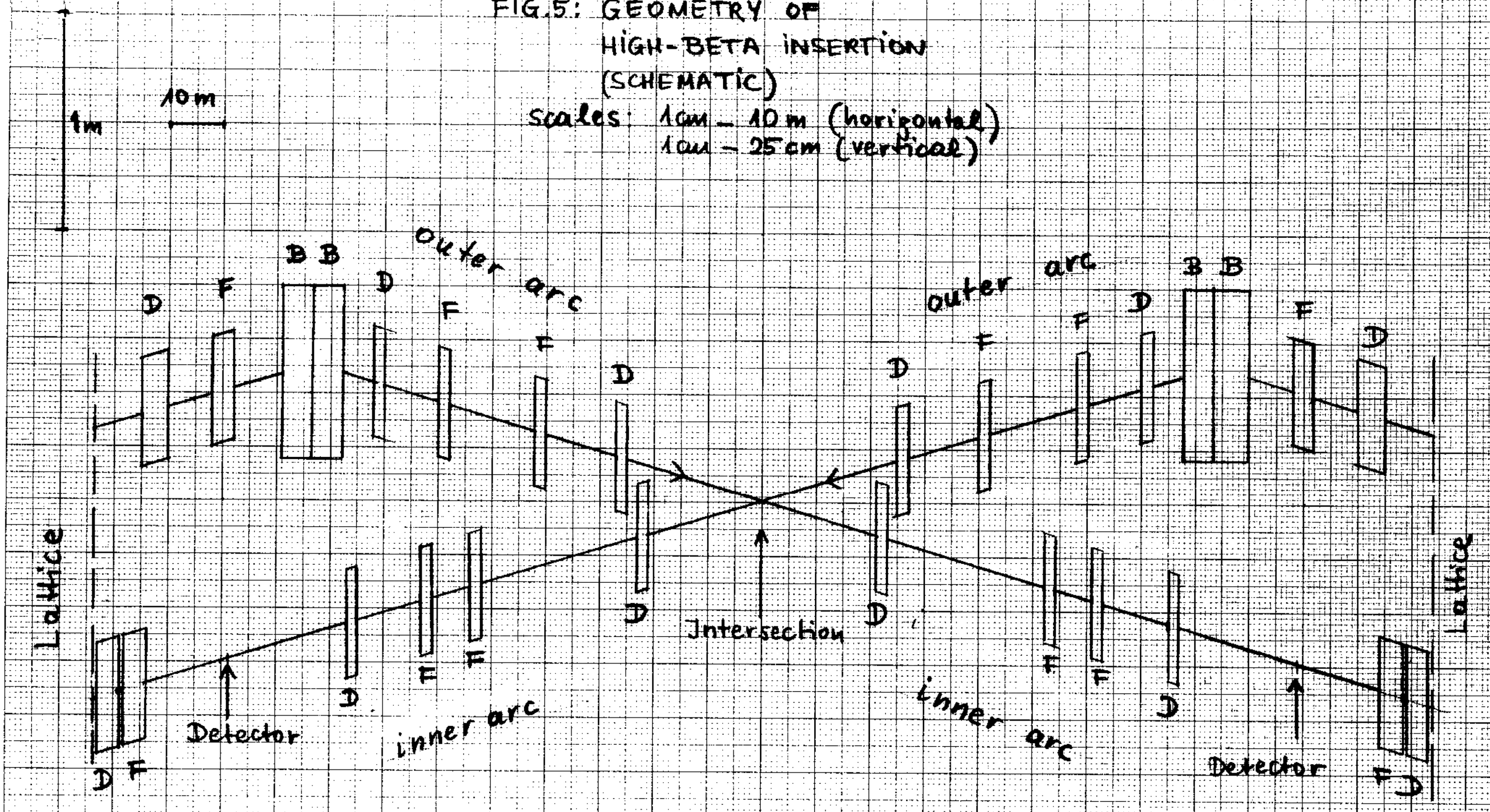


FIG.4: LOW-BETA INSERTION
DISPERSION AND BETATRON
FUNCTIONS (OUTER ARC)

FIG.5: GEOMETRY OF
HIGH-BETA INSERTION
(SCHEMATIC)
Scales: 1cm – 10 m (horizontal)
1cm – 25 cm (vertical)



