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THE EUROPEAN HADRON FACILITY

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1. INTRODUCTION

The European Hadron Facility (EHF) is a new research facility for nuclear and particle physics which is proposed for Western Europe in the 1990's. It consists of a complex of accelerators to produce a high-intensity (100μA) proton beam of 30 GeV kinetic energy, and is meant to provide a broad range of intense, high-quality secondary beams of neutrinos, muons, pions, kaons and antiprotons. A distinctive feature of this machine is that it has been designed to accelerate polarized proton beams to full energy.

The physics case for the project has been studied over almost three years by a group of European physicists, the EHF Study Group (the present composition of the group is given in Table 1), and has been reviewed and discussed at many workshops, topical seminars and conferences. The first of these was the workshop on "the Future of Intermediate Energy Physics in Europe", held in Freiburg im Breisgau in 1984 [1], and important milestones since then have been the Workshop on Nuclear and Particle Physics at Intermediate Energies with Hadrons, held in Miramare (Trieste) [2], the meeting on "The future of Medium and High-Energy-Physics in Switzerland", held at Les Rasses [3], and the series of Heidelberg Workshops on the Physics of Hadron and Nuclear Structure [4]. All these activities culminated in the International Conference on a European Hadron Facility, held in Mainz from 10 to 14 March, 1986, the main purpose of which was to review the physics program in both low-energy particle physics and in modern nuclear physics, with special emphasis on strong interactions in the confinement regime of quantum chromodynamics (QCD)[5]. A "Letter of Intent" was subsequently written [6] by the EHF Study Group to provide concise information on the proposed machine and on the Physics case.

Since August, the Study Group has been actively engaged in the preparation of a detailed Proposal, which should be ready by April '87, and which will consist of the machine study I will briefly summarize in this talk and of a selection of first-generation experiments which the European Users would like to carry on at the new facility. The Physics area which have been identified to this purpose and the names of the physicists who have volunteered as conveners to coordinate the work of the respective working groups are listed in Table 2.

The physics case for the EHF is extremely good and well demonstrated, as evidenced also by the existence of similar projects in North America (at Los Alamos [7] and at TRIUMF [8])and in Japan [9]. It is also clear by now that there is a strong and competent community of European physicists keen to build this facility in Europe, and for this reason the EHF study group urged in the summer of '85 a feasibility study of a "siteless-EHF", i.e. a facility which might be built anywhere in Europe and would not assume any particular existing accelerator as injector.

2. A HADRON FACILITY FOR EUROPE

The demand for a Hadron Facility in Europe is very strong. Using the words of F. Scheck, Chairman of the EHF Study Group, in his introductory remarks at Mainz [10], "this field of research in Particle and Nuclear Physics has a strong tradition in Europe. European groups have had a long and successful history of research which was possible thanks to the first-rate research facilities available in Europe as well as to the excellent interplay between experiment and theory. This tradition, experience and know-how provide the necessary guarantee for competent exploitation of EHF, for quality and success of its research program. It would be unwise and a waste of scientific culture and achievement to transplant a productive branch of European physics out of the continent or, even worse, to let it dry out completely".

Quite recently one more first-rate research facility, the Gran Sasso Underground Laboratory, has become a reality in Europe. The possibility of using an underground detector placed in the Laboratory to detect neutrino beams created at CERN has been discussed since a long time [11], but the possibility of producing neutrino beams at a new Hadron Facility in Europe has opened up extremely ambitious perspectives. In particular, the "neutrino working-group" of Table 2 has proposed [12] to combine the intense neutrino flux obtainable at the EHF with the large fiducial mass ($5\cdot10^3$ tons of liquid argon) and excellent electron identification of the ICARUS Detector [13], and has shown that the sensitivity of such an experiment to neutrino oscillation is excellent and strongly enhanced if the distance between EHF and ICARUS is of the order of 10^3 Km. In this geometry the experiment could distinguish between the two presently considered solutions to the solar neutrinos puzzle, the ν-oscillation one or the breakdown of the solar model. The discrepancy between the measured rate of solar neutrinos in the experiment of Davies et al. [14] and the rate expected from the solar model [15] can in fact be interpreted as due to neutrino oscillations, giving two sets of limits in neutrino mixing angle and mass difference, one of which is accessible to the proposed experiment. Clearly at this stage it is impossible to quantify the chances of solving the solar neutrino puzzle: still it is extremely interesting to see how ambitious experimental programs can be pushed forward by a close interplay of existing facilities. In this sense neutrino physics to me is very relevant to the quoted remark by F. Scheck. Fascinating possibilities open up for Europe just because the Gran Sasso Laboratory exists, and their realization suggests the construction of EHF either at CERN, or in a new Laboratory, located at a suitable ($\sim 10^3$ km) distance from the Gran Sasso mountain. I will come back to the problem of the site for EHF in the last part of my talk.

3. EVOLUTION OF THE PROJECT

A preliminary conceptual design for the EHF has been worked out and the present report gives a short description of the various accelerators involved and of the criteria adopted. The work has been carried through by an international team made up of the accelerator physicists from Europe and from oversea listed in Table 3. The activities of the group have been sponsored in so far by Germany, Italy and Switzerland, and have had as milestones six dedicated workshops, in Trieste (9-16 Oct., 85), at SIN (9-11 Dec. 85), in Karlsruhe (3-5 March 86), at CERN (7-9 May 86), at Capri (1-4 OCt. 86), and again at CERN (4-5 Dec. 86).

A first description of the project was given at the Mainz International Conference in March '86 [16] while a more detailed report was issued by the Design Group in June '86 [17]. While the basic parameters of the machine are still the ones which are given in these two reports, the design has advanced considerably since last summer, and we are about to update the project.

As it will be illustrated in the parallel sessions of this workshop, a lot of work has been devoted to the linear injectors [18,19], to the injection scheme, to the synchrotrons lattices [20] and specifically to the maintainance of the beam polarization [21], to the design of the RF cavities [22] and to the storing of $\bar{p}$'s [23].

A further EHF Workshop in Frankfurt, 23-27 March 87, will provide the material for our Proposal, while the studies presently under way are expected to go on untill the end of the year, to advance as much as possible with the design and to be ready to switch over to the executive stage as soon as a positive decision is taken by the relevant authorities.

4. ACCELERATORS PARAMETERS

The terms of reference for the EHF as given by the Study Group asked for an accelerator complex to accelerate a 100 μ Amp proton beam ($.6 \cdot 10^{15}$ protons/sec) to an energy of 30 Gev. Further constraints regarded

i) the capability to produce polarized proton beams;

ii) the presence of both fast and slow extraction systems (duty factors 10^{-4} and 1 respectively) to produce neutrino beams and a spectrum of intense,high quality μ,π,k and $\bar{p}$ beams;

iii) easy upgrade of the designed maximum energy to ~40 GeV.

No existing injector was suggested, since no existing site or laboratory was to be assumed for the moment. On the other hand, the possibility of building the EHF in the framework of CERN suggested a further constraint, i.e.

iv) 960 m for the length of the 30 GeV proton-synchrotron so that eventually it could fit into the ISR tunnel.

Actually, given the energy of the machine, this last requirement turned out to be no constraint at all.

The proposed EHF is the complex of accelerators schematically illustrated in Fig. 1, whose main components are a high-energy LINAC, accelerating a H^- beam to 1.2 GeV, and two fast cycling synchrotrons, a 9 GeV Booster Ring and a 30 GeV Main Ring, with radii and repetition rates of ratios 1:2 and 2:1 respectively. The repetition rates of the LINAC and of the Booster are the same, 25 Hz. The H^- beam pulse coming from the LINAC is stripped into a proton beam by passing through a thin foil and injected directly into the Booster over 200 turns.

Two more rings complement the system,a 9 GeV Holder Ring, with the same radius as the Booster, and where the Booster pulses are stored before being transferred to the Main Ring, and a 30 GeV Stretcher Ring, having the same radius as the Main Ring synchrotron, where the fast extracted 30 GeV beam from the Main Ring is stored and then slowly extracted to produce 100% duty factor secondary beams. The 1:2 ratio between the repetition rates of the Main Ring and the Booster allows us to have a Holder Ring of the same size as the Booster, rather than of the same size as the Main Ring as customary. Only one Booster pulse is thus stored in the Holder Ring, the second one passing through the just emptied Ring and going directly to the Main Ring. The use of these two relatively low-cost storage rings allows us to continuously run acceleration cycles in the Booster and Main Ring without the need to "flat-top" or "flat-bottom" the magnet cycles. The net advantages are less strain on the RF system and a 100% duty factor for the slowly extracted proton beam.

The operation of the complex can be understood by looking at the time diagram in Fig. 2. Acceleration cycles of the Booster and of the Main Ring are shown, as well as the beam transfers between the various rings. The ramping of the magnets is done with a dual resonance circuit [24] in which the up and down ramp frequencies are in a 1:3 ratio, so that the up ramp frequency of the two synchrotrons is 2/3 of the repetition rate, with a corresponding reduction of the peak RF voltage.

5. DESIGN CRITERIA

Some basic choices in the design are straightforward,and in particular this is the case for the building blocks in Fig. 1. Also the repetition rate of the Main Ring, 12.5 Hz, follows directly from the EHF current requirements (100 μ Amp) and from the limit to the maximum number of protons per pulse given by current experience with existing similar machines ($N_p \simeq 5\cdot 10^{13}$). On the other hand, the definition of the parameters of the various machines is the result of a long and careful optimization procedure aimed at maximizing the reliability and minimizing beam losses, within the boundary conditions set by the EHF Study Group and within a reasonable economic frame.

Minimization of beam losses has been achieved by (i) properly choosing the main accelerator parameters which are of relevance for the beam instabilities, (ii) phase locking all the machines, so that the beam is always transferred bunch-to bucket, (iii) proposing a new beam injection technique for entering into the Booster, as described in Section 6, and (iv) placing very safe margins on the magnets apertures.

As regards point (i)

a) the normalized emittance is taken 25mm mrad in both planes;
b) the "Laslett" incoherent tune-shift does not exceed a value of 0.20;
c) the bucket area is filled at most to 50%, corresponding to extreme phases of ±100° for a matched bucket;
d) in the Booster the longitudinal emittance is about 0.05 eVs;
e) in the Main Ring the longitudinal emittance will be blown up to 0.15 eVs during the early acceleration to avoid the microwave instability (Keil-Schnell criterion);
f) crossing transition is avoided both in the Booster and in the Main Ring.

