EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN – PS DIVISION

PS/RF Note 2001-017

PROPOSAL FOR A 3 MEV H^{-} TEST FACILITY IN THE PS SOUTH HALL

K. Bongardt, F. Caspers, R. Garoby, D. Küchler, A.M. Lombardi, A. Mostacci,
M. Paoluzzi, U. Raich, M. Vretenar (ed.)

Geneva, Switzerland
5 November 2001

TABLE OF CONTENTS

1 INTRODUCTION

The acceleration of protons has been at the core of CERN activities since the origin of the organisation, and the uninterrupted improvement in performance of the proton beams has largely contributed to keep it at the forefront of particle physics all along its history. Such progress has been obtained by re-using extensively and upgrading regularly most of the low and medium energy machines, and adding high energy extensions.

In this context, a 2.2 GeV superconducting H^- linac (SPL) has been proposed [1] which could both deliver high beam power to a new generation of experiments, and upgrade the performance of the PS complex by replacing the present Linac 2 – PS Booster (PSB) cascade of accelerators. Although based on existing RF equipment dismantled from LEP, the SPL is a state of the art machine, which requests further studies and developments.

As a first stage, we propose to realise a subsystem corresponding to the first 3 MeV of the complete machine. This will need the development of challenging pieces of equipment like the H^- ion source, the LEBT, the RFQ and the chopper line, which govern the beam quality delivered by the full linac. Extensive measurements of the beam characteristics at 3 MeV will help optimise the rest of the accelerator, especially in terms of halo and beam losses.

In a second stage, this pre-accelerator could be used as the low energy part of a 120 MeV linac injecting H^- into the PSB to upgrade the performance of the PS complex in general, and the flux of protons for the CNGS target by a factor 1.8 [2]. This linear accelerator will be designed to integrate smoothly in the full SPL that could be built at a later stage.

2 DESCRIPTION OF THE FACILITY

2.1 Technical Goals

The main technical goals of the 3 MeV facility are:

1. Develop an H^{-} source suitable for the PSB and that could evolve towards the SPL specifications. Gain experience in the source design and operation with the aim to improve the reliability, particularly important in the CERN environment, together with the performance. The developments done in other laboratories will constitute the starting point for this activity.
2. Develop a fast chopper structure together with an associated pulsed power supply that could provide a large flexibility in painting the longitudinal phase space at injection in the ring following the linac. The same chopper can be used for the PSB, the PS or a future accumulator ring. The chopper structures developed in other laboratories have shown some technical limitations and a pulse generator for 2 ns rise time, in principle possible with present technology, has never been built and tested.
3. Optimise and test in a real environment the chopper line, a critical part of the linac design. A practical work on the line would allow minimising emittance growth and halo formation and optimising of the separation and dumping of the chopped beam. The simulation codes are limited in this respect by the high space charge and by the problem to incorporate in the codes the real fields of the many elements in the line.
4. Acquire and commission at CERN a Radio Frequency Quadrupole (RFQ), optimised for both low and high duty cycle operation. The RFQ will benefit from the ongoing development of similar 352 MHz structures at CEA-Saclay and at INFN-Legnaro, and its cost for the project can be minimised.
5. Test on the RFQ in a real accelerator environment the pulsed mode operation of the LEP klystrons. The possibility to use efficiently in a pulsed linac the LEP klystron, intended for CW operation, has been demonstrated by a preliminary proof-of-principle test. Long term testing in a real linac environment is now essential to assess their use for a new linac at CERN.
6. Provide a complete and consistent set of measured beam data at different positions along the 3 MeV pre-injector. This set of data would be crucial to optimise the different elements, to obtain and maintain the required beam quality and would be the basis for finalising the design of the Drift Tube Linac (DTL) that will follow this line.
7. Provide an environment to develop and optimise the beam diagnostics at low-energy that is an essential tool for the linac setting-up and optimisation.

However, the final goal of the 3 MeV line is to become in a longer term the pre-injector of a new H^{-} linac to be built in the PS South Hall.

2.2 Overall Design

2.2.1 Main components

The elements that constitute the 3 MeV facility are:

