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CONCEPTUAL DESIGN OF THE EHF

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CONCEPTUAL DESIGN OF THE EHF

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1. INTRODUCTION

A preliminary conceptual design for the European Hadron Facility (EHF), a high current proton synchrotron in the 30 - 40 GeV energy range to be built in Western Europe, 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 stimulated by the EHF Study Group and has been carried through by an international team made up of the accelerator physicists from Europe and from oversea listed in Table 1. The activities of the group have been sponsored in so far by Germany, Italy and Switzerland, and have had as milestones three dedicated workshops, in Trieste (Oct. 9 - Oct. 16, 1985), at SIN (Dec. 9 - Dec. 11, 1985), and in Karlsruhe (March 3 - March 5, 1986).

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 ($.6 \times 10^{15}$ 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 $\sim$40 GeV.

No existing injector was suggested, since no existing site or laboratory was to be assumed for the moment, and in this sense the project which is described in this report has been usually referred to as the "siteless EHF"[1]. Being a European project clearly a Swiss option using the 590 MeV SIN isochronous cyclotron as injector has been kept in mind from the very beginning (option A in ref. 1) and is still being investigated by the SIN staff[2], but has not been studied by the group in Table 1 and I will not report about it. 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.

2. ACCELERATORS PARAMETERS

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 Accumulator, 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 an Accumulator 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 Accumulator, the second one passing through the just emptied Accumulator 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. Bucket-to-bucket transfer of the beam from one machine to the next minimizes beam losses, as will be explained in Section 5. The ramping of the magnets is done with a dual resonance circuit[3)] 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.

3. BEAM LOSSES

A crucial issue in the design of every single part of the EHF has been the minimization of beam losses.

A 1% beam loss at EHF would correspond to the loss of the full beam at the CERN PS or at the Brookhaven AGS, a perspective which is clearly unacceptable and would put excessive requirements on shielding and remote control of the machine components and seriously question the reliability of the entire complex. It turns out, however, that by careful design and parameter optimization beam handling can be effectively lossless, so that the general radioactivity level will be equivalent to that of an existing accelerator of the same energy. Of course, the machine must be adequately shielded (underground tunnels, $\sim$20 mt deep, are needed to house the accelerators) but mainly as a precaution against accidents, and no particular radiation damage of the various components is foreseen.

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 sect. 5, and (iv) placing very safe margins on the magnets apertures.

As regards point (i)

a) the normalized emittance is taken 25 mm mrad in both planes, a compromise value, avoiding too expensive magnets apertures and space charge problems;
b) the "Laslett" incoherent tune-shift does not exceed a value of 0.20, so that one can find a location in the tune diagram where the beam can nominally be tuned and be safely away from major resonances;
c) to avoid losses during the transition from coasting to accelerated beam, the bucket area is filled at most to 50%, corresponding to extreme phases of $\pm 100^{\circ}$ for a matched bucket;
d) in the Booster the longitudinal emittance is about 0.05 eVs in order to keep the trapping voltage to a reasonable level and still ensure beam stability;
e) in the Main Ring the longitudinal emittance will be blown up to $\sim$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 by suitable choices of the magnet lattices;
g) the impendances of the vacuum chambers are minimized to avoid longitudinal microwave instabilities.

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 $\pi/\beta\gamma$ (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. The resultant magnet apertures are 71 mm for the Booster and 51 mm for the Main Ring, for maximum values of 15 m and 30 m respectively for the vertical beta-functions.

Although a precise evaluation of the beam losses has not yet been done and will require the running of long simulation programs,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, particular pieces of equipment will be handled by remote control.

4. 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 ($N_p \simeq 5 \times 10^{13}$). 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. 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[4]), 6 GeV for LAMPF II[5])), 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[6]) in the Main Ring so as to preserve the beam polarization. Since the magnets in the snakes work at constant field and some 15 T.m are needed, at least 9 GeV are required to keep the magnet apertures within reasonable limits.

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. Moreover, there are less problems with microwave instabilities. Also, since polarization is guaranteed by the Siberian Snakes, low superperiodicity lattices may be used for the Main Ring, thus allowing long dispersion-free straight sections for rf cavities, injection and extraction.

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 2, all four rings are evenly distributed into the two tunnels, Main Ring and Stretcher in the big tunnel and Booster and Accumulator 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 Accumulator 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. Eventually even polarized proton physics or kaon physics can be carried on by operating the Accumulator as a Stretcher for the Booster pulses.

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 π 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 6.

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 11, 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.

5. 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.inject 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. This method 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 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.

Although the longitudinal emittances differ by three orders of magnitude

$$\varepsilon_L^{LINAC} \simeq 0.6 \times 10^{-4} \mathrm{eV.sec}, \qquad \varepsilon_L^{Booster} \simeq 0.05 \ \mathrm{eV.sec}$$

the filling of the longitudinal phase-space is limited by the energy jitter in the LINAC, so that an energy analysis of the LINAC beam, as shown in Fig. 1, is necessary to provide a fast control of painting.

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.

6. 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 2 MV/m and the SCL with an average gradient of 3.2 MV/m, resulting in a total length of about 400m for the whole LINAC, but it is possible that these gradients be increased in the final project to reduce somewhat the investment cost.

7. BEAM POLARIZATION IN THE SYNCHROTRON

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[6), namely when the precession frequency of the spin $f = G\gamma$ (G is the usual proton gyromagnetic 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 $G\cdot\gamma = kP\ Q_y$ (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.

8. THE BOOSTER SYNCHROTRON

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 β-functions. The horizontal tune has been designed to be 13.4, in order to push γ_{TR} well above the maximum energy of the Booster. There are six superperiods, providing six long (2 x 6.5 m) straight dispersion-free sections for installation of the rf cavities and for injection and extraction. Table 2 summarizes the Booster parameters and Fig. 5 shows the beta functions and the dispersion function for one superperiod.

The beam power is 1.6 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[7] will be used. Twenty cavities will be needed, with a peak voltage of 50kV per cavity.

The parameters of the Booster we propose are somewhat similar to the FNAL Booster, as shown in Table 3. Clearly the improvement in intensity aimed for is large, but the substantial increase in the injection energy makes the design perfectly feasible.

9. THE MAIN RING SYNCHROTRON

The Main Ring lattice has been chosen essentially to provide long (3x7.8 m) dispersion-free straight sections for insertion of the Siberian snakes ($\sim$20 m) magnets and for extraction. Slow Extraction in this energy range requires straight sections about 20 m long. 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 clearly 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 8. The amplitude functions are given in Fig. 6, whilst all the relevant parameters of the lattice are summarized in Table 4.