As regards point (iv), we have assumed the betatron acceptance to be four times larger than the beam emittance at injection (defined with 2 σ amplitudes, thus containing 87% of the total beam), that is 100 π/β (mm mrad), in order to accomodate beam tails and injection errors. For closed orbit distorsions we have added ±2 mm in the vertical direction and ±5 mm in the horizontal direction. To each side, 6.5 mm have been added for the vacuum chamber.

A characteristic feature of the complex we propose is the injection energy of the Main Ring, 9 GeV, which is rather high as compared with that of similar projects (3 GeV for TRIUMF [8], 6 GeV for LAMPF II [7], and which in turn demands a rather high energy LINAC (1.2 GeV).

Such a choice for the injection energy into the Main Ring presents several advantages with respect to somewhat cheaper options with a 4-30 GeV Main Ring, namely

i) the possibility of using Siberian Snakes [25] in the Main Ring so as to preserve the beam polarization.
ii) More flexibility with lattice design. It is easy to avoid transition crossing by placing the transition energy well outside the energy range of interest.
iii) Owing to the reduction of the incoherent space-charge tune shift by $1/\beta^2\gamma^3$ one can increase the number of particles per pulse in the Booster and consequently decrease the repetition rates of the LINAC and Booster to 25 Hz, namely twice that of the Main Ring. As a nice consequence of this ratio for the repetition rates, as already seen in Section 5, all four rings are evenly distributed into the two tunnels, Main Ring and Stretcher in the big tunnel and Booster and Holding Ring in the small tunnel.
iv) The RF-requirements in the Booster are released, since the RF swing is rather small (11%) due to the high injection energy (1.2 GeV).
v) An upgrade of the energy of the Main Ring to 40 GeV is quite easy, due to the low packing factor.
vi) There is a possibility for a staged construction where the LINAC, Booster and Holding Ring are built first and the Main Ring and Stretcher added later. It is indeed possible to carry out a useful physics program at 9 GeV especially with low energy neutrinos, and for that reason the Fast Extraction Hall in Fig. 1 can be fed directly from the Booster.

The energy of injection into the Booster ring, 1.2 GeV, has been fixed essentially on the basis of the maximum value accepted (0.2) for the incoherent space-charge tune shift and the normalized beam emittance (25 mm mrad). The complex therefore requires a rather long and expensive LINAC, which however is well within present technology, as will be shown in Section 7.

The cost of the machine turns out to be some 70-80 MDM (million of Deutsch Marks) higher than the minimum cost, where the running parameter is the Booster energy, and the LINAC energy being fixed accordingly. Still, when comparing this amount of money with the overall cost of the facility, as discussed in Section 14, we believe that the many advantages of the 9 GeV scenario, which ultimately result in less beam losses and more reliable machine operation, largely compensate the extra cost.

A precise evaluation of the beam losses is still going on with simulation programs, but we are confident that they can be kept within the 10^{-4} level. Losses will be significant, at the 10^{-2} level, only at two points, namely at injection into the Booster, where the H° beam passes through the stripping foil, and in the septum magnet for the slow extraction from the Stretcher, where again beam losses are unavoidable. In both cases, however, beam losses are localized, and will be dealt with by using collimators and beam dumps, and where necessary, plugged-in components will be used.

6. INJECTION SCHEME FROM LINAC INTO BOOSTER

LINAC's and synchrotrons have conflicting requirements as regards the RF systems, since LINAC's want high frequencies, even a few GHz, to reduce beam losses and the length of the structure, whilst synchrotron cavities prefer a "low" frequency because of the frequency swing (11% in our Booster). The final choices have been made to minimize costs, 50 MHz in the Booster and 400 MHz in the LINAC. The beam pulse coming from the LINAC is thus a train of bunches at a frequency which is 8 times the RF frequency at injection of the Booster. To optimize the filling of the Booster bucket, six out of the eight buckets, coming from the LINAC are left empty, so that only two consecutive bunches will be transfered at the time into each RF bucket of the Booster, as shown in Fig. 3.

To cope with the required intensity a beam pulse equivalent to the length of 200 turns has to be injected into the Booster. The only way to do this is by H^- stripping, i.e. injecting a beam of H^- which will eventually lose their orbiting electrons by hitting a foil during the first time they go around into the Booster. Actually, to reduce the length of straight sections needed for the injection, this process will occur in two steps. The H^- beam from the Linac is first stripped to H° in the fringe region of a high field bending magnet, before entering the Booster Ring. The H° beam will then enter into the Booster via the yoke of a Booster dipole magnet, and will subsequently go through a thin stripping foil to convert the H° atoms to protons [26].

This method of injection is not phase space area preserving and therefore allows reasonably small beam emittances. In each RF buckets two more consecutive bunches will add up every turn to the ones previously injected, by using a special "painting" technique in both longitudinal and transverse phase space, which has been first suggested to us by the Los

Alamos and TRIUMF groups. Such a technique will allow to fill the bucket area uniformily, thus reducing the space-charge forces. In particular, the scheme proposed of 2 out of 8 bunches transferred from the LINAC into each Booster RF bucket at the time, possibly in the center of it, is meant just to eliminate the possibility of losses by placing the beam too close to the boundary of the RF buckets. Along the same line, the RF bucket of the Booster will be filled only to 50% so as to avoid beam losses during the early period of acceleration.

Detailed calculations are still needed to evaluate precisely the losses of the proposed scheme, but preliminary estimates already make us confident that the system has a very high efficiency and well justify our claim that beam handling will not be a serious problem for EHF.

7. THE 1.2 GEV LINAC

The linear accelerator is made up of a source of negative hydrogen ions, followed by a combination of a buncher and two RFQ's (Radio Frequency Quadrupoles), operating at 50 MHz and 400 MHz respectively, one drift tube LINAC (DTL), operating at 400 MHz and finally a side coupled LINAC (SCL) running at 1200 MHz. The final energies of the various stages are 0.2, 2, 150 and 1200 MeV respectively.

The beam pulse will be 360 μsec long. The desired time structure for optimal injection into the Booster is generated in the two RFQ's, as illustrated in Fig. 4. The first RFQ captures and bunches the dc beam from the ion source to a certain extent. The compressed phase structure of that beam is then taken over by the second RFQ, which will further accelerate and bunch the beam to match it to the 400 MHz time structure of the Alvarez section. In between the two RFQ's, a 0.55 MHz chopper will create a 100 nsec hole (5 empty buckets out of a total of 90 buckets) in the Booster to allow the operation of the kicker and a lossless fast extraction of the beam from the Booster into the Accumulator.

After coming out from RFQ2, the beam is injected into the 400 MHz Alvarez Structure. No problems are foreseen in handling the effective beam current of 50 mA. From the DTL the beam is injected into the SCL, where there will be a frequency jump of a factor of three to increase the LINAC efficiency. Space charge problems are even less important than in the DTL due to the increased particle energy. In particular the empty buckets should cause no problems either in the DTL nor in the SCL due to the high amount of stored energy in the tanks compared to the beam power.

The design of both the DTL and of the SCL are on the safe side, and beam dynamic calculations showed no problems. In particular, the DTL is very similar to the CERN 50 MeV DTL, being somewhat more efficient because of the higher frequency (400 MHz rather than 200 MHz), which in turn is possible since the peak current is here 3 times less. The SCL is more demanding, and it will be the highest energy proton LINAC in the world. Its structure is similar to that of the Los Alamos 800 MeV LINAC, but again it will be more efficient because of the higher frequency and of the higher gradients, which are possible thanks to the present existence of more powerful klystrons.

The DTL will accelerate with an average gradient of 4 MV/m and the SCL with an average gradient of 6.2 MV/m, resulting in a total length of about 320m for the whole LINAC, but it is possible that these gradients be increased in the final project to reduce somewhat the investment cost.

8. BEAM POLARIZATION IN THE SYNCHROTRONS

A very clear message from the EHF study group demanded for this machine capability of accelerating polarized proton beams of the same intensity as the unpolarized beams. Even if today polarized H^- sources cannot deliver such intensities, there is confidence that technological improvements will fill in this gap by the time EHF is in operation. Whilst the maintenance of polarization is guaranteed in the LINAC, the horizontal components of the magnetic fields in the four Rings, required for the strong focusing,induce rotations of the proton spins which tend to destroy the vertical polarization. This situation is particularly dangerous when depolarizing resonances occur [25], namely when the precession frequency of the spin $f=G\gamma$ (G is the usual proton gyro-magnetic ratio $G = (g-2)/2 = 1.79$) coincides with the frequency of a disturbing horizontal magnetic field as seen by the circulating beam (either due to an imperfection in the lattice, or to the intrinsic periodicity of the strong focusing forces). Such resonance condition is met when $G\gamma = n$ (imperfection resonances) or when $G\gamma = kP + Q_y$ (intrinsic resonances), where n and k are any integers and P and Q_y are the number of superperiods and the vertical betatron tune of the lattice respectively. When these resonance conditions are met, depolarization of the beam takes place at a rate which depends on δ, the intrinsic strength of the resonance and on α, the speed with which the resonance is crossed during the acceleration cycle,according to the Froissart-Stora formula $P_f/P_i = 2 \cdot \exp[-\pi|\delta|^2/2\alpha] - 1$. These factors, as well as the number of depolarizing resonances themselves, depend crucially on the choice of the lattice. For this reason great care and effort have been devoted to choose lattices for the booster and the Main Ring which would minimize the depolarization of the beam.

There exist several ways to preserve the polarization,

i) choose a high periodicity lattice to avoid intrinsic resonances,
ii) cross resonances with a fast Q-jump or an adiabatical spin flip. These are methods already used in the AGS and in Saturne,
iii) introduce spin trasparency into the lattice, which makes the strength of the resonance small when the resonance is crossed,
iv) use a pair of Siberian Snakes diametrically located in the lattice in order to make the spin tune energy independent.

Solution (i) was eventually ruled out because it demanded for unpractically large values for P or Q, incompatible with other requirements, such as long straigth sections for injection and extraction.

Solution (iii) has been kept in mind, but the proposed lattices could not reduce the strength of all the resonances down to the desired level, so that it could not solve the problem by itself alone. At the end we decided to propose method (ii) for the Booster and method (iv) for the Main Ring, as will be explained in more details by P. Blum [21] at this Conference.

9. THE BOOSTER

The Booster Ring is the most challenging part of the project, therefore particular care has been devoted to the choice of the lattice.

Since it was impossible to avoid the 0^+ resonance ($G\cdot\gamma = Q_y$), some depolarizing resonances had to be accepted in the lattice, but they have been chosen to be not too strong and will be crossed by fast Q-jump. A separated function lattice has been adopted to have more flexibility to adjust the tune.