1. The **H^- source**, which for the PSB has to produce a 50 mA beam at the maximum pulse length of 0.5 ms, and should be slowly improved up to the SPL design pulse length of 2.8 ms at the lower current of 30 mA. The design extraction voltage is set to 45 kV, typical value for H^- sources and well adapted to the required source current. An additional gap could be added to raise the beam energy to 90 keV, in case the CEA RFQ would be used. The existing spare proton source can be used to test the facility with protons, during development and upgrading of the H^- source.
2. The **Low Energy Beam Transport** (LEBT), which transports and matches the beam out of the source. It could also include some pre-chopping element and some diagnostics.
3. The **Radio Frequency Quadrupole** (RFQ), which bunches the beam out of the source and accelerates it up to 3 MeV. It operates at 352 MHz frequency, and uses one LEP klystron as RF power source.
4. The **chopping line**, which transports the beam through the chopping structures. These are electrostatic travelling-wave deflectors that dump at low energy a fraction of the linac beam, creating in this way a beam time structure that minimizes losses in the following ring. The line is also used to match the beam to the DTL. It contains quadrupoles, RF bunching cavities and diagnostics elements, plus the off-line dump for the chopped beam.
5. The **diagnostic line**, a temporary (destructive) measurement line, which includes an emittance measurement device, a spectrometer and a fast phase probe as well as more sophisticated dedicated diagnostics tools. The same line can be placed in different locations along the 3 MeV facility, in order to characterise the beam after the source, the LEBT, the RFQ and at different locations inside the chopping line.
6. A low-power **dump**, which stops the beam at the end of the measurement line. It has to dissipate a power between 180 W (PSB test beam) and 5.5 kW (SPL test beam).

Figure 1 shows the main components of the 3 MeV test stand. The facility is made of individual building blocks that can be added up progressively. At every stage, a complete set of beam measurements is foreseen before installing the next element. The line can be tested with protons from the spare Linac2 source, making the beam measurements on the line independent from the planning for the development of the H^- source.

The design of the 3 MeV line presented here follows the main lines of the study done for the SPL [1]. However, while the general parameters have been analysed and optimised, the detailed design presented in Figure 1 and described in this paper is still being finalised. In particular, the RFQ can be defined only when the terms of the collaboration with the other Laboratories pursuing RFQ developments will be worked out. In addition, more work is needed for a fine optimisation of the chopper line.

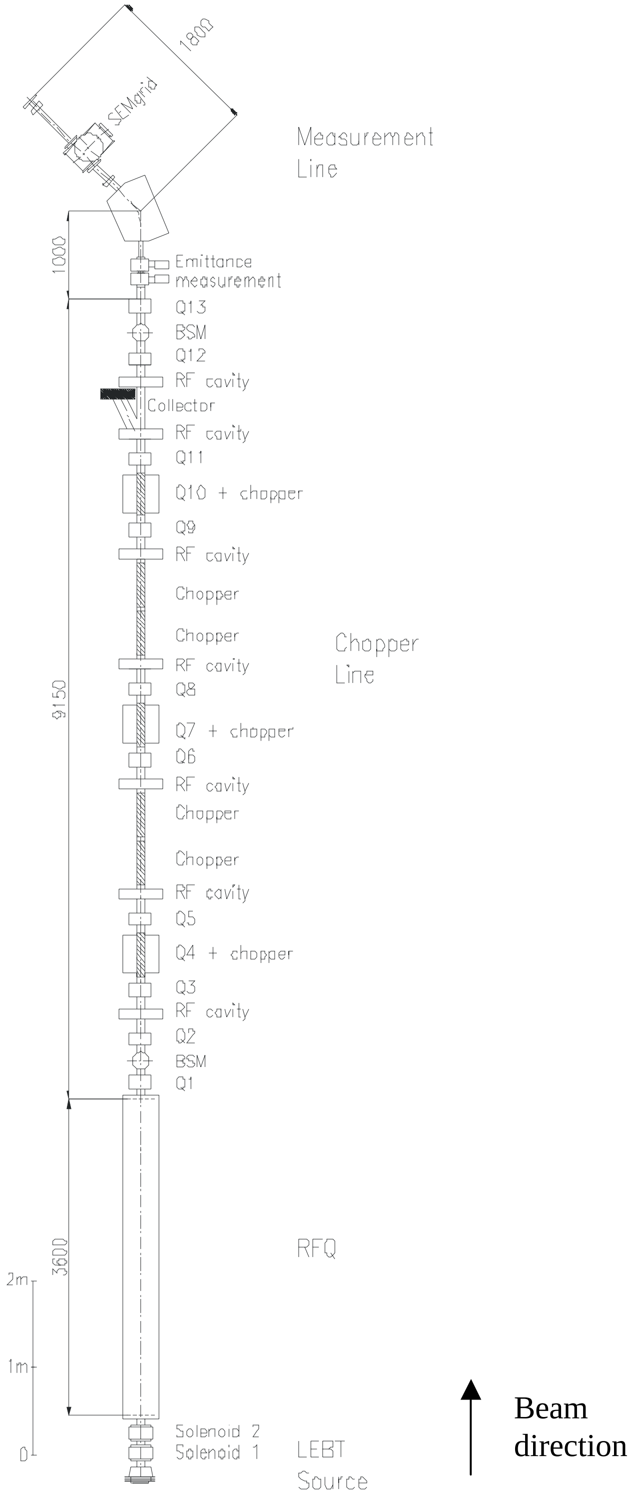

Figure 1: Layout of the 3 MeV facility.