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-four cavities, again of the type developed at FNAL, will be used, at a peak voltage of 85 kV/cavity, and will be arranged in four straight sections. Two more sections will contain the Siberian Snakes, one more section will house the injection and extraction system and one section is left free for future options.

A possible arrangement of magnets, rf cavities and transfer lines for both the Main Ring and the Booster is shown in Fig. 7. Table 5 summarizes the number of magnets needed and their apertures, determined as described in Section 3. No detailed designs have been worked out at this stage of the project for the Accumulator and the Stretcher ring, but they are simple DC rings and do not pose any particular problem.

10. 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.8. 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. 9 and are really impressive. Furthermore new ideas on internal targets are being elaborated which could eventually lead to further reduction of the emittance of the secondary beams-particularly important for the separated kaon or antiproton beams, where the net gains in phase space densities could even be three orders of magnitude[9)]. A yield of $\sim 10''$ $\bar{p}$/sec $\cdot$ GeV/c $(\pi \text{ mm mrad})^2$ can be attained, so that new possibilities to store antiprotons can be envisaged which compare favourably with the present techniques used at CERN, unable to hold the fluxes foreseen for EHF.

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.

11. 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,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. Also, the running cost of the Facility has not yet been estimated.

As mentioned in Section 4, some cost reduction can be obtained by lowering the energy of the Booster to $\sim$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 abmitious project like EHF, were considered more important than just straightforward cost considerations.

12. CONCLUSIONS

I have tried to summarize in this report the results of a Feasibility Study for a European Hadron Facility[10]. Clearly, a lot of work has still to be done to complete the design: the DC rings have not yet been studied, the SCL structure has to be calculated and tested,the Booster and Main Ring lattices have to be checked and eventally improved, items such as painting, or precise evaluation of beam losses and beam depolarization demand for computer tracking with multiparticle simulation codes. Further studies may also lead to improvements 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.

This comunity has demonstrated to be strong and competent, and the success of this Conference in Mainz is a further demonstration of this fact. Like many other colleagues who are working in this field I am convinced that the case for a new laboratory in Europe is well justified and that the most reasonable option would be a site in Italy, which at present has no heavy commitments with big International Research Laboratories on its territory. I am perfectly aware of the advantages of an alternative "CERN option", namely of the possibility of realizing the EHF at CERN as a "supplementary program" sponsored by Germany, Italy, Switzerland and eventually other countries. The use of the ISR tunnel to house the Main Ring and the Stretcher, of the West Area for experimentation and eventually of some CERN infrastructure would result in consistent savings. Moreover the scientific atmosphere of CERN unquestionably would be an absolute guarantee of success for our Hadron Facility. Still, CERN is bound to pursue the frontier for higher and higher energies, and it is not obvious that in this effort it can afford a supplementary program at all.

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 reasonble 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.

13. ACKNOWLEDGEMENT

The work I report on has been carried out by the EHF Design group listed in Table 1, to whom I would like to express my sincere thanks. The facility we are proposing has not yet been approved, still the persons I am referring to have dedicated a considerable fraction of their time to seriously think about it. I find this mostly encouraging, since it proves that the problems we have faced have some fundamental interest of their own and their solution will any way contribute to the advance of our knowledge of accelerators.

It is a pleasure for me to acknowledge the assistance received from A. Ruggiero in organizing the activities of the EHF Design Group, the contribution of P. Blüm and K. Bongardt when preparing this talk and the many enlightening discussions I had with M. Weiss.

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REFERENCES

1) Proceedings of the "Workshop on the Future of Intermediate Energy Physics in Europe", Freiburg im Breisgau, 10-13 April 1984, Edited by S. Galster, KfK Karlsruhe.

2) W. Joho and J. Crawford, "Proposal for a High Intensity Proton Synchrotron at SIN", Proceedings of the Workshop on Nuclear and Particle Physics at Intermediate Energies with Hadrons, Miramare-Trieste, Italy, 1-3 April 1985, Ed. by T. Bressani and G. Pauli, p. 197.

3) W.F. Praeg,"Dual Frequency Ring Magnet Power Supply with Flat-Bottom", IEEE Trans. Nucl. Sci. NS-30, 4 (1983).

4) TRIUMF "KAON Factory Proposal", September 1985.

5) "A proposal to Extend the Intensity Frontier of Nuclear and Particle physics to 45 GeV (LAMPF II)", December 1984, LA-UR-84-3982.

6) See, for instance, R.D. Ruth, "A Review of polarized proton Beam Techniques", Proceedings of the 6th International Symposium on High Energy Spin Physics, Sept. 12-19, 1984, Marseille (France), ed.by Journal de Physique, Colloque C2, supplement au n^{o} 2, Février 1985, p. 611.

7) J.A. Dinkel, Q.A. Kerns, L.A. Klaisner and G.S. Tool,IEEE Trans. Nucl.Sci. NS-16, 510 (1969).

8) C. Tschalar, "Multiple Achromatic Extraction System", 1986, to be published in Nucl. Instr. and Methods.

9) C. Tschalar, "LAMPF II Experimental Area, A new concept using Internal Targets, LAMPF II Technical Note 85-010.

10) "Feasibility Study for a European Hadron Facility" to appear in June 1986.

TABLE 1: EHF Design Group.

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TABLE 2: Booster parameters.

energy range	1.2 - 9.0 GeV		
circumference	480 m		
repetition rate	25 Hz		
particles/pulse	2.5 10^{13} ppp		
number of superperiodes	6		
number of cells	54		
cell structure	separated function magnets, DFO		
phase advance/cell	$\sim \pi/2$		
tune: horizontal	13.4		
vertical	10.2		
γ_{TR}	12.7		
β_{max}: horizontal	12.8 m		
vertical	14.3 m		
D_{max} : horizontal	1.9 m		
depolarizing resonances			
$(kP)^{\pm}$	18^-	$\gamma = 4.4$	$\delta = 0.0025$
	0^+	$\gamma = 5.7$	$\delta = 0.0181$
	24^-	$\gamma = 7.7$	$\delta = 0.0076$
	6^+	$\gamma = 9.0$	$\delta = 0.0136$

TABLE 3: Comparison between EHF and FNAL Booster.