As the beam at injection is close to the space-charge limit, a doublet has been taken as focusing structure, to provide low amplitude functions. The lattice consists of 6 superperiods each of which includes nine cells. The phase advance per cell is about $\pi/2$ to push the transition energy well above the maximum energy (γ_{tr} = 12.55). Each superperiod shows a missing magnet arrangement, which, due to the selected phase advance, forms two 2π achromats, leading in turn to long dispersion free straight sections. Table 4 summarizes the Booster parameters and Fig. 5(a) shows the beta functions and the dispersion function for one superperiod.

Two families of sextupoles have been inserted into the lattice to correct for chromaticity. As the first four cells of each superperiod form a 2π achromat, it is sufficient to insert sextupoles in those four cells only, for a total of 48 sextupoles.

The are six long (2·6.5 m) dispersion free straight sections which are used for

- H° injection (one)
- fast extraction (one)
- RF cavities (four)

as shown schematically in Fig. 5(b). Six fast pulsed quadrupoles will be used to overcome the depolarizing intrinsic resonances, and have been placed in the six straight sections with dispersion. Finally, the effect of the imperfection resonances to the polarization will be minimized with the help of correction dipoles. Each dipole will be placed in the middle of a quadrupole doublet, for a total of 54 correction dipoles. In this way the arrangement of all the correction elements will not break the basic sixfold symmetry of the Booster Lattice.

The beam power is 1.65 M Watt, and so as not to have beam loading problems we decided for an RF system delivering 3.2 M Watt total power. To provide the required 11% frequency swing, ferrite-loaded cavities of the Fermilab type [27] will be used.

A prototype cavity has been designed [22], and is shown in Fig. 6. It is a symmetric double-gap cavity, two of which can be fitted conveniently in one straight section. Operating at 36 kV per gap, 14 cavities are needed to deliver the 1 MV per turn which is required for acceleration, and, as shown in the lay-out of Fig. 5(b), in the available zerodispersion straight sections 16 cavities can be accomodated.

All the technical details of the cavity shown in Fig. 6 aim at compactness and simplicity. In particular, the very compact coupling of the drive tube to the accelerating structure (no dc blocking capacitor is inserted!) is meant to improve the stability, bandwidth, and general efficacy of any feedback loop which will be operated in conjection with the cavity. We will try to construct during 1987 a prototype of the cavity to start testing various tuner designs,performance of several power amplifier tubes, and operation of cavity and beam control feedback loops.

10. HOLDING RING

The Holding Ring will be loaded from the Booster, and will keep the beam over one Booster cycle. Then the Main Ring is fed from the Holding Ring and the Booster directly in one turn. Since the Holding Ring and the Booster will be installed in the same tunnel, the lattice which has been worked out for the Holding Ring is essentially identical to the one proposed for the Booster and already shown in Fig. 5(a), with six superperiods and the doublet focussing structure. No correction elements are needed, since the beam is not accelerated and the Ring operates at fixed field.

The only noticeable difference regards the bending magnets, which have a smaller aperture, and consequently provide a higher field and can be made shorter. The RF power needed to keep the beam bunched will be provided by a single unit of the type illustrated in Fig. 6.

11. THE MAIN RING

The Main Ring lattice has been chosen essentially to provide long dispersion-free straight sections for insertion of the Siberian Snakes (20m) magnets and for extraction. Slow Extraction in this energy range requires straight sections at least 20m long, but, as will be discussed in the next section, ∿100m straight sections would be highly desirable to accomodate a high-beta insertion. Although the slow extraction system will be installed in the Stretcher, it still represents a constraint for the Main Ring, since it will be convenient to install the two machines one on top of the other, so they must have a similar lattice.

Like for the Booster,we have selected for the Main Ring a separated function lattice, with a regular FODO cell structure and a superperiodicity of 4. It consists basically of four arcs joined by dispersion suppressors and straight sections. Each arc is made up of seven regular cells, with a phase advance per cell of about 60°, to push the transition energy below injection energy ($\gamma_{TR} = 7.8$). The arc is separated from the straight sections by two dispersion suppressors, each of which consisting of two cells with the same focussing structure as the regular cells but half the bending strength (the second cell is free of any bending magnet). The dispersion free straight sections consist of two regular cells free of any bending magnet. In total, sixteen halfcells of a length of 8.33 m and zero dispersion an available for the RF cavities and the Siberian Snakes.

Due to the length of the Siberian Snakes (11 m), two straight sections had to be modified to achieve a long enough section free of any element. By a suitable rearrangement of the quadrupoles a free space of 16.28 m could be obtained, as described in Ref.[21], where a full discussion of the maintainance of the polarization in EHF is given. The resulting orbital functions for the proposed lattice, including the snakes, are given in Fig. 7(a), whilst all the relevant parameters of the lattice are summarized in Table 5. A possible arrangement of magnets, RF cavities and transfer lines for the Main Ring is shown in Fig. 7(b).

The RF system will consist of 28 cavities of the type described in paragraph 9, to provide a voltage gain of 2 MV per turn. As the frequency swing is only 0.4%, a higher beam-loading ratio of 2:1 has been adopted. The total power needed is then 6.6 MWatt for a beam power of 4.4 MWatt. Twenty two cavities can be installed in zero-dispersion straignt sections, while 8 more cavities will be installed in straight sections with dispersion, but symmetrically, as shown in Fig. 7(b), to avoid coupling between betatron and synchrotron oscillations.

Tracking studies have been carried through in the Main Ring and have proven [28] that the proposed design is stable against the effects of magnetic field errors, second-order aberrations and single-particle instabilities. Essentially no particles were lost after 500 turns even assuming magnet errors four times larger than the anticipated manufacturing tolerances.

12. THE STRETCHER

The stretcher is fed from the Main Ring, and gives a continuous beam in between two successive Main Ring pulses using slow resonant extraction. A preliminary study [29] has shown that to achieve an extraction efficiency larger than 0.99 the extraction septum has to be located at a distance of at least 40 mm from the beam axis. A high beta insertion is consequently highly desirable to amplify the betatron motion only in vicinity of the septum and to keep the apertures in the rest of the lattice small.

The lattice proposed is a separated function FODO lattice with four superperiods, simular to the one of the Main Ring. Since the Stretcher operates dc, we could increase the bending field to 1.7 T, and then shift two of the arc cells per superperiod into the straight sections. The resulting straight sections have now the equivalent length of 4 cells (72.85 m) and we have designed a high beta insertion similar to the one of LAMPF II. The insertion is symmetric to the center and consists of two matching cells and a high beta cell, containing four quadrupole doublets with a phase advance of π. The resulting lattice and the orbital functions are shown in Fig. 8(a), while a pictorial view of the Stretcher with a tentative location of the various components is given in Fig. 8(b).

A highly efficient slow extraction from the Stretcher is a foundamental prerequisite for EHF and work is going on this subject. Present technology for electrostatic septune is probably inadequate at full Main Ring repetition rate (12 Hz), but due to the diversified experimental program foreseable at EHF and the many request for a Fast Extracted beam mode of operation (ν -physics, $\bar{p}$-production, pulsed μ-beams), probably only a few pulses per second will be slowly extracted.

On the other hand, the possibility of using internal targets in the Stretcher, either H_2 jet targets or production targets [30] for secondary beams, suggests for the Stretcher a separate tunnel from the Main Ring, to avoid radiation problems to the latter. If eventually this will be our choice, more freedom will be gained for the lattice of the Stretcher, and the high-beta concept can be pushed even further and better tailored to the needs of the users.

13. EXPERIMENTAL AREAS AND BEAM INTENSITY

As shown in Fig. 1, both slow extracted and fast extracted beam will be used for experiments.

The intensity gain of two orders of magnitude in the primary proton beam of the EHF as compared with the beam of the CERN PS or of the AGS will guarantee the same gain in the intensities of the secondary beams, the quality factor of capital importance to the physicists who will come to carry out experiments. Clearly, this gain in intensity can in many cases be usefully converted into a gain in beam quality, that is in beam purity, momentum resolution, and phase space. It turns out, however, that by improved target systems and secondary beam design, larger gains can actually be expected. This is the case, for instance, when adopting the MAXIM system [8] for the slowly extracted primary proton beam, a system for Multiple Achromatic Extraction of Independent Momentum beams. Such a system allows extraction of several secondary high-energy charged-particle beams from a production target at zero angle to the primary beam. The beam intensity and quality is thus improved because generally the production cross sections are peaked in the forward direction and because long targets can be used (tipically one interaction length), without increasing the transverse dimension of the beam source.

The system consists of a pair of sectors of concentric circular bending magnets of opposite polarities, centred on the production target. As the magnetic field is rotationally symmetric with respect to a vertical axis through the target, any charged particle emitted from the target centre will emerge from the system travelling on a radial plane through the axis. Although all momenta are focused into any radial direction, there is a one-to-one correspondence between any given direction and the sign and momentum of the forward going-secondaries.

A possible beam layout for the Slow Extraction Area using two MAXIM schemes and three production targets to eat up essentially all the primary beam is shown in Fig. 9. The first target is half an interaction length, while the other two are one interaction length. The layout is based on previous work done at SIN by the secondary beam group for HIPS (High Intensity Proton Synchrotron). The parameters of the beam lines are given in Table 6. The angular acceptance for the unseparated beam lines are given in parenthesis. The π , k and $\bar{p}$ intensities which can be obtained in the various lines are given in Fig. 10.

The Fast Extraction Area in Fig. 1 is situated so that it can be fed either from the Main Ring or from the Booster. This possibility is quite attractive in a staged construction of the EHF because the 9 GeV Booster can be an excellent source of low-energy neutrino beams and fast-pulsed muon beams. The facility will consist of the usual production target, a magnetic horn as focusing device, a long decay section, and a huge shielding block in front of the fast extraction hall.

14. COST

A cost estimate for a "green pasture" laboratory including machines, tunnels, buildings, basic infrastructures, and two experimental areas, namely the Fast Extraction and the Slow Extraction ones, has been made in May 1986, and is given in Table 7. The estimates were mainly based on the comparable facilities proposed at TRIUMF and Los Alamos, but were adjusted to European prices by using the experience of CERN, DESY, GSI and SIN. The table does not include minor items such as the control system, probably 5% of the cost of the accelerators, and it has no allowance for inflation or contingency. The estimated operational budget, not included in the table is about 100 MDM/year.