2.2.2 Design Parameters

The beam parameters for the 3 MeV line are based on the assumption that this facility would be the front-end of a new linac injector for the PSB, and that in a second time it could become the first part of a Superconducting Proton Linac (SPL).

For PSB injection, the new linac would operate at a low duty cycle, dictated by the 2 Hz maximum PSB repetition frequency. In this case, there is a clear advantage to operate the pre-injector at the maximum current that the source can deliver, in order to increase the RF efficiency in the entirely room-temperature 120 MeV linac and to minimise the number of turns at injection into the PSB. In the present design, the goal for the H^- source has been conservatively set to 50 mA, the same as e.g. the SNS source, with 40 mA expected at the exit of the RFQ. The chopping factor could be modulated around a mean value of 25% to allow painting inside the PSB bucket, fixing the goal for the 3 MeV pre-injector to 30 mA mean current during pulse. In this scenario, at the standard 1 Hz repetition frequency the $6{\cdot}10^{13}$ particles in the PSB corresponding to the present PS intensity limitation could be obtained with a 320 μs linac pulse, while the pulse length could be increased up to 500 μs to reach $9{\cdot}10^{13}$ particles per pulse for ISOLDE. Pushing the repetition frequency up to the PSB limit of 2 Hz could reduce the pulse length.

For the SPL instead, the superconducting cavities are more efficiently exploited with longer pulses at lower beam current. In this case, the source has to provide a stable beam of about 30 mA during 2.8 ms. The requirement on the source pulse length is particularly challenging, and in this respect the 3 MeV test stand would be an invaluable tool to analyse and slowly improve the performance of the source towards the SPL specifications.

Table 1 summarises the main parameters for phase 1 (PSB) and phase 2 (SPL).

Table 1: Main beam parameters for the 3 MeV pre-injector

	Phase 1 (PSB)	Phase 2 (SPL)	
Maximum repetition rate	2	50	Hz
Source current *	50	30	mA
RFQ current *	40	21	mA
Chopper beam-on factor	75	62	%
Current after chopper *	30	13	mA
Pulse length (max.)	0.5	2.8	ms
Max. beam duty cycle	0.1	14	%
Max. number of particles per pulse	0.9	2.3	$\cdot 10^{14}$
Transverse norm. emittance (rms)	0.25	0.25	π mm mrad
Longitudinal emittance (rms)	0.3	0.3	π deg MeV

*: mean current during pulse

The pre-injector energy of 3 MeV has been determined taking into account the overall length of the chopper structures, the space charge effects in the line, and the feasibility of the critical first DTL cells.

In the design of the RFQ and of the chopper line particular care is taken to minimise emittance growth and to avoid formation of beam halos leading to losses in the following machines, which often come from the pre-injector. In this respect, the

3 MeV test stand, operating initially at a low duty cycle, will be an essential tool to study and minimise the formation of beam halos.

2.3 Source and LEBT

While the specifications of an H^- source for the PSB are well within reach of existing sources, as the SNS or the DESY source, no source is available today that would meet the more demanding SPL specifications, i.e. the higher repetition rate and the longer pulse, even at the low SPL current.

For a 3 MeV test injector, it is not realistic to envisage the development of a completely new source at CERN. An existing design that has a performance as near as possible to the SPL requirements would be copied, operated at the PSB parameters, and used as a test bench to design an adequate source for the SPL. Several candidate sources exist:

1. The source designed and built for SNS [3,4]. This is a cesiated RF driven source using a dual frequency technique to ignite and sustain the discharge. The source gives 50mA average current in a 400 µs long pulse (extraction voltage 65 kV) [3] or 42 mA in a 0.8 ms long pulse at 60 Hz [4]. The normalized rms emittance is 0.27 π mm mrad. The electrostatic LEBT consists of 6 electrodes to transport, steer and chop the beam and to remove the electrons. Open issues are the antenna lifetime, the caesium coating and the electron removal and dumping.
2. The source running at DESY [5,6], also a RF driven source. The source can deliver 80 mA in a pulse of 100 µs at a low repetition rate without using caesium (extraction voltage 35 kV). The emittance was 0.4 π mm mrad (normalized, 90%). The advantage of this source is that the antenna is outside the plasma cylinder and so the source could run 7000 hours.
3. The source at Rutherford Appleton Laboratory [7]. This is a cesiated surface plasma source of the Penning type. It can deliver 35 mA of H^- in a 200 µs long pulse at 50 Hz. The emittance is 2 π mm mrad (normalised, 95%). The extracted beam is not round due to a slit extraction system.
4. ECR type source are still a topic but there is still no source that can deliver several mA of H^-. In [8] is referred to a 2.45 GHz ECR source that delivered 5 mA with 700 W microwave power (with a tantalum foil, non resonant ECR mode, 5 mm extraction hole). Development of an ECR type source is the subject of a Framework Collaboration within the EEC [9].