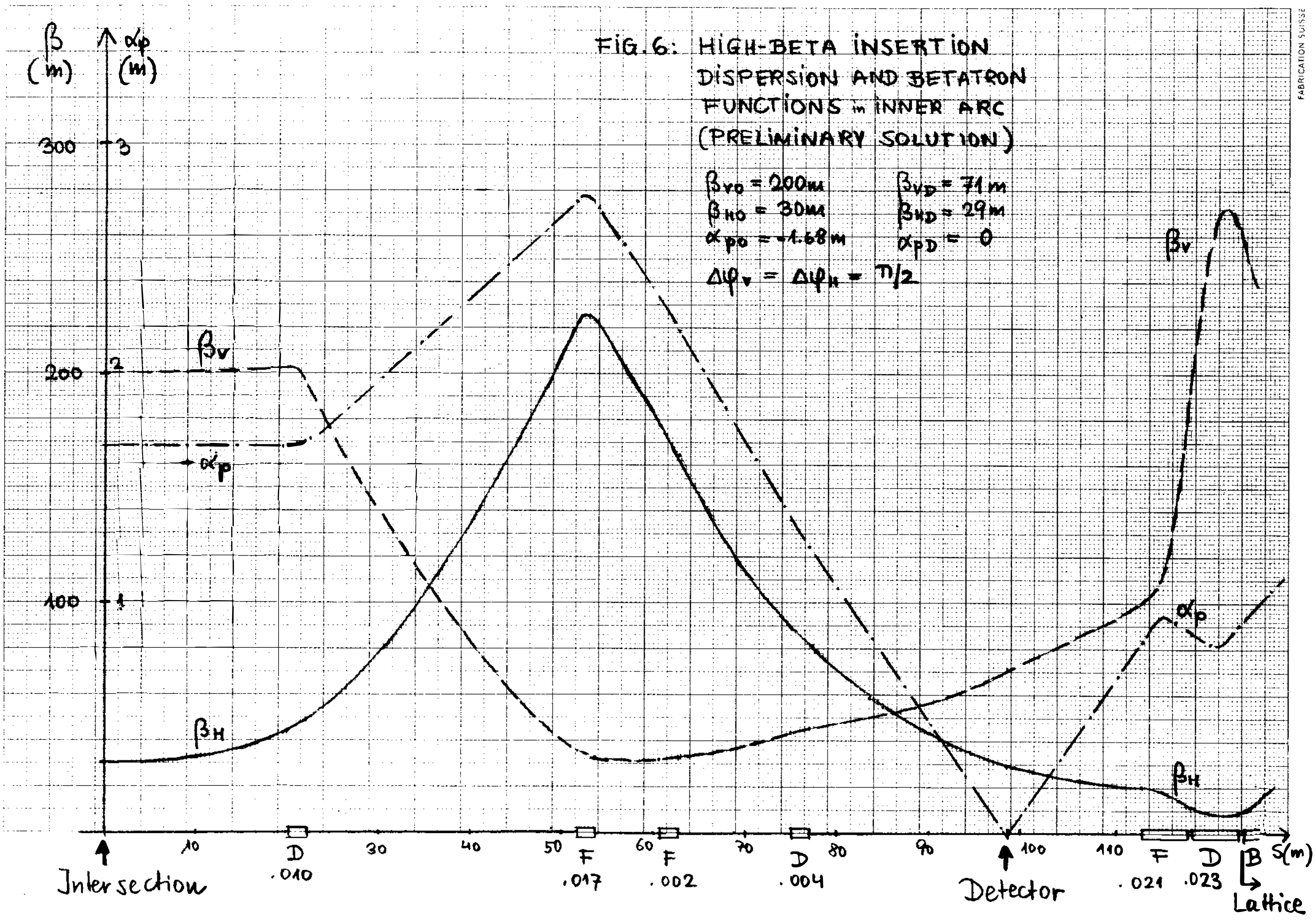


FiG. 6: HiGH-BETA iNSERTiON
DiSPERSiON AND BETATRON
FUNCTiONS in iNNER ARC
(PRELiMiNARY SOLUTiON)

$\beta_{V0} = 200$m
$\beta_{H0} = 30$m
$\alpha_{p0} = -1.68$m
$\beta_{VD} = 71$m
$\beta_{HD} = 29$m
$\alpha_{pD} = 0$
$\Delta\varphi_V = \Delta\varphi_H = \pi/2$