As mentioned in Section 5, some cost reduction can be obtained by lowering the energy of the Booster to 4 GeV and correspondingly adopting a shorter LINAC, accelerating the beam to about 600 MeV. Eventually this scenario was disregarded. Reliability of the design and excellence of performances, essential prerequisites for an ambitious project like EHF, were considered more important than just straightforward cost considerations.

15. CONCLUSIONS

I have tried to summarize in this report the results of a Feasibility Study for a European Hadron Facility, which has been carried through by the international team listed in Table 2, to whom I would like to express my sincere thanks. Clearly, a lot of work has still to be done to complete the design: the SCL structure has to be calculated and tested, items such as painting, or precise evaluation of beam losses and beam depolarization demand for computer tracking with multiparticle simulation codes, hardware tests are necessary for the R-F cavities, for the fast kickers, for the slow Extraction System. Further studies may also lead to improvements in the design, possibly resulting in better performance and lower cost of the Facility. Still, we believe the project we have worked out to be rather satisfactory and the price estimate reasonable and fairly accurate. The next step therefore is to the comunity of the physicists who want the Facility, and as a member of this comunity I would like to add a few personal remarks.

At variance with the other proposals for Hadron Facilities, EHF is not being proposed by a National a International Laboratory, it is a project which has been proposed by a comunity of European physicists, the potential EHF Users. This unusual situation clearly points at a weakness of our project, and will ultimately result in a longer time scale for its realization. On the other hand, it guarantees its basic soundness, and it hints at a dangerous gap which since a few years developed between the physicists community and the European institutions.

Elementary particle physics and nuclear physics at intermediate energy just cannot presently be pursued in Europe. Work is going on at low energy, at LEAR, at SIN and at Saclay, but from there to LEP and HERA there is a single big gap. This is a unique situation, because both at Brookhaven and at KEK vigorous upgrading programs of the existing machines are being undertaken, and this is the reason why the demand for a Hadron Facility in Europe is so strong.

At present, two alternatives seem realistic, and are both being explored by the Study Group. The first one is to build EHF in a new Laboratory in Italy, which at present has no major commitment to a large International Research Laboratory on its territory, while is contributing to most European Laboratories(CERN, HERA, JET, NET, ISIS, ESRF). The second one is some form of "CERN option", i.e. the possibility of realizing EHF at CERN and using some existing infrastructure (ISR tunnel for housing the Main Ring and the Stretcher, the West Hall for experimentation). Considering the present size of CERN and its commitment to pursue the high energy frontier, and the cost of EHF and the difficulties that CERN has had over the last ten years to maintain an adequate budget level, my personal opinion is that the first option after all might turn out to be easier than the second one.

To set up a new Laboratory for fundamental research in Europe in the nineties might look like a terrible task. Personally I am convinced it is perfectly feasible, and that such a choice will be extremely rewarding in the long run. Large scale projects like RHIC, or CEBAF, will be proposed in Europe in the next few years, and it does not seem reasonable to pile up all these machines in the Geneva area. An existing EHF would represent a very interesting option for all these projects, and from the experience of CERN we know that a proton-synchrotron can be profitably used also to accelerate electrons or heavy ions. The physics case for EHF is perfectly well demonstrated and has been agreed upon over the last two or three years, so EHF could really be the first move towards a new European Laboratory for Research in Nuclear Physics and low energy Elementary Particle Physics.

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Table 1: EHF Study Group

R. BERTINI	Saclay	C. KLEINKNECHT	Mainz
R. BEURTEY	Saclay	H. KOCH	Karlsruhe
F. BRADAMANTE	Trieste	G.C. MORRISON	Birmingham
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W. BREUNLICH	Wien	J.M. RICHARD	Grenoble
A. CITRON	Karlsruhe	R. RUCKL	DESY
P. DALPIAZ	Ferrara	F. SCHECK	Mainz
J. DOMINGO	SIN	J. SPETH	Julich
R. ENGFER	Zurich	T. WALCHER	Mainz
S. GALSTER	Karlsruhe	W. WEISE	Regensburg
W. JOHO	SIN	B. ZEITNITZ	Karlsruhe
B. JONSON	Göteborg		

Table 2: TOPICS and CONVENERS for EHF proposal

INTRODUCTION and general survey	G. Preparata	(Milano)
	J.M. Richard	(Paris)
	F. Scheck	(Mainz)
Rare Decays	K. Kleinknecht	(Mainz)
Neutrino Physics	P. Pistilli	(Roma)
Physics with EHF muon beams	Th. Walcher	(Mainz)
Polarization Studies at EHF	A. Penzo	(Trieste)
Hyperon Production and Spin observable	R. Bertini	(Saclay)
Hyperon-nucleon Scattering	V. Hepp	(Heidelberg)
Antiproton Physics	P. Dal Piaz	(Ferrara)
Spectroscopy	H. Koch	(Karlsruhe)
Hypernuclear and Antiproton-Nucleus Physics	T. Bressani	(Torino)
Selected Precision Experiment	E. Zavattini	(CERN)
Physics with pions at EHF, K^+-Nucleus Scattering	J. Domingo	(SIN)

TABLE 3 : EHF Design Group and Contributors

R. ABELA	SIN Villigen	G. MACKENZIE	TRIUMF
R. BAARTMAN	TRIUMF	M.R. MASULLO	Napoli
G. BENINCASA	CERN	A. MASSAROTTI	Trieste
B. BERKES	SIN Villigen	D. MÖHL	CERN
P. BLUM	Karlsruhe	M. PABST	KFA Julich
K. BONGARDT	KFA Julich	F. PILAT	CERN/Trieste
J. BOTMAN	Eindhoven	A. PISENT	Karlsruhe/Pavia
A. CITRON	Karlsruhe	M. PUGLISI	Pavia
E.D. COLTON	Los Alamos	M. PUSTERLA	Padova
M. CONTE	Genova	G. REES	Rutheford
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M. CRADDOCK	TRIUMF	A. RUGGIERO	Argonne
J. CRAWFORD	SIN Villigen	G. SCHAFFER	Karlsruhe
H. DEITINGHOFF	Frankfurt	A. SCHEMPP	Frankfurt
F. GALLUCCIO	Napoli	H. SCHÖNAUER	CERN
E. GIANFELICE	L.N.Frascati	A. THIESSEN	Los Alamos
J. GRIFFIN	FNAL	C. TSCHALAR	SIN Villigen
W. JOHO	SIN Villigen	V. VACCARO	Napoli
H. KLEIN	Frankfurt	M. VRETENAR	Karlsruhe/Trieste
P. LAPOSTOLLE	France	M. WEISS	CERN
P. LEFEVRE	CERN	Th. WEIS	Frankfurt
A. LOMBARDI	CERN	C. WIEDNER	MPI Heidelberg

TABLE 4: Booster parameters.

energy range		1.2 - 9.0 GeV		
circumference		480 m		
repetition rate		25 Hz		
particles/pulse		$2.5 \cdot 10^{13}$ ppp		
number of superperiodes		6		
number of cells		$6 \cdot 9$		
cell structure		separated function magnets, DFO		
phase advance/cell		$\sim \pi/2$		
tune: horizontal		13.23		
vertical		10.22		
γ_{TR}		12.55		
β_{max}: horizontal		12.6 m		
vertical		14.0 m		
D_{max}: horizontal		1.9 m		
depolarizing resonances				
	$(kP)^{\pm}$	18^-	$\gamma = 4.3$	$\delta = 0.0028$
		0^+	$\gamma = 5.7$	$\delta = 0.0207$
		24^-	$\gamma = 7.7$	$\delta = 0.0084$
		6^+	$\gamma = 9.0$	$\delta = 0.0152$

Table 5 : Main Ring parameter

energy range		9.6 - 30.0 GeV
circumference		960 m
repetition rate		12.5 Hz
particle/pulse		$5 \cdot 10^{13}$ ppp
number of superperiodes		4
number of cells		$4 \cdot 13$
cell structure		separated function, FODO
phase advance/cell		$\sim \pi/3$
tune:	horizontal	8.65
	vertical	8.80
γ_{TR}		7.78
β_{max}:	horizontal	32.9 m
	vertical	31.3 m
D_{max}:	horizontal	4.2 m
Siberian Snakes		yes

TABLE 6: Secondary beam characteristics for external W-targets (slow extraction).

BEAM	LENGTH m	l_{tg} mm	INTER. PER PROTON	ABSORPTION FACTOR	α_s mr	β_s mr	a_s mm	b_s mm	Ω msr	$\Delta p/p$	EXTRACT. ANGLE	PROD. ANGLE
S 0.2	20	50	.4	.9(π, μ)	80	200	1.1	2.1	50	.15	120°	120°
S 0.8	18	50	.4	.76(K,$\bar{p}$)	22	71	0.9	1.8	5(8)	.05	11.5°	0 - 5°
S 1.5	25	100	.4	.64(K,$\bar{p}$)	11	56	.74	2.8	2(5)	.03	5.7°	0 - 4°
S 3	35	100	.4	.64(K,$\bar{p}$)	5.5	56	.57	2.8	1(5)	.05	5.7°	0 - 3°
S 6	75	50	.4	.75(K,$\bar{p}$)	0.6	36	.50	1.0	0.07(3)	.05	0°	0 - 3°
S 20	130	100	.4	.55(K,$\bar{p}$)	0.6	25	.50	1.35	0.05(.5)	.05	0°	0°
K_L^0	15	100	.14	.7 (K^0)	10	2.5	.70	.52	0.1	wide band	0°	0°

TABLE 7: (in Million of Deutsch Marks).