	FNAL Booster	EHF Booster
particle per pulse	$3x10^{12}$	$2.5x10^{13}$
injection energy	.2 GeV	1.2 GeV
maximum energy	8 GeV	9 GeV
repetition rate	15 Hz	25 Hz
r-f	10-50 MHz	50.5-56 MHz
peak r-f power	1.8 MWatt	3.2 MWatt

TABLE 4: Main Ring parameters.

energy range	9.0 - 30.0 GeV
circumference	960 m
repetition rate	12.5 Hz
particles/pulse	5×10^{13} ppp
number of superperiodes	8
number of cells	56
cell structure	separated function, FODO
phase advance/cell	$\pi/3$
tune: horizontal	9.2
vertical	9.2
γ_{TR}	8.2
β_{max}: horizontal	30.2 m
vertical	29.5 m
D_{max}: horizontal	6.9
Siberian Snakes	yes

TABLE 5: Magnet apertures.

	BOOSTER	MAIN RING
DIPOLES		
number	36	80
length [m]	5.49	6.77
field range [T]	0.203-1.05	0.383-1.196
half width [mm]	41.3	46.9
half gap [mm]	33.6	25.25
QUADRUPOLES		
number	108	112
length [m]	.75	.8
gradient [T/m]	14.8	15.2
bore radius [mm]		
hor.	41.8	48.7
ver.	34.9	25.3

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	149
1.2-9 GeV BOOSTER	104
9 GeV ACCUMULATOR	42
9-30 GeV MAIN RING	130
30 GeV STRETCHER	55
BUILDINGS	71
CENTRAL FUNCTION	10
COMMON SERVICES AND UTILITIES	60
FAST EXTRACTION HALL	46
SLOW EXTRACTION HALL	190
ARCHIT./ENG.	10
TOTAL	867

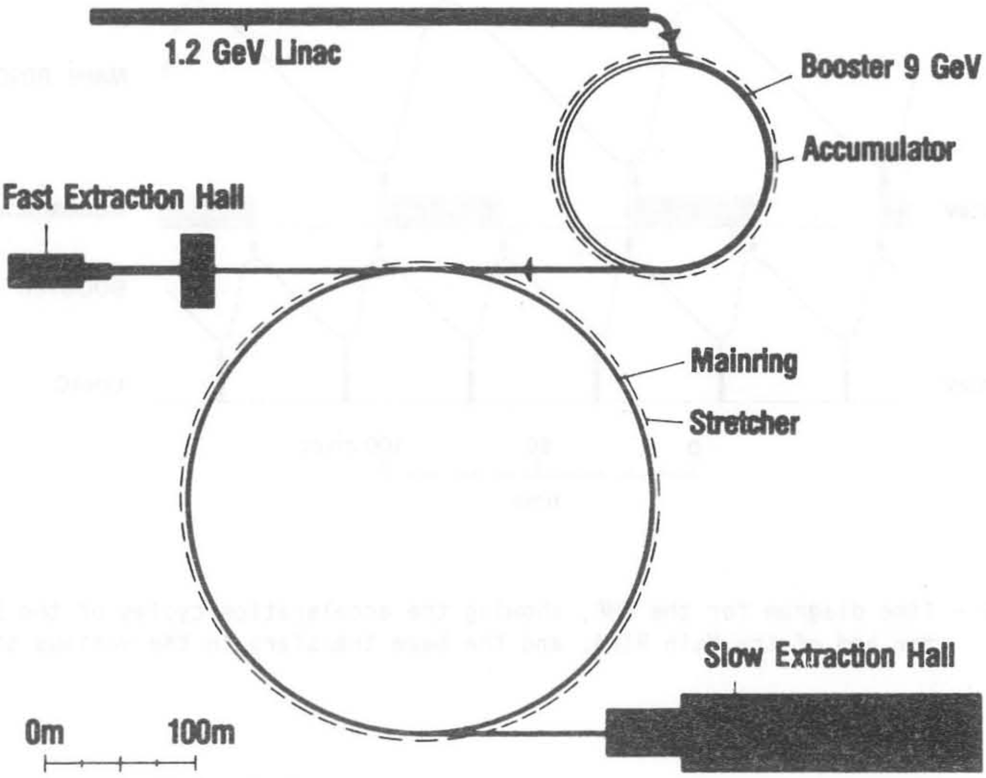

Fig. 1 - Schematic layout of the European Hadron Facility.

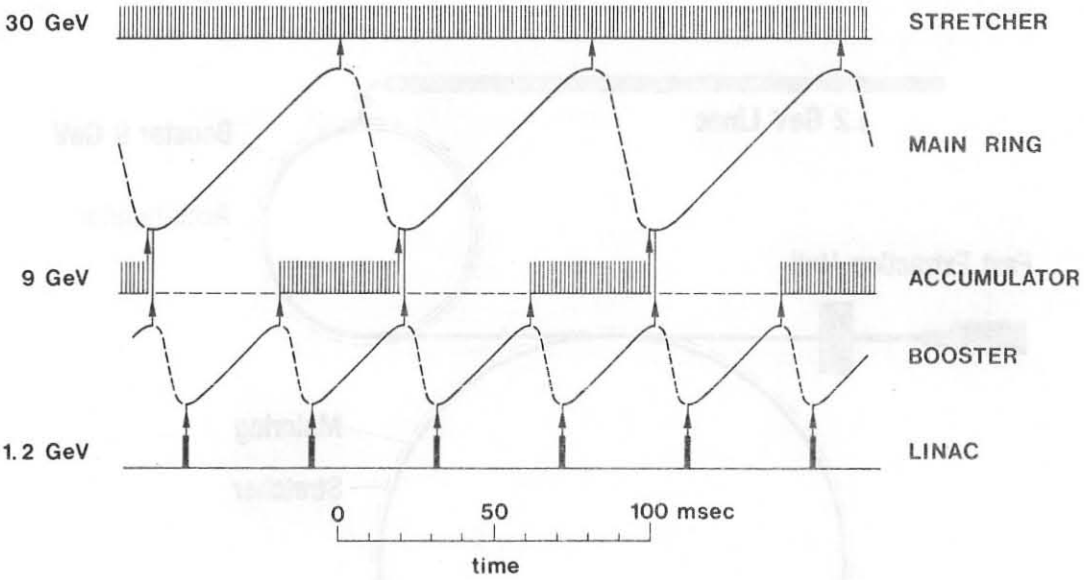

Fig. 2 - Time diagram for the EHF, showing the acceleration cycles of the Booster and of the Main Ring, and the beam transfers in the various stages.