One of these sources could be chosen, copied and used for the running in of the 3 MeV machine. However, the RF driven sources will require the development of high power (50 kW), 2 MHz pulsed power packs together with matching and electrical isolation networks. A source that uses caesium could be problematic to any downstream RFQ. Slit extractions would need a careful design of the LEBT optics to symmetrise the emittance. The chosen source could then be further optimised to meet the 3 MeV design goals.

2.4 RFQ

2.4.1 Construction

The availability of the LEP klystrons and the possibility to operate them in pulsed mode gives a strong economic argument for the choice of the 352 MHz frequency for the RFQ, as well as for the following linac. Moreover, from the beam dynamics point of view this frequency is perfectly adapted for an H^- RFQ in this energy range. Another important parameter for the RFQ construction technique is the duty cycle, which is low for injection into the PSB, but goes up to some 14% for the SPL operation, requiring an appropriate design of the cooling system and a careful analysis of the temperature distribution in the RFQ, to avoid field distortion coming from thermal deformations.

The development of an RFQ structure being a long and expensive process that requires a large amount of machining, brazing, cooling and RF prototyping, it is considered that CERN should not start an in-house development, but instead look for a collaboration with a laboratory that has already gone through the development stage, in order to profit from their experience and their investments. In particular, two laboratories in Europe are presently pursuing the construction of a CW RFQ at 352 MHz, CEA-Saclay [10] and INFN-Legnaro [11]. Both designs are for high beam power proton linacs, and for this reason their parameters are different from the CERN ones: input and output energies are higher (90 keV to 5 MeV), the beam current is higher (100 mA and 30 mA respectively for the two designs), the RFQ's are longer (about 8 m) and their duty cycle is 100%. However, two approaches can be considered to profit at CERN of this on-going work:

a. Either of the RFQ's under construction can be directly used in the 3 MeV facility. In this case, the output energy can be adjusted by taking only few RFQ sections (construction is modular). The vane modulation optimised for protons at higher current would remain, with possible emittance growth at lower current but still a high transmission, while the longitudinal emittance would be larger than what specified for the SPL. The higher input energy could be obtained by an additional gap at the source extraction.

b. A vane modulation design optimised for the CERN beam parameters can be applied to either of the RFQ resonator designs. In this case, a new RFQ has to be built, with a CERN-designed vane modulation, but the existing mechanical drawings together with the manufacturing and test facilities could be used, with substantial economic savings. Moreover, an RFQ designed for the CERN application would be shorter, thanks to the lower injection energy.

In both cases, the fact that the structure is designed for 100% duty cycle provides a useful safety margin against thermal problems when operating at 14% duty. In the case of a new modulation design, it offers as well an additional degree of freedom in the beam dynamics design, permitting the choice of higher electrode voltages with more power dissipation but reducing the length of the RFQ.

Up to this moment, CEA-Saclay has expressed its preliminary support for the scenario a) above, considering shipping their RFQ at CERN at the end of the IPHI tests at Saclay, while INFN-Legnaro is ready to contribute to the scenario b), making its know-how and infrastructure available for CERN.

2.4.2 Technical characteristics

The RFQ layout presented here starts from the assumption that the vane modulation can be optimised for the CERN specifications, and therefore refers to option b) above, taking the INFN RFQ design as reference. In case option a) is instead adopted, there is no need to study the RFQ design, and effort should go into adapting the LEBT and the chopper line to the beam that has to go into and will come out of an already existing RFQ.

The optimum input and output energies for the RFQ are 45 keV and 3 MeV, determined by the source extraction and by the chopping line requirements, respectively. The availability of a LEP klystron as RF power source provides the additional degree of freedom of a design that is not power limited, because only a fraction of the 1 MW peak klystron power will be actually needed by an RFQ starting at 45 keV. Both the RFQ structures considered are brazed 4-vane structures made out of copper bars, with water cooling channels inside the vanes and in the external jacket. Figure 2 shows a cross-section of the INFN RFQ.

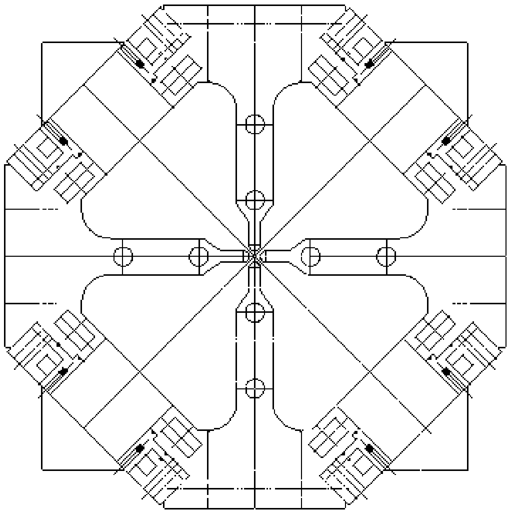

Figure 2: Cross-section of the INFN-Legnaro RFQ.