1.2 GeV LINAC	136
1.2-9 GeV BOOSTER	90
9 GeV HOLDING RING	32
9-30 GeV MAIN RING	147
30 GeV STRETCHER	45
BUILDINGS	77
CENTRAL FUNCTION	10
COMMON SERVICES AND UTILITIES	60
FAST EXTRACTION HALL	46
SLOW EXTRACTION HALL	195
ARCHIT./ENG.	10
TOTAL	848

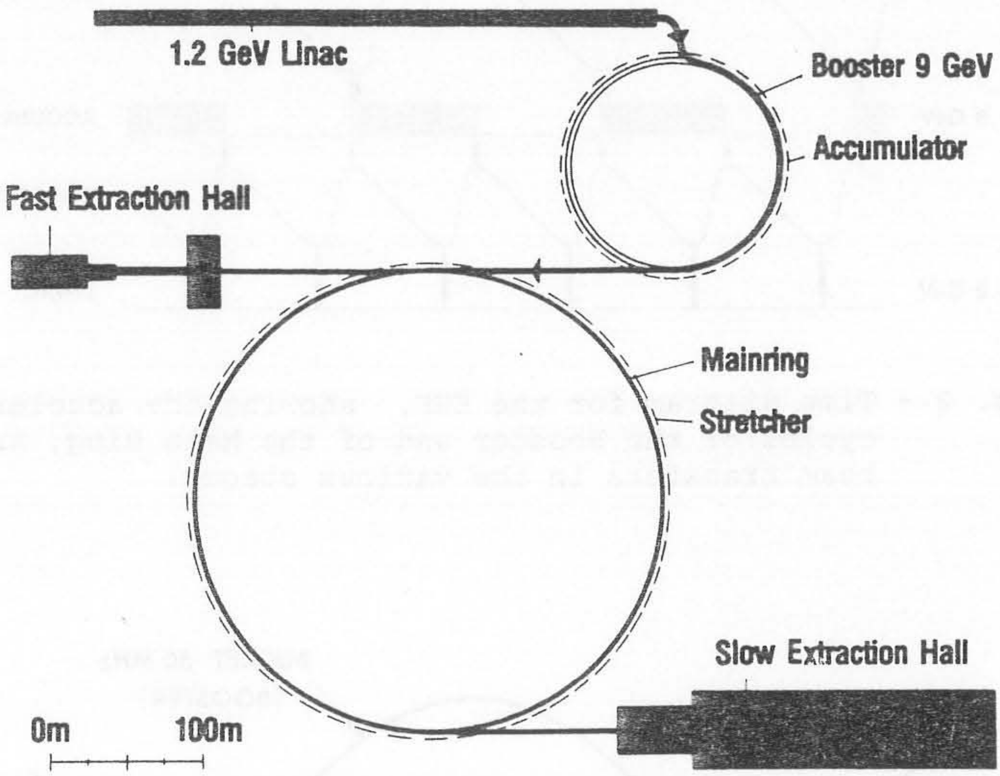


Fig. 1 - Schematic layout of the European Hadron Facility.

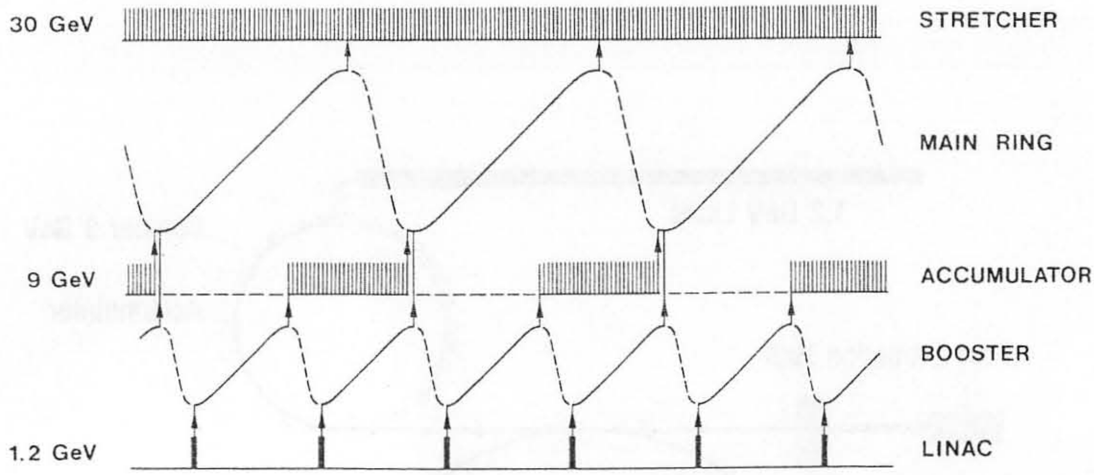


Fig. 2 - Time diagram for the EHF, showing the acceleration cycles of the Booster and of the Main Ring, and the beam transfers in the various stages.

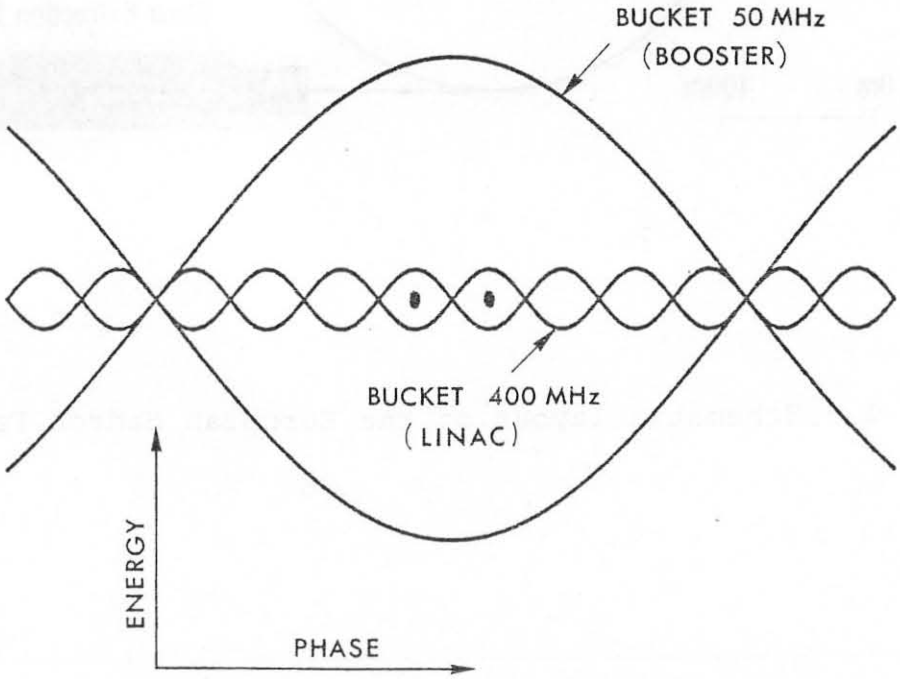


Fig. 3 - Longitudinal phase-space diagram showing the relative position of the LINAC bunches and the Booster bucket. By a suitable "painting" technique at injection 50% of the bucket area will be uniformily filled.

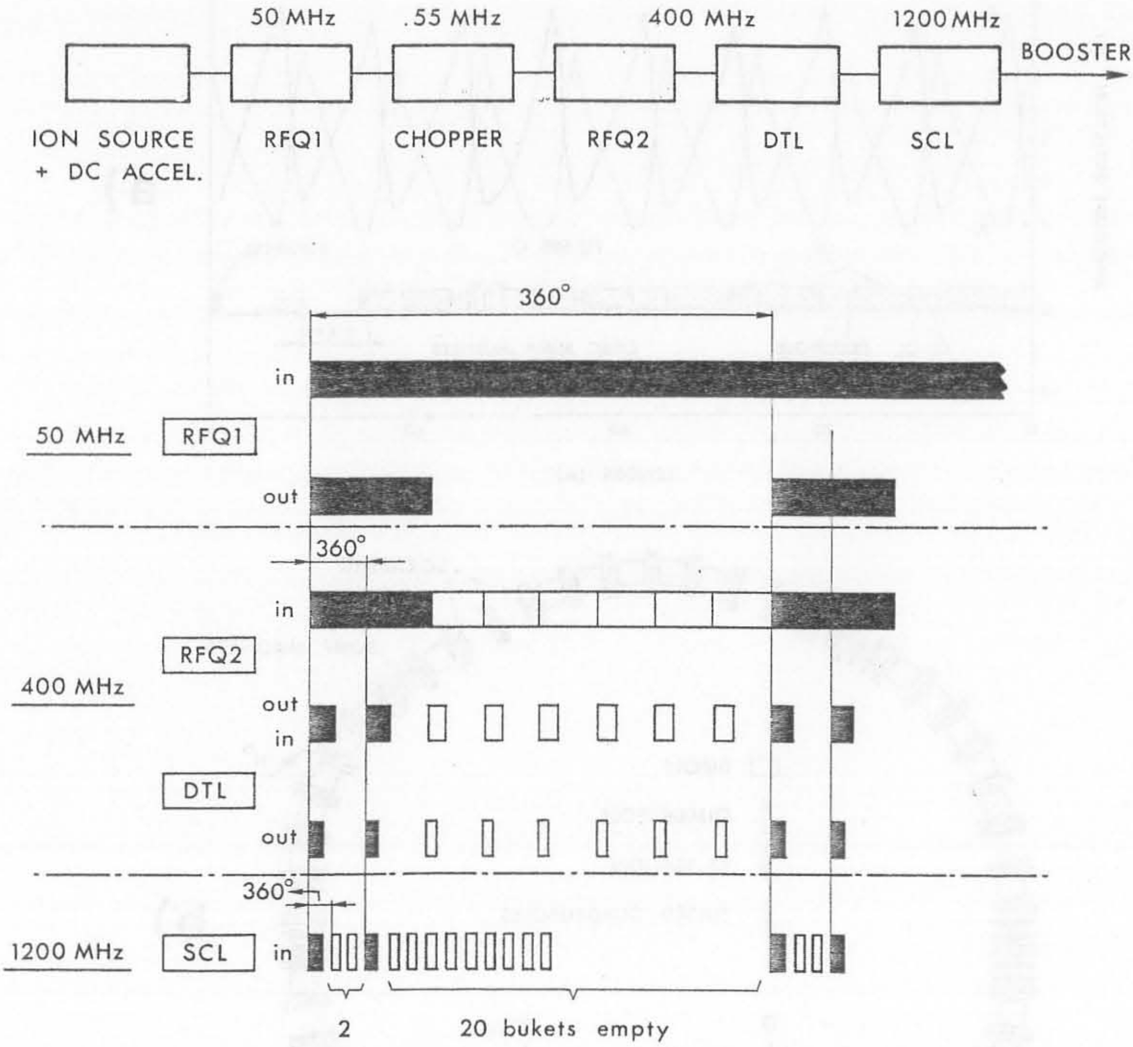
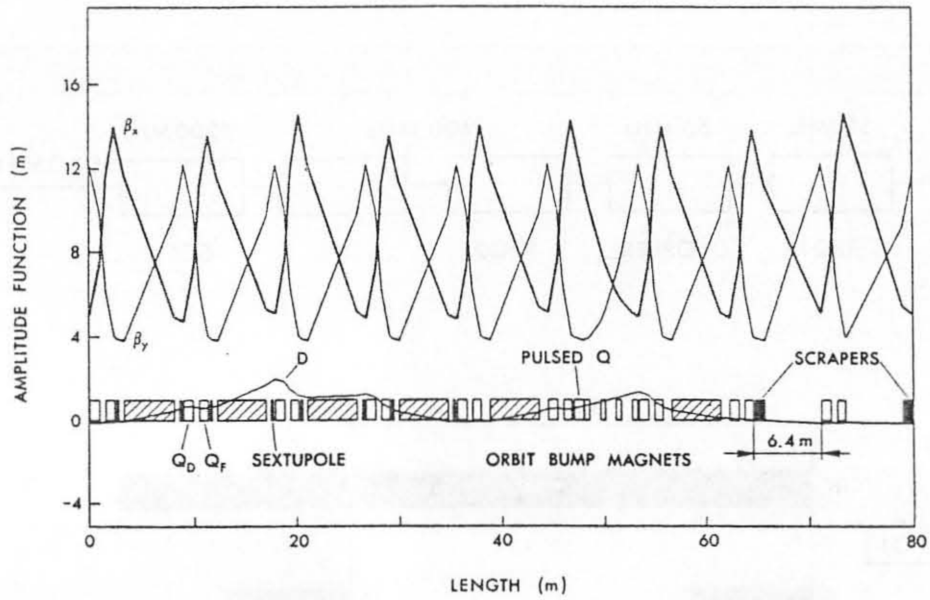
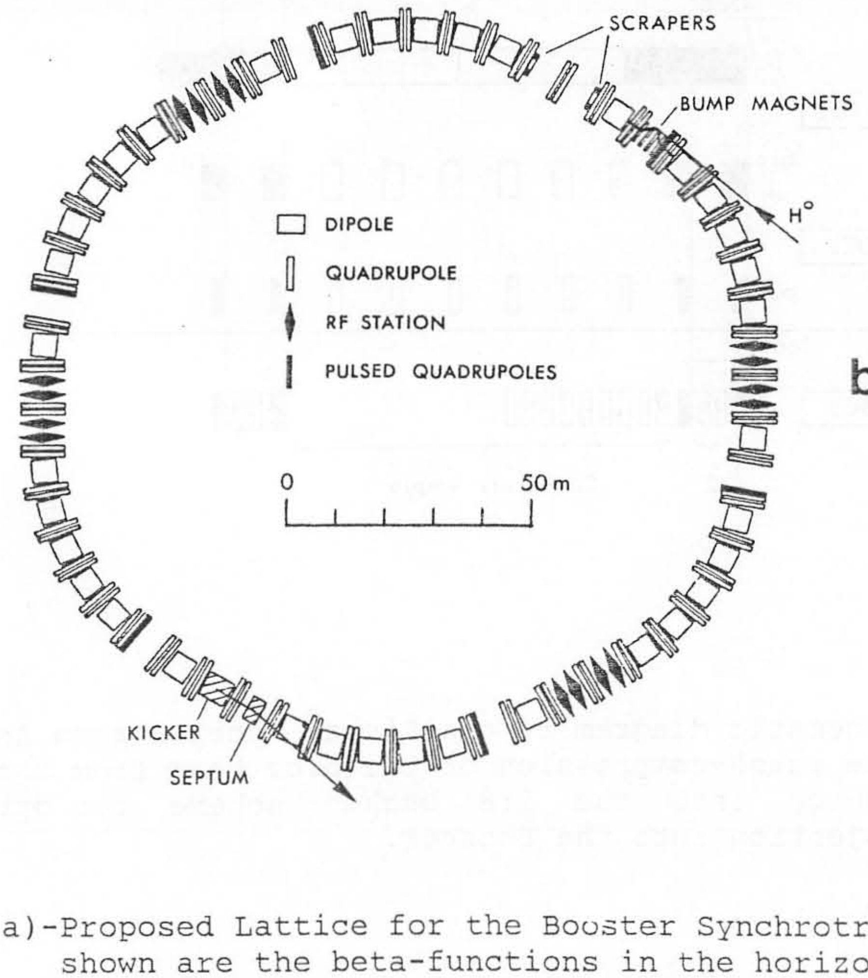