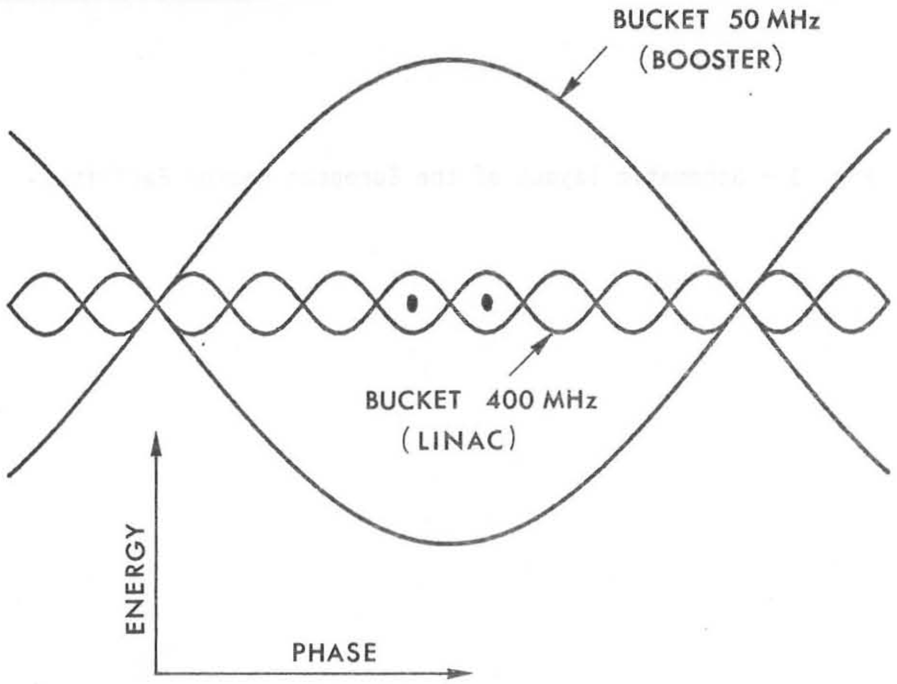

Fig. 3 - Longitudinal phase-space diagram showing the relative position of the tion of the LINAC bunches and the Booster bucket. By a suitable "painting" technique at injection 50% of the bucket area will be uniformily filled.

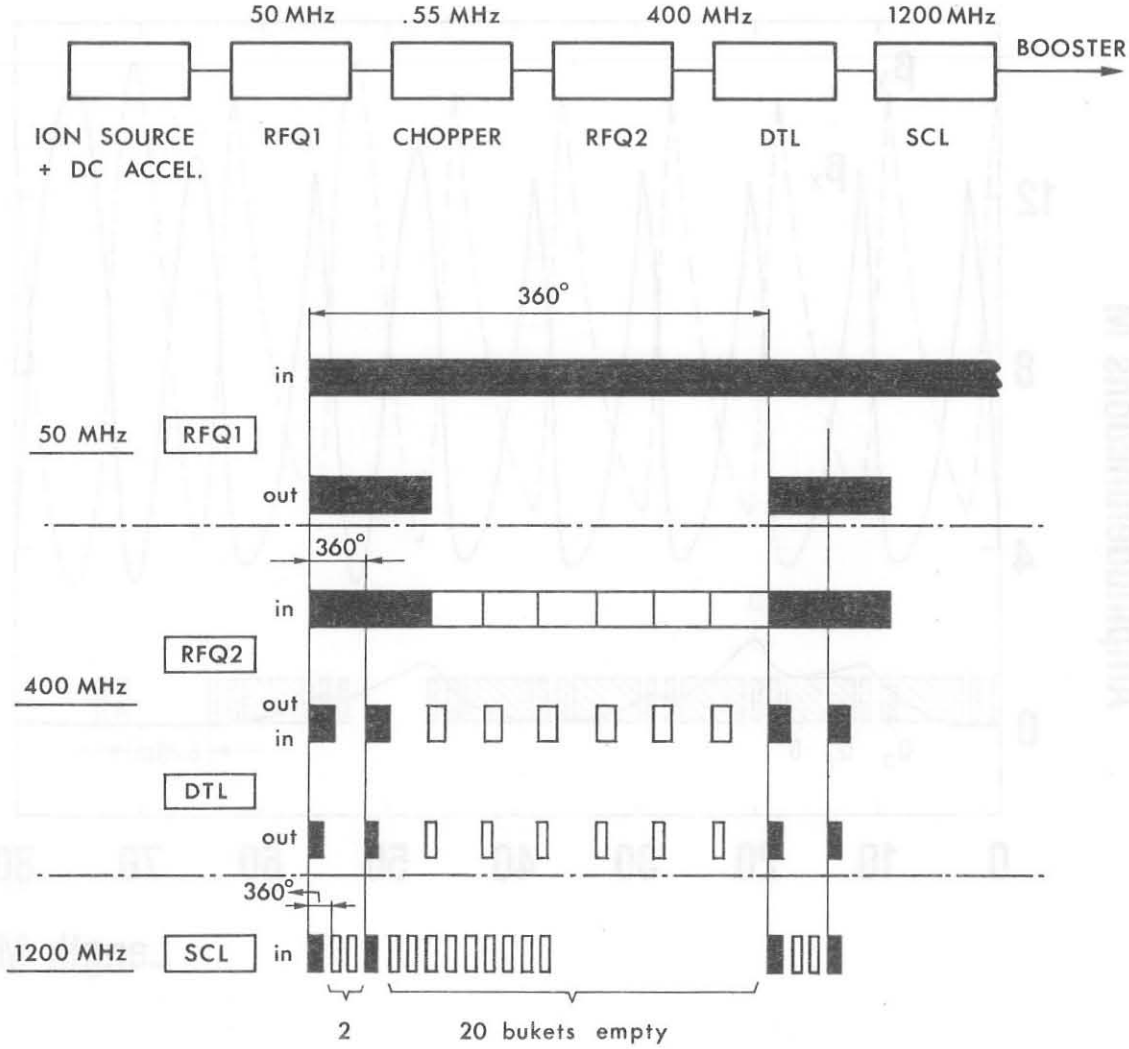

Fig. 4 - Schematic diagram of the Linear Accelerators and of the phase-compression of the d.c. beam from the ion source into the 2:8 bucket scheme for optimal injection into the Booster.