Adopting an existing RFQ structure design gives an additional constraint on the length, the RFQ needed at CERN being shorter than the CEA or INFN devices, thanks to the lower input and output energies. However, both reference designs are made of a combination of identical RFQ sections. Taking again as a reference the Legnaro RFQ, made of 6 sections each 1.2 m long, two alternative RFQ designs are possible in order to achieve the CERN specifications combining 1.2 m long segments, which are summarised in Table 2. The “short” RFQ design is made of 2 sections, for a length of 2.4 m, while the “long” design is based on three sections for 3.6 m, a more expensive solution but with more relaxed parameters. Moreover, the “short” version would require some modifications to the cavity design and to the drawings, to adjust the frequency for a different aperture and vane curvature radius.

For both versions, the beam dynamics has been optimised for transmission (>90%) and beam quality, with no transverse emittance increase for nominal current and output longitudinal rms emittance of the order of 0.12 deg MeV. Figure 3 shows the simulated output beam for the two cases.

Table 2: RFQ main parameters for the two solutions

	“short”	“long”
Input energy	0.045 MeV	0.045 MeV
Output energy	3 MeV	3 MeV
Frequency	352 MHz	352 MHz
Voltage	93 kV (1.7 Kilp.)	67 kV (1.2 Kilp.)
Maximum surface electric field	37 MV/m (2. Kilp)	31 MV/m (1.7 Kilp.)
Length	2.4 m	3.6 m
Shunt impedance	60 kΩ m	60 kΩ m
Cavity RF power	345 kW	270 kW
Beam RF power (40 mA)	118 kW	118 kW
Total RF power	463 kW	388 kW
Maximum duty cycle	20 %	20 %
Mean power dissipation per meter	29 kW/m	15 kW/m
Average bore radius	0.35 cm	0.30 cm
Modulation factor (max)	2.4	2.0
Vane transverse radius of curvature	0.25 cm	0.30 cm
Min. longitudinal radius of curvature	0.88 cm	1.3 cm
Transmission (at 30mA current)	92%	95%
Design current	30 mA	30 mA
Current limit (up to 5 % extra loss)	50 mA	50 mA
Design emittance (rms, norm.)	0.2 π mm mrad	0.2 π mm mrad
Transverse acceptance (rms, norm.)	0.26 π mm mrad	0.3 π mm mrad
Output longitudinal emittance (rms)	0.12 π deg MeV	0.12 π deg MeV

The beam quality at the output of the two RFQ designs is about the same for the nominal beam: the “short” RFQ has been designed with a higher inter-electrode voltage and consequently a higher pole tip field. The ratio transverse radius of curvature to average radius has then been chosen to minimise the pole tip field and maximise the voltage holding capabilities. The effects of the higher order multipoles, which become more important in this case, are controlled. It is nevertheless clear that the “short” RFQ design is more demanding, with 15% smaller transverse acceptance, 3% lower transmission and 20% higher fields, up to twice the Kilpatrick limit. It would have however the advantage of a lower cost, even taking into account the modifications to the cavity design. Due to the higher voltage, in spite of the shorter length this design requires more RF power, leading to an RF power dissipation of 22 kW/m, still 4 times lower than the CW RFQ designs. On the other side, the achievement of the required field flatness in the RFQ is easier for the “short” version than for the “long” one, which has a total length of 4.2 times the wavelength.