Fig. 4 - Schematic diagram of the Linear Accelerators and of the phase-compression of the d.c. beam from the ion source into the 2:8 bucket scheme for optimal injection into the Booster.



a)



b)

Fig. 5(a)-Proposed Lattice for the Booster Synchrotron. Also shown are the beta-functions in the horizontal and vertical planes and the dispersion function, for one superperiod.

5(b)-Possible arrangement of magnets and RF cavities.

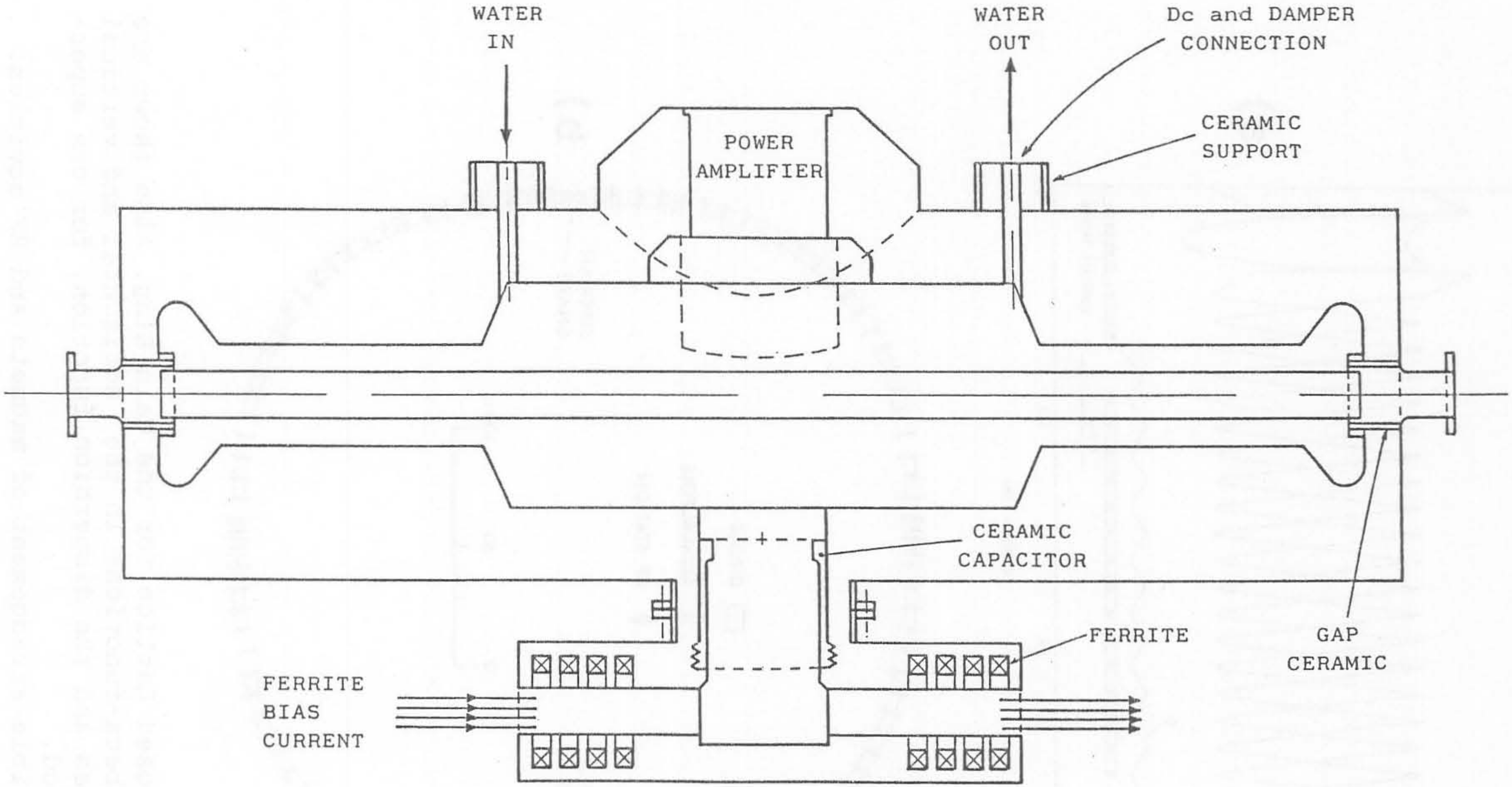


Fig. 6 - Schematic drawing of the double-gap RF cavity proposed for EHF.