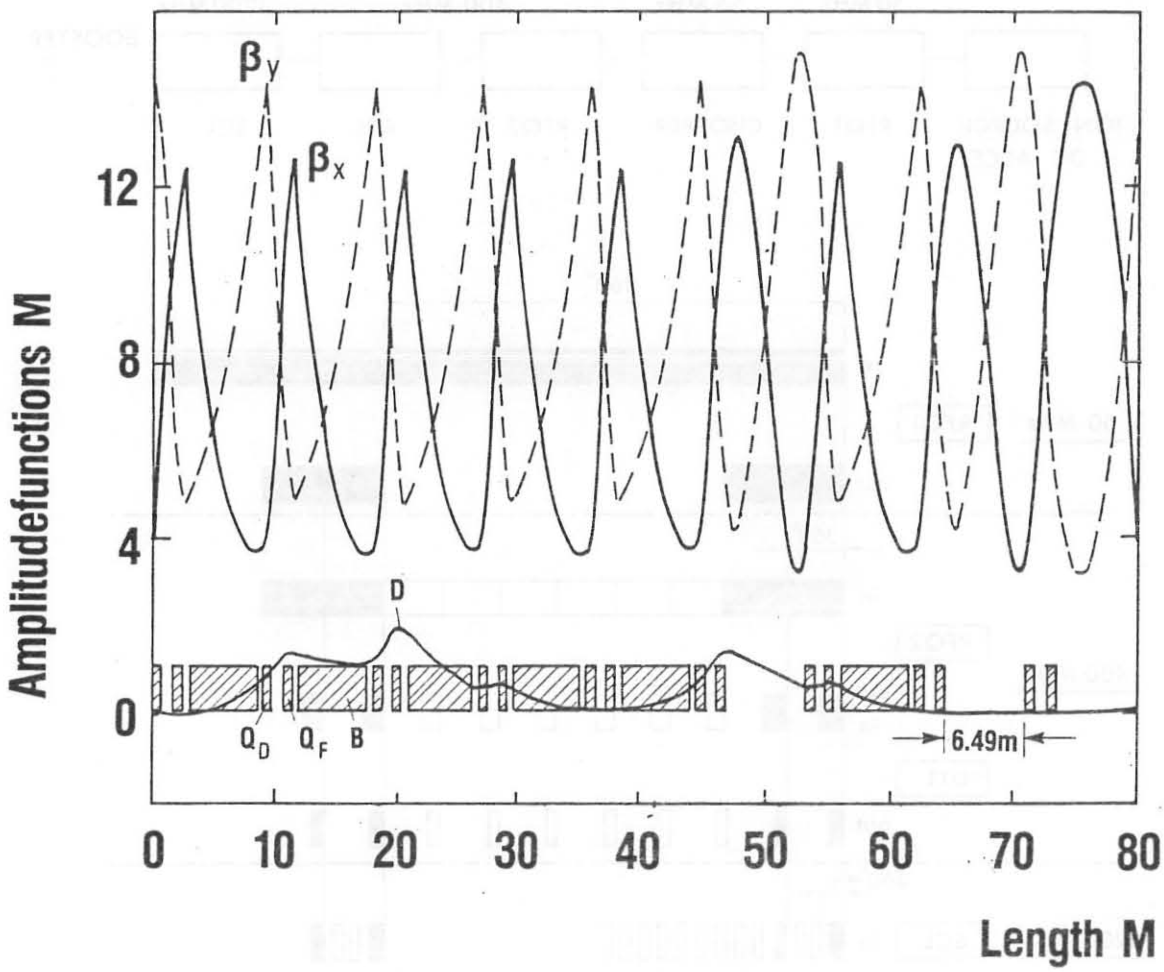

Fig. 5 - Proposed Lattice for the Booster Synchrotron. Also shown are the beta-functions in the horizontal and vertical planes and the dispersion function, for one superperiod.

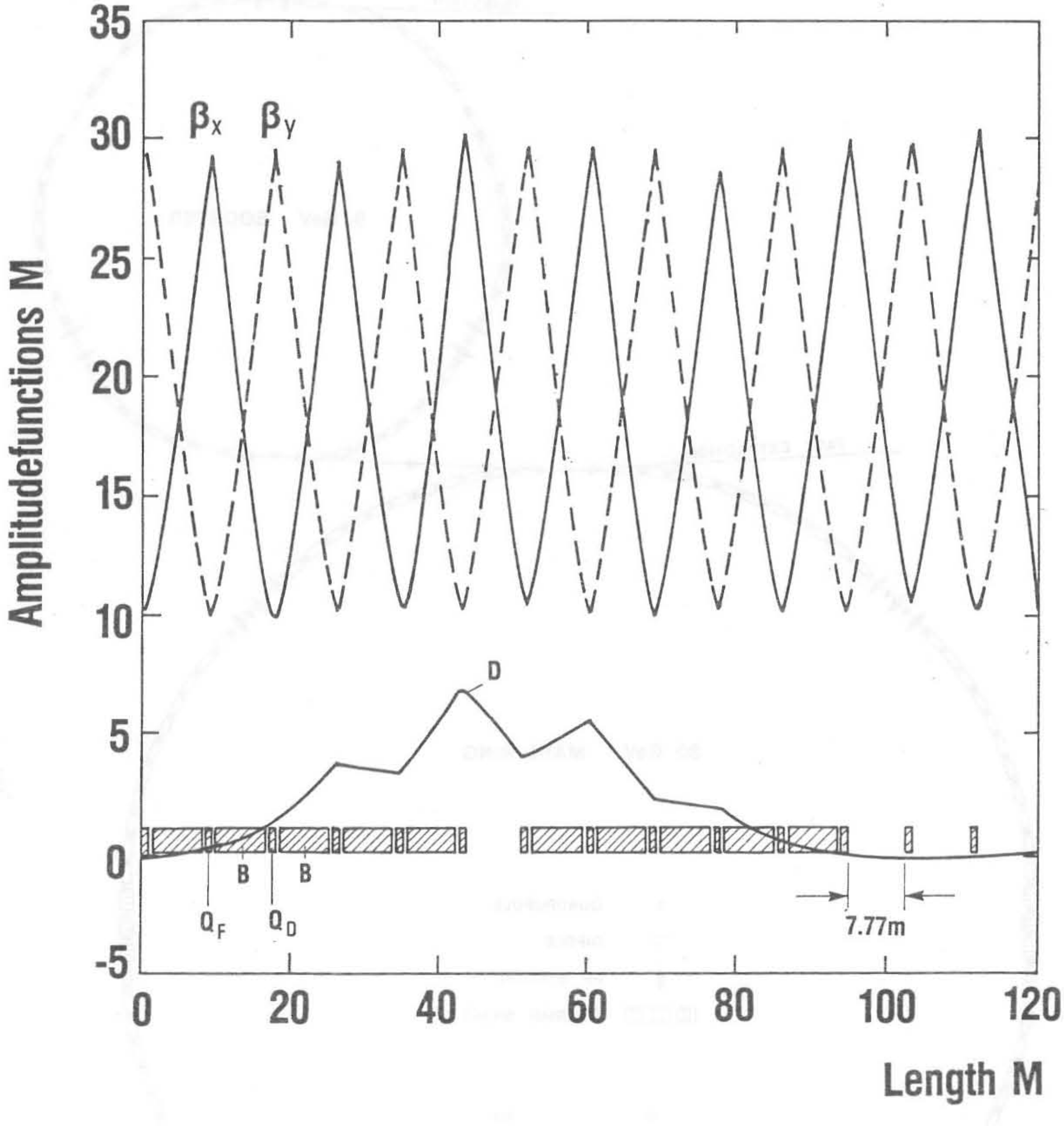

Fig. 6 - Proposed Lattice for the Main Ring. Also shown are the beta-functions in the horizontal and vertical planes and the dispersion function, for one superperiod.