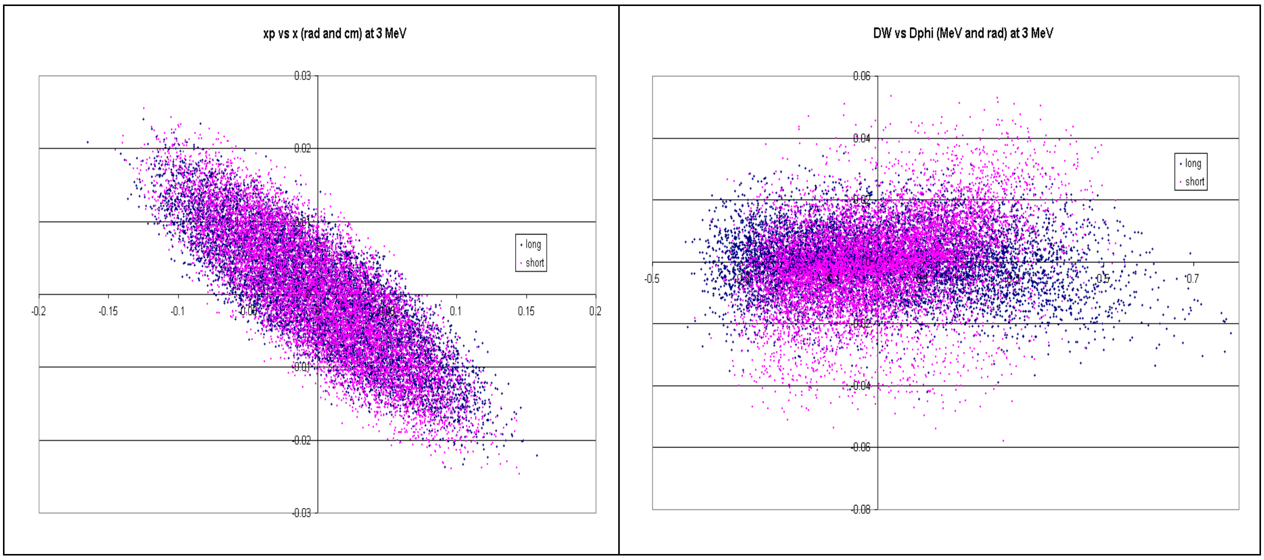

Figure 3: Transverse (left) and longitudinal (right) phase space plots (10’000 particles) for the two RFQ designs, “long” (dark grey) and “short” (light grey).

2.5 Chopper Line

2.5.1 The chopper deflecting structure

The chopper deflecting structure is a travelling wave device where the beam is deflected by an electric field orthogonal to its propagation axis. To a great extent, it is similar to a parallel plates capacitor except that the two metallic plates are replaced by two “meanders” printed on dielectric substrates and separated by 30 to 45 mm total aperture (depending on the envelope of the beam).

A layout of the basic topology used is presented in Figure 4, which shows the top view of one of the two plates for a 20 cm long section of a test structure. The main guidelines of the design are:

- the whole device should have a characteristic impedance equal to 50 Ω;
- the travelling wave should be synchronous with the beam;
- the overshoot and the rise time in the step response should agree with the specified 2 ns rise time (10%-90% definition).

The proposed scheme (details in Figure 4, lower part) consists essentially of a 50 Ω line on a 3 mm thick alumina substrate (ε_r=9.6), which splits into two parallel 100 Ω lines and forms a kind of interconnected double meander topology. The ratio between the width (*w*) of the micro-strip and the thickness (*t*) of the substrate corresponds to a line with 50 Ω characteristic impedance, while w/h=0.15 for 100 Ω [12]. The characteristic impedance of the entire device can then be slightly modified (to be exactly 50 Ω) with the triangular cuts in the basic cell of the meander. The travelling wave velocity is adjusted by varying the width of the meander cells (42.5 mm in our case). On the contrary, the periodicity in the beam direction (i.e. the spacing along z-axis between adjacent conductors) affects the dispersion properties of the whole deflecting plate. In fact, the dispersion degradation is due to the amount of cross-talk or coupling taking place among the cells; in principle simply increasing the cell period could reduce it but this will have serious drawbacks on the field coverage factor. The field coverage factor is defined as the ratio of deflecting E-field seen by the beam for the given deflecting structure as compared to a massive metal strip of same width calculated at DC. For a given strength of the deflecting field, the smaller is the coverage factor the higher is the required voltage from the amplifier driving the deflector.

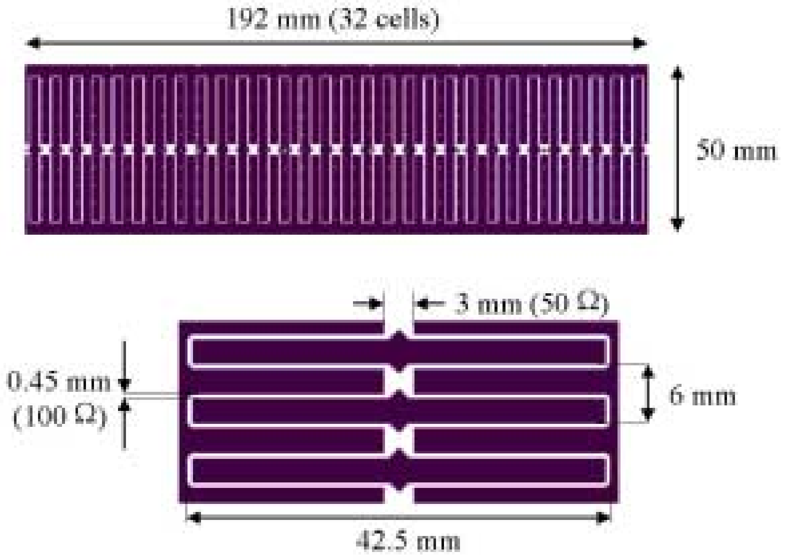

Figure 4: Proposed layout of the chopper deflecting structure.