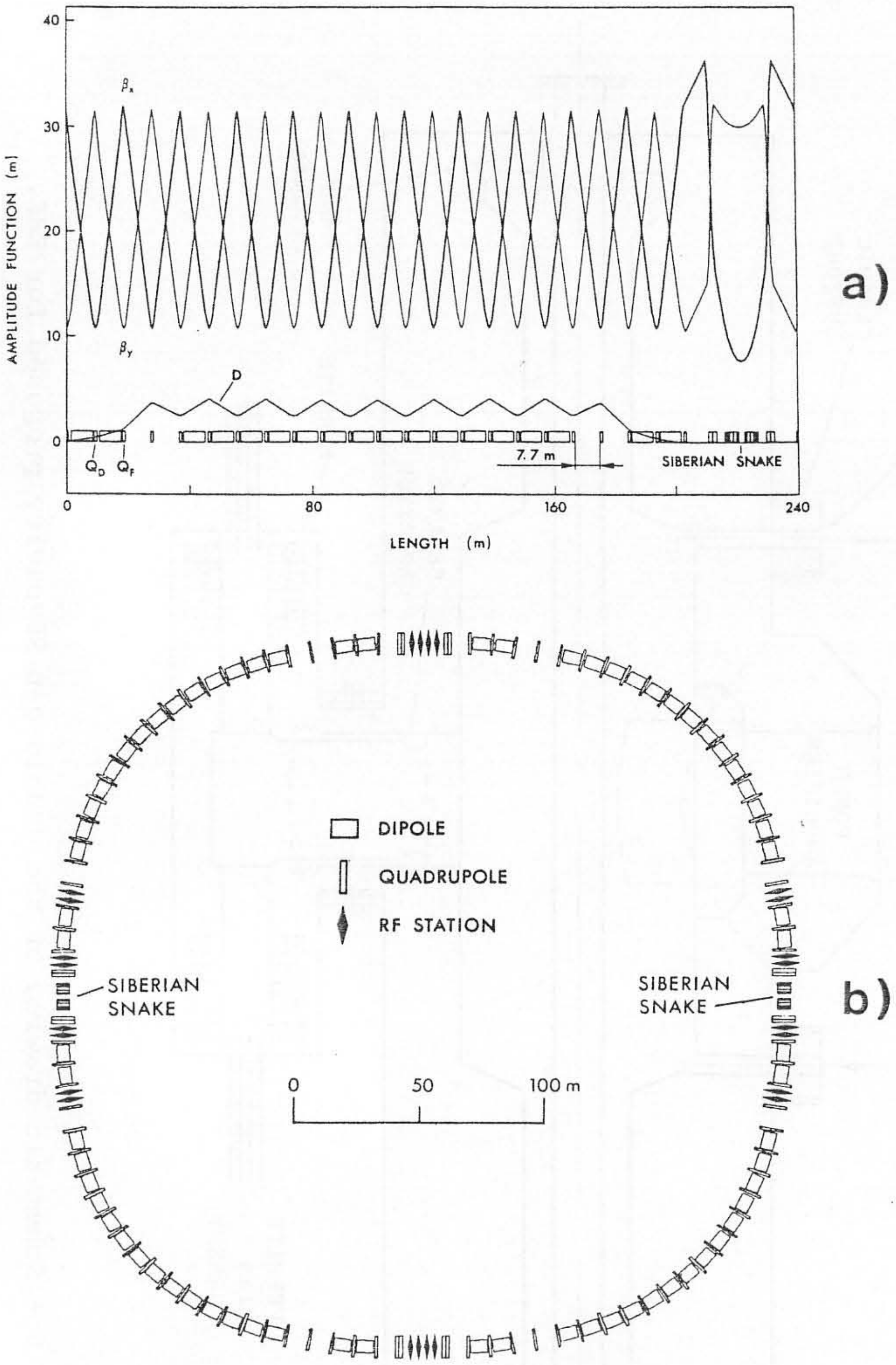


Fig. 7(a)-Proposed Lattice for the Main Ring. Also shown are the beta-functions in the horizontal and vertical planes and the dispersion function, for one super-period.

7(b)-Possible arrangement of magnets and RF cavities.

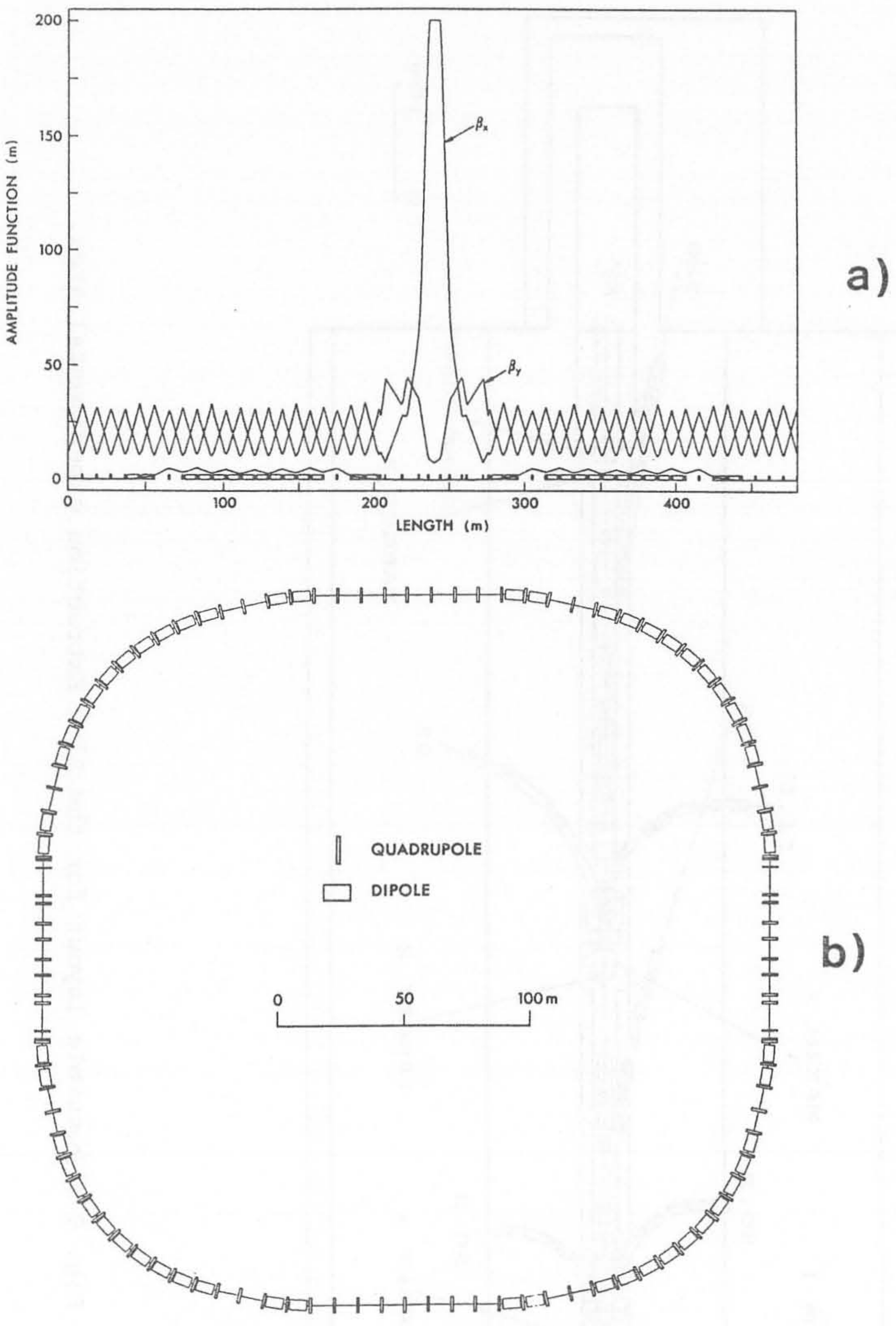


Fig. 8(a)-Proposed lattice for the Stretcher Ring. Also shown are the beta-functions in the horizontal and vertical planes and the dispersion function, for one superperiod.
8(b)-Possible arrangement of magnets and RF cavities.

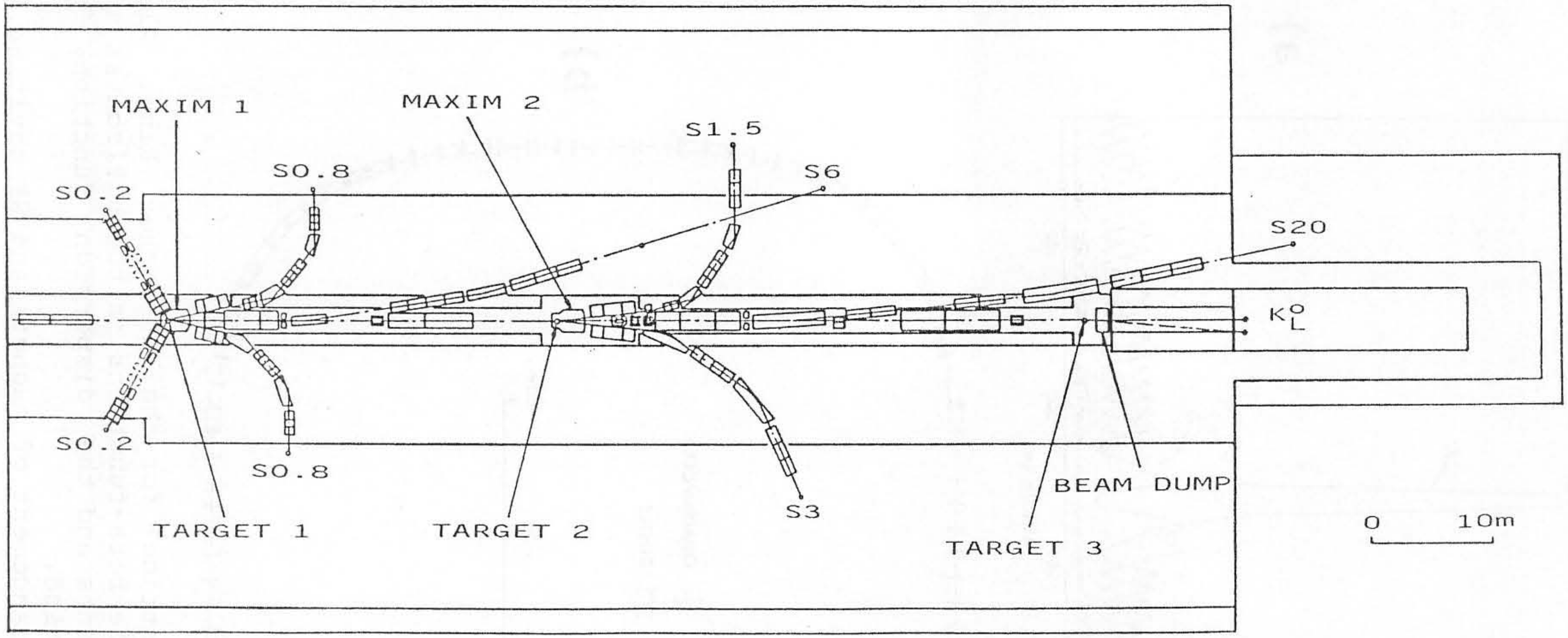


Fig. 9 - Possible layout for the Slow Extraction experimental area.