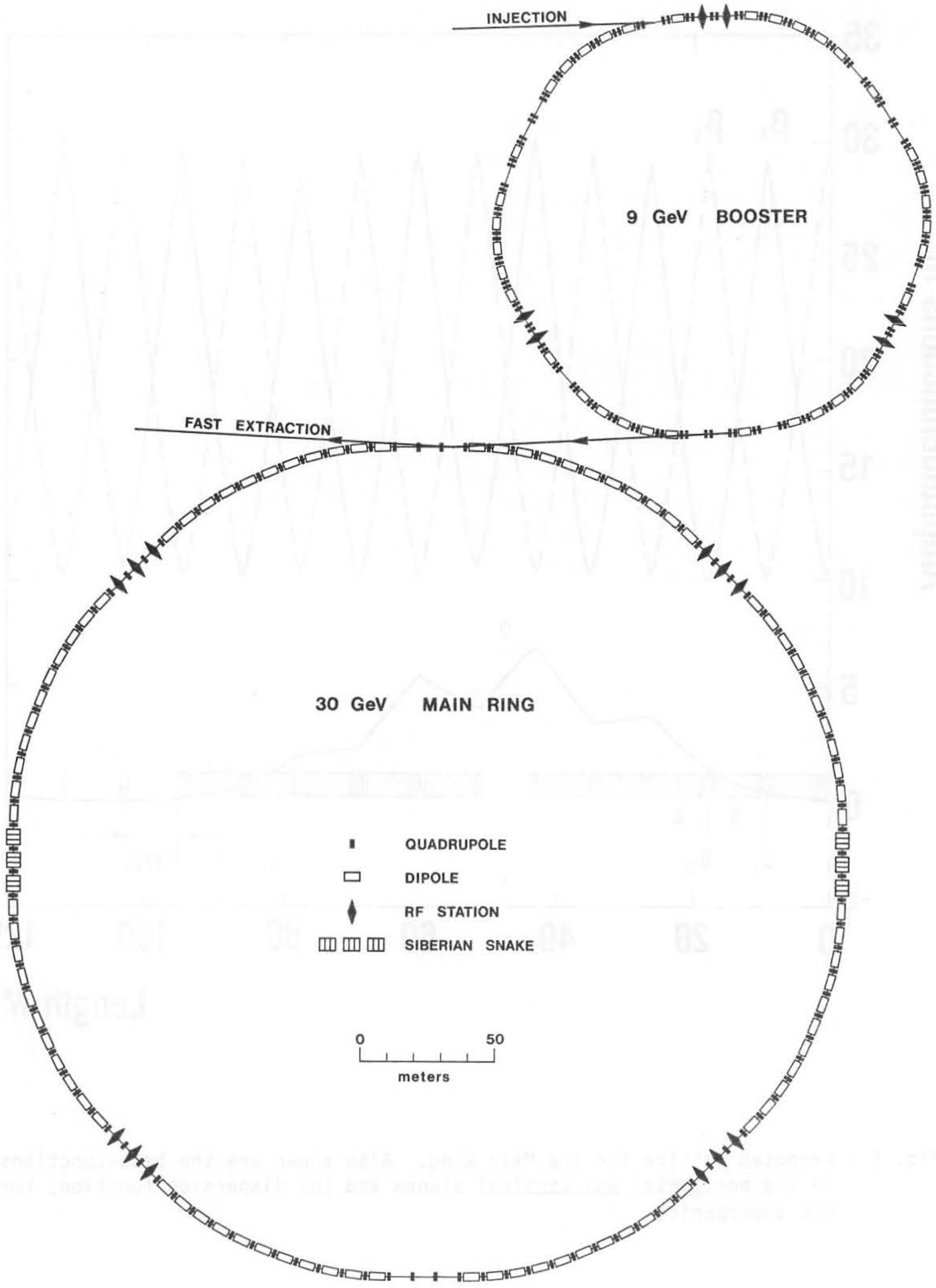

Fig. 7 - Arrangement of magnets and rf cavities for the Booster and Main Ring.

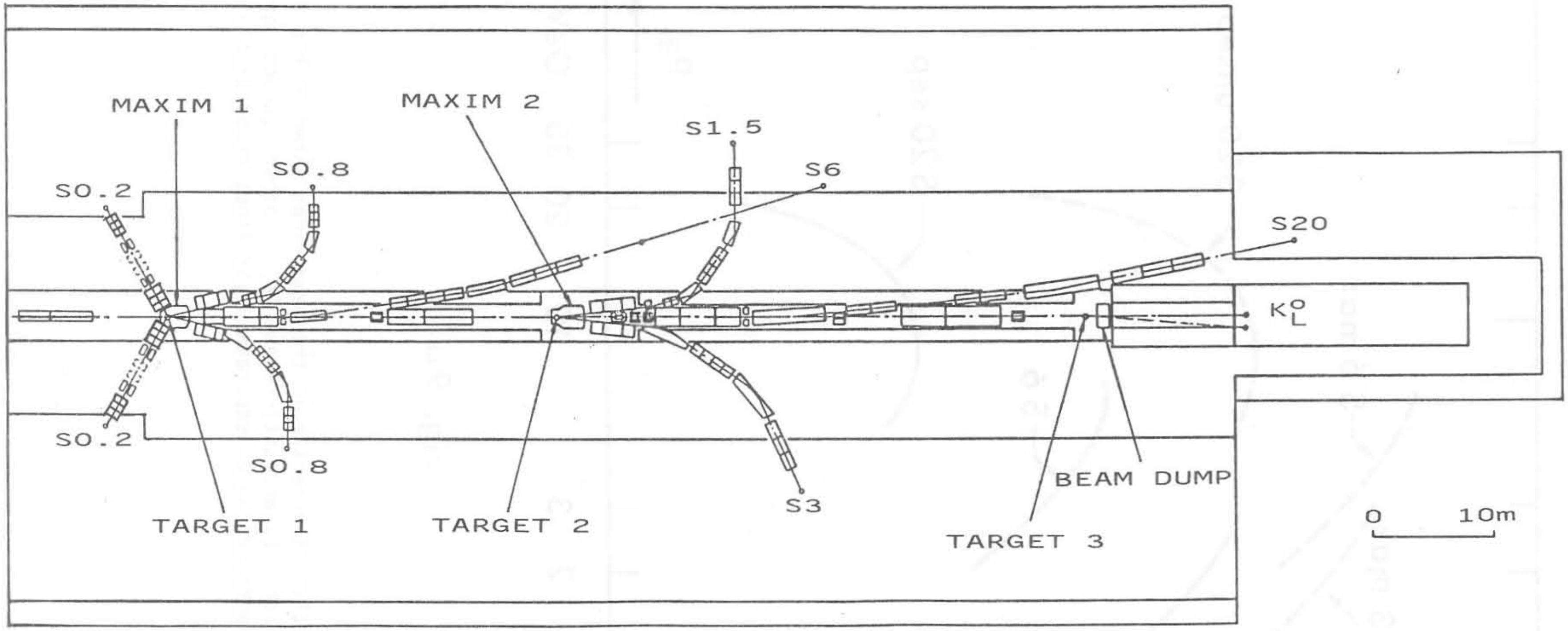

Fig. 8 - Possible layout for the Slow Extraction experimental area.

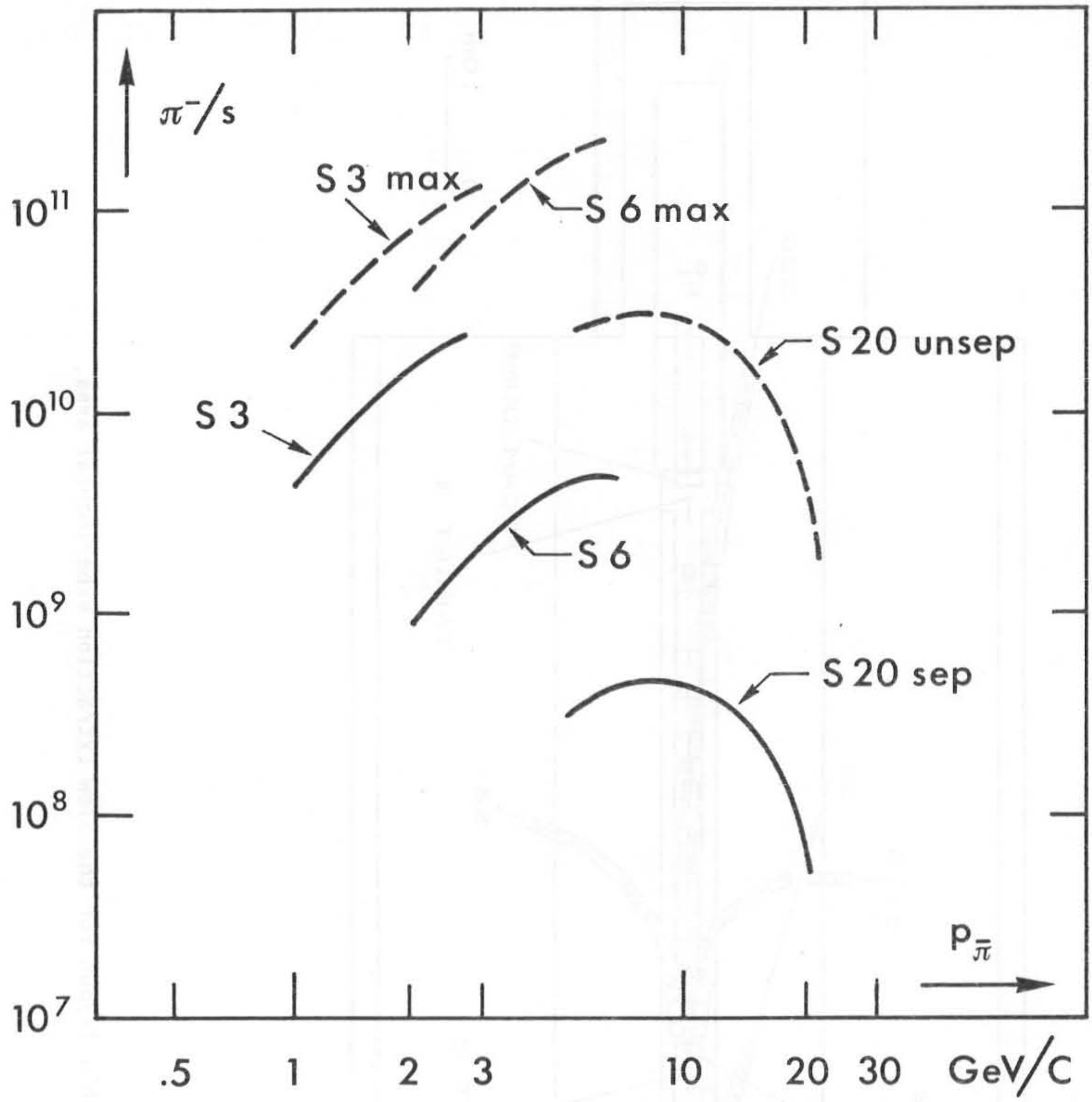

Fig. 9a

Fig. 9 - Particle Intensities vs momentum in the beam lines shown in Fig.8, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.

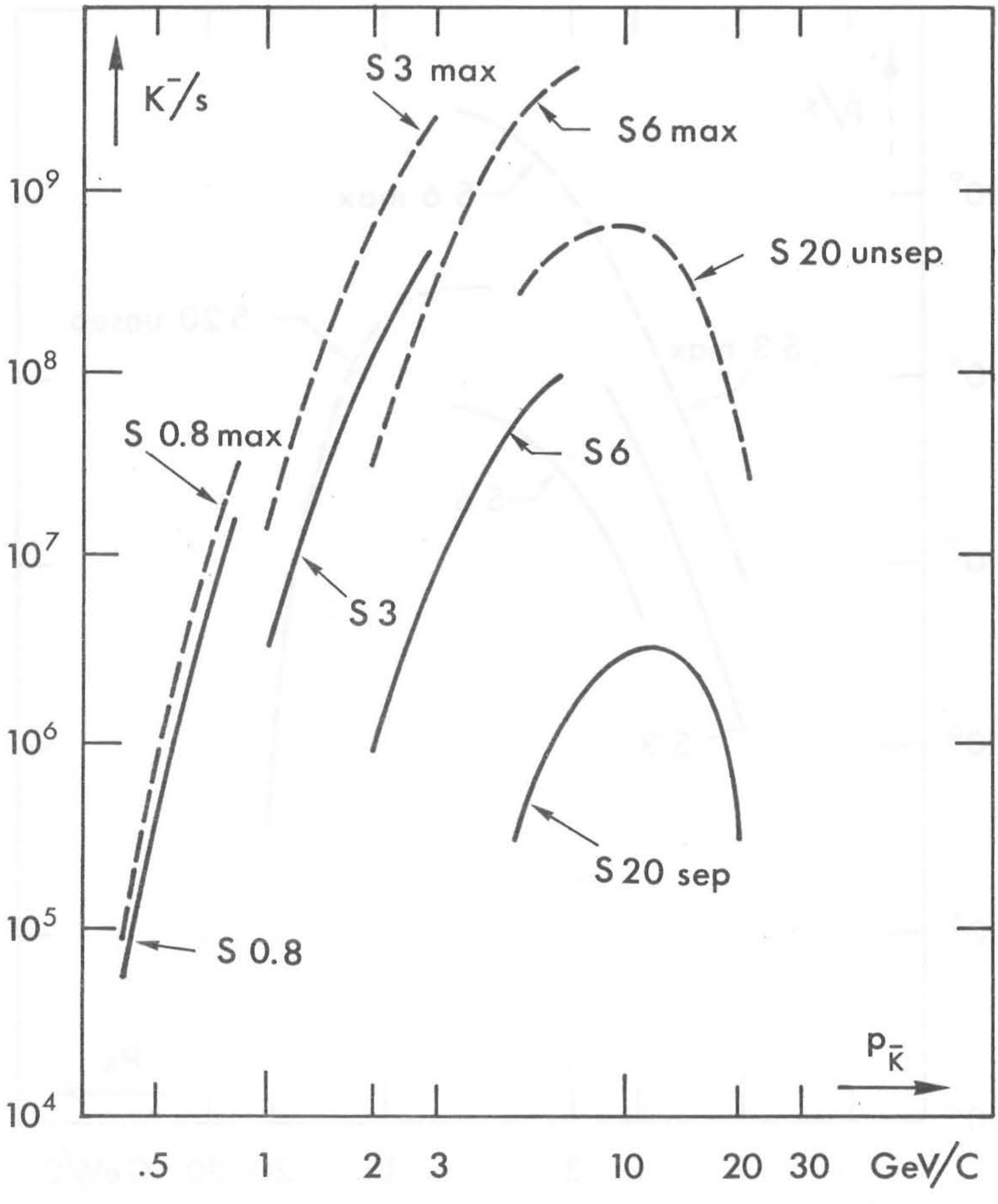

Fig. 9 b

Fig. 9 - Particle Intensities vs momentum in the beam lines shown in Fig.8, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.

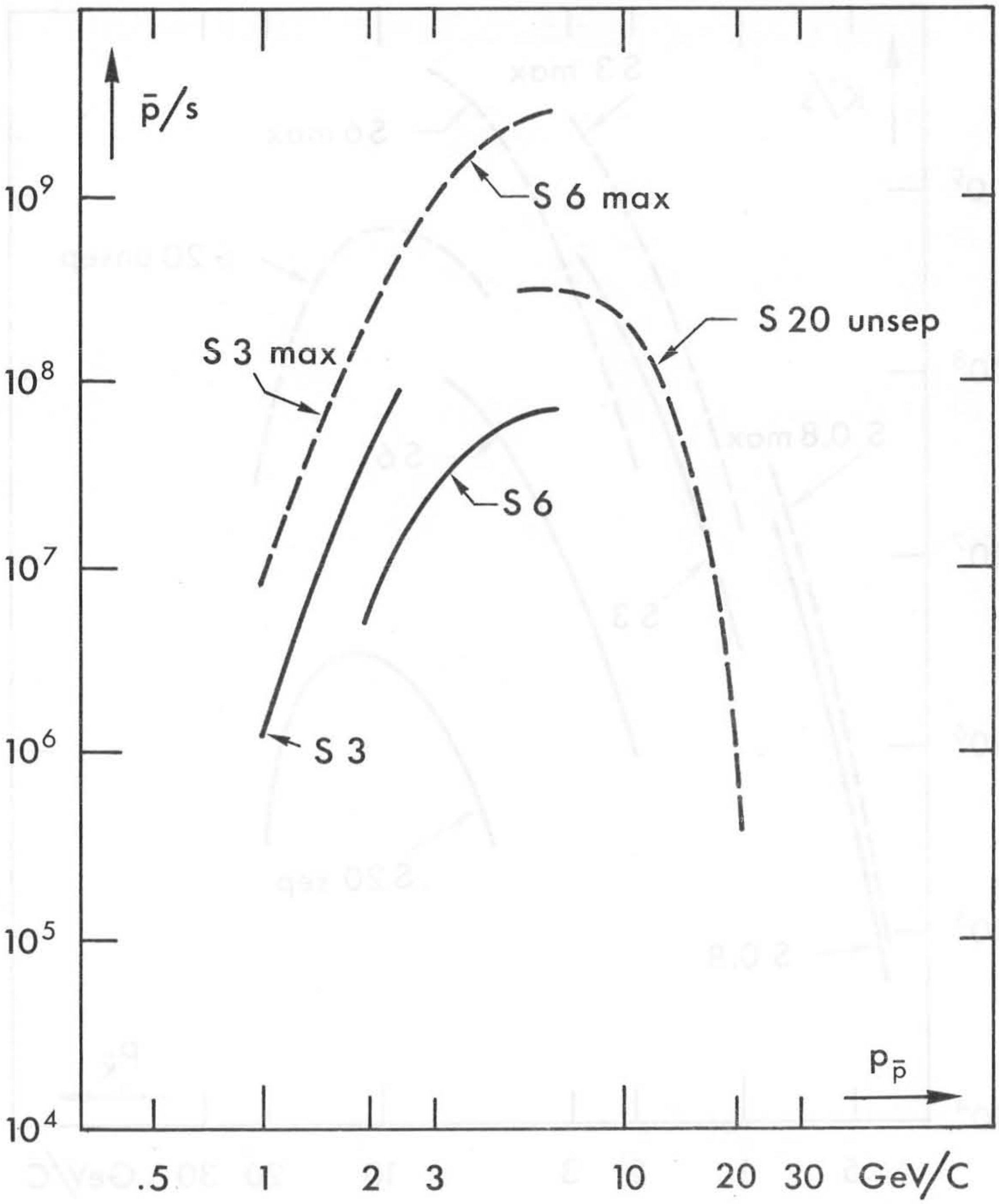

Fig. 9 c

Fig. 9 - Particle Intensities vs momentum in the beam lines shown in Fig.8, for pions (a), for kaons (b) and antiprotons (c). Dashed curves or full curves refer to unseparated or separated beam lines respectively.