In Figure 5 is shown the measured pulse response of a 50 cm long meander with a 40 µm thick metallisation; the actually printed strip in this prototype is very similar to the one shown in Figure 4 and the minor differences are not believed to affect significantly the step response reported below. As it can be clearly seen, the limiting factor is the phase or group delay dispersion that causes ringing and overshoot: increasing the bandwidth of the exciting signal, the input step is (obviously) sharper, but the out-coming signal exhibits a more relevant overshoot (Fig. 5, right). From the picture, it is clear that to meet the specification of 2 ns rise-time at the output, the input step has to be fast enough (1.65 ns rise-time for the prototype under test). The 50 cm long meander under test has a characteristic impedance of roughly 46 Ω that can be adjusted modifying certain dimensions of the printing mask as discussed above.

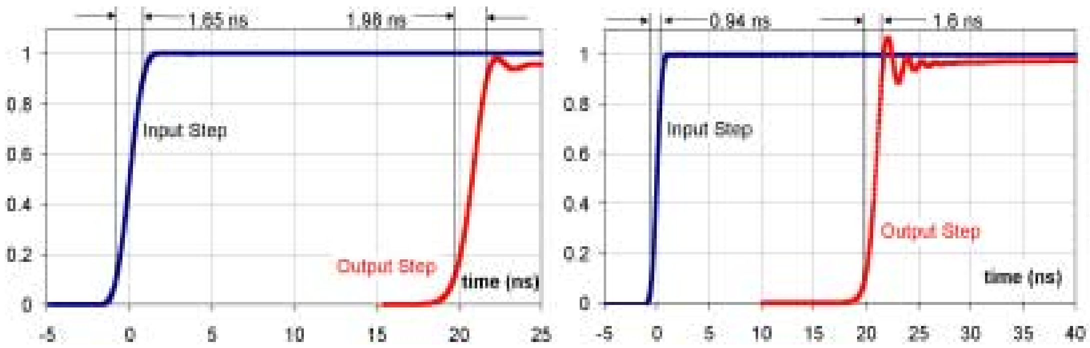

Figure 5: Input and output pulse of a 50 cm long meander (0-600MHz bandwidth and 0-1 GHz respectively)

For the present layout, even when there is only less than 15% of the alumina surface covered by conductors, the field coverage factor is nearly 80% [13]. This value is reasonably close to the one (90%) computed for the SNS type meander that profits from separating ridges between adjacent cells [14].

For the moment it can be said that this kind of 50 Ω double meander printed line on 3 mm alumina is a good candidate for the SPL chopper. Big advantages of using alumina substrates (comparing to other proposals) are good ionising radiation resistance as well as excellent out-gassing properties and good thermal conductivity. The question on radiation resistance is a serious issue, since there may be several tens of Watts of beam power lost into the deflecting structure. Losses and dispersion are acceptable and rather close to the SNS version. The structure can stand high radiation doses as well as a considerable heat load (when water cooled in the metal support) and should have very good vacuum properties. Wideband impedance matching and reasonable field coverage factor have been achieved.

2.5.2 The chopper pulse generator

Generation of single polarity pulses with rise and fall times below 2ns requires a frequency response extending from DC to well above 200MHz. This, together with the high pulse amplitude (>500V) and repetition rate (44MHz), puts the specifications close to the technological limits of available active devices. To overcome these major difficulties, the present design is based on the idea of generating the low and high frequency part of the spectrum with two separate modules; they are then merged by a special diplexing scheme with a crossover point around 1MHz.

The high frequency module is built around four vacuum tubes type YL1056 mounted in common cathode configuration. The input circuit has a strongly non-linear behaviour. It matches the TTL input signal to the 8 Ω grid de-Qing resistors by means of an RF MOSFET. The plate circuit is composed of an inverting, 1 to 4 impedance transformer that insures proper matching of the 50 Ω output to the required 12.5 Ω plate load. It also provides AC/ DC de-coupling for plate connection to the DC power supply. A first 250 V prototype (¼ of the required version) has already been produced and tested. Performances were close to specifications and permitted to identify the limiting parameters. Improved performances are expected from the 500 V prototype presently under construction.

The low frequency modules use high voltage, N- and P-channel mosfets operated in saturation mode and controlled by a high speed gate driver. The output circuit is simply composed of an R-C combination and a 500 V power supply. Merging of the two signals is obtained by connecting the high frequency generator to the slow-wave structure using galvanic isolation so as to leave the reference plane floating. The slow-wave reference-plane is then connected to the low frequency generator and used as a deflector. The beam then makes the integration of the two fields.

The proposed solution tries to relax some parameters by using two separate generators. This could be avoided if sufficiently fast high voltage, solid-state devices existed and might become possible in the next future (1~2 years) because of fast improvements of high voltage FETs. Actually, 1kV, 2ns devices came on the market in the past months. They improved by a factor 2 the previous speed characteristic and available current. But the most promising technology is probably that of Silicon Carbide semiconductors. Because of its high breakdown field, Silicon Carbide is an ideal semiconductor for the fabrication of high-power, high-speed devices that might come on the market in time to be used for this application.

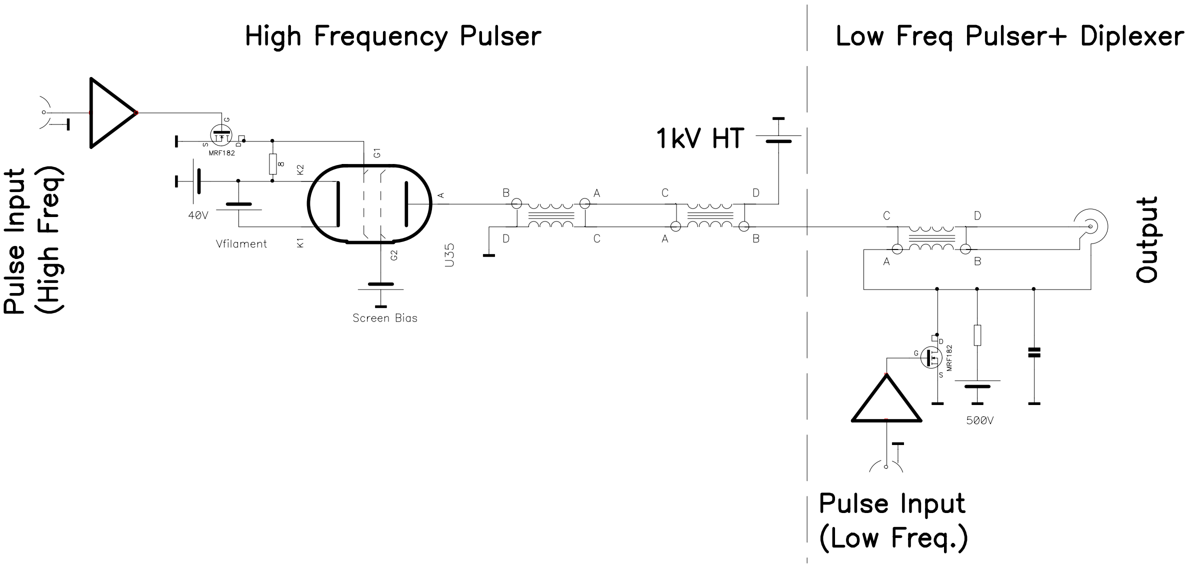

Figure 6: Scheme of the chopper pulser

2.5.3 Design of the chopping line

The guidelines for the design of the chopping line are minimum emittance increase (transverse as well as longitudinal), good separation between the chopped and the un-chopped beam and finally enough flexibility for matching into the following DTL. The line design (Figure 1) is modular, made of three identical sections composed of a triplet, three choppers and two RF cavities. Two matching sections with two quadrupoles each at RFQ exit and DTL input complete the line. Instead of the last chopper, the third section houses the collector for the chopped beam.

In the present design, the line includes 13 quadrupoles and 7 RF cavities for a total length of 9.15 m. The quadrupole fields are modest (much less than 1 T pole tip field) and the RF voltage per cavity is about 100 kV. There are 7 chopper structures inside the line, 3 inside long quadrupoles and 4 between RF cavities. Each chopper structure is 40 cm long, with plate separation from 30 mm in the first chopper to 45 mm in the last one and presents to the beam a total voltage of 350 V, which takes into account a 78% field coverage factor. The deflection is done in the vertical plane, where the beam radius is smaller. The aperture radius of the quadrupoles containing the chopper structures is 50 mm, a value compatible with their length and with the modest gradient required. The transverse and longitudinal beam radii together with input and output emittances are plotted in Fig. 7 for a beam current of 30 mA. The beam envelopes are symmetric around the centre quadrupole triplet. The beam size is roughly constant along the line thus keeping constant the space charge effects along the line.

This line achieves a satisfactory 25 mm separation between chopped and unchopped beam at the collector position keeping the voltage out of the pulser below the maximum of 500 V per plate that can be provided at 2 ns rise time. In case a higher voltage could be reached by a new pulser technology, the design would remain valid and the number of sections could be reduced.

The collector for the chopped beam is placed between the two last RF cavities. A guideline for the design of the collector is the TZM (molybdenum alloy with titanium and zirconium) collector developed for the SNS chopper [15].

This preliminary design has to be considered as particularly safe and conservative; the distance between elements is large enough to minimise the mechanical constraints and to leave space for diagnostics elements. More work is now going towards compacting this line with the aim to reduce the overall length and to eliminate some RF cavities and some quadrupoles. In parallel will start a detailed optimisation of the line with a multiparticle simulation code, which will take into account all non-linear effects.