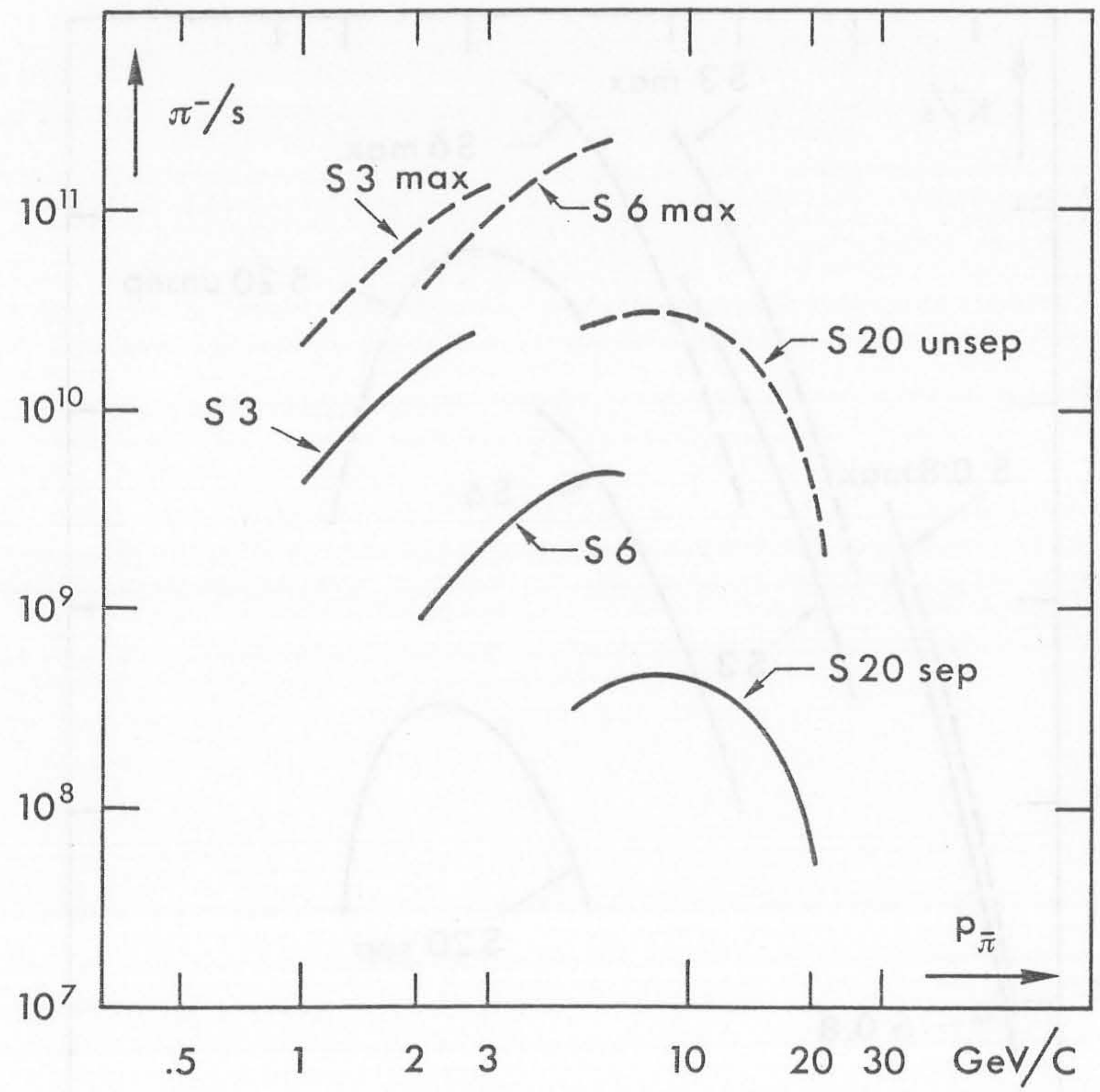


FIG. 10a

Fig. 10 - Particle Intensities vs momentum in the beam lines shown in Fig. 9, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.

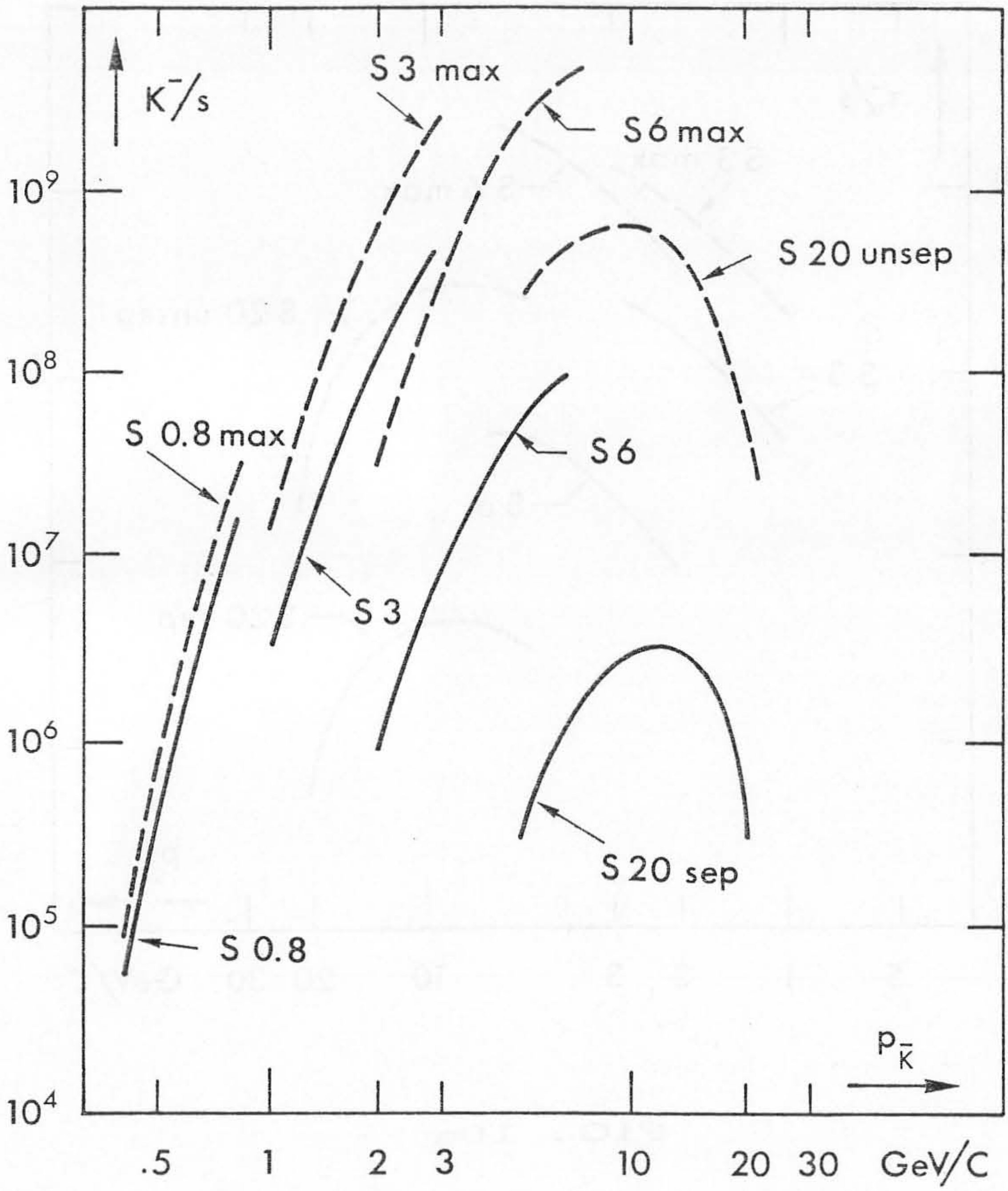


FIG. 10b

Fig. 10 - Particle Intensities vs momentum in the beam lines shown in Fig. 9, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.

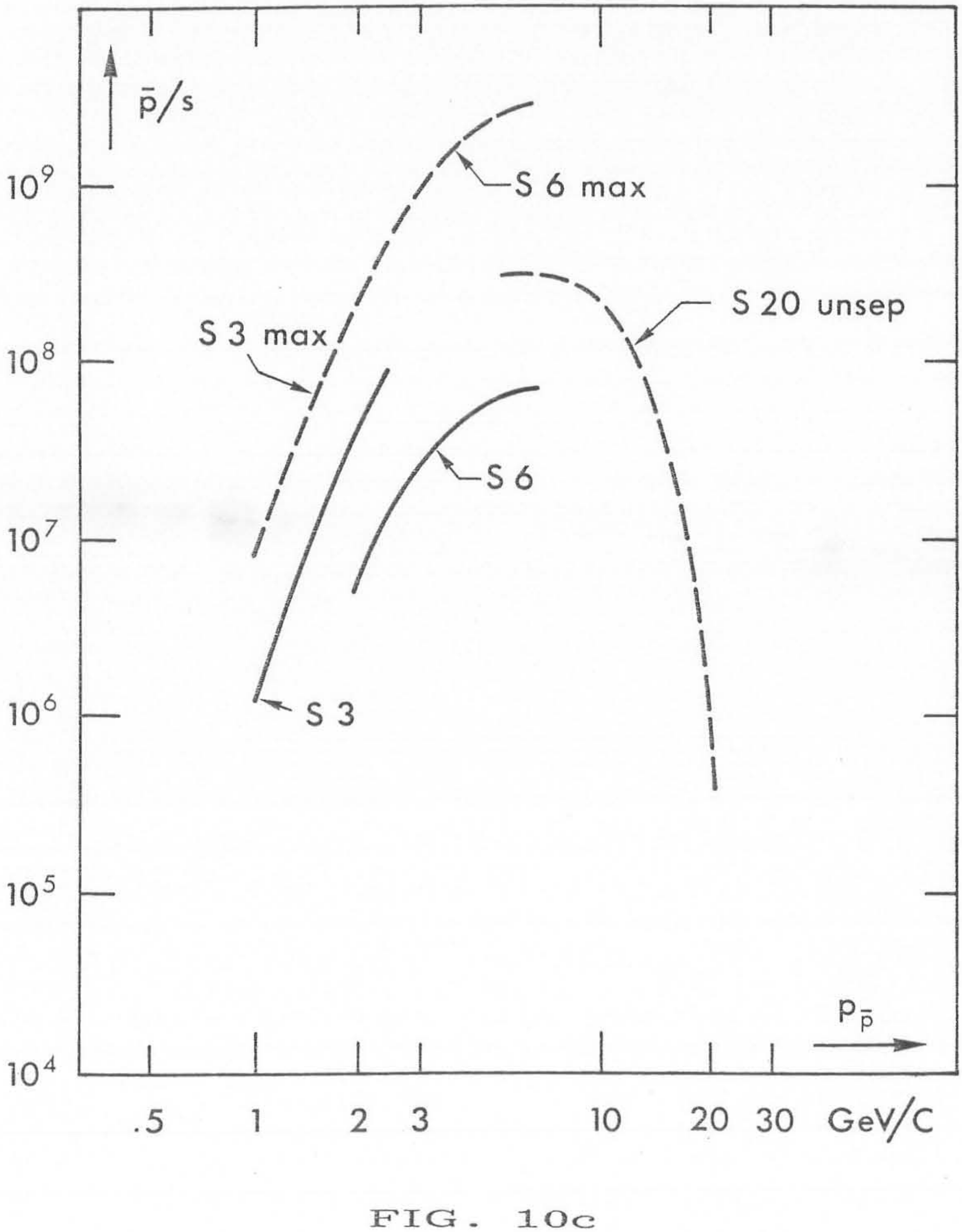


FIG. 10c

Fig. 10 - Particle Intensities vs momentum in the beam lines shown in Fig. 9, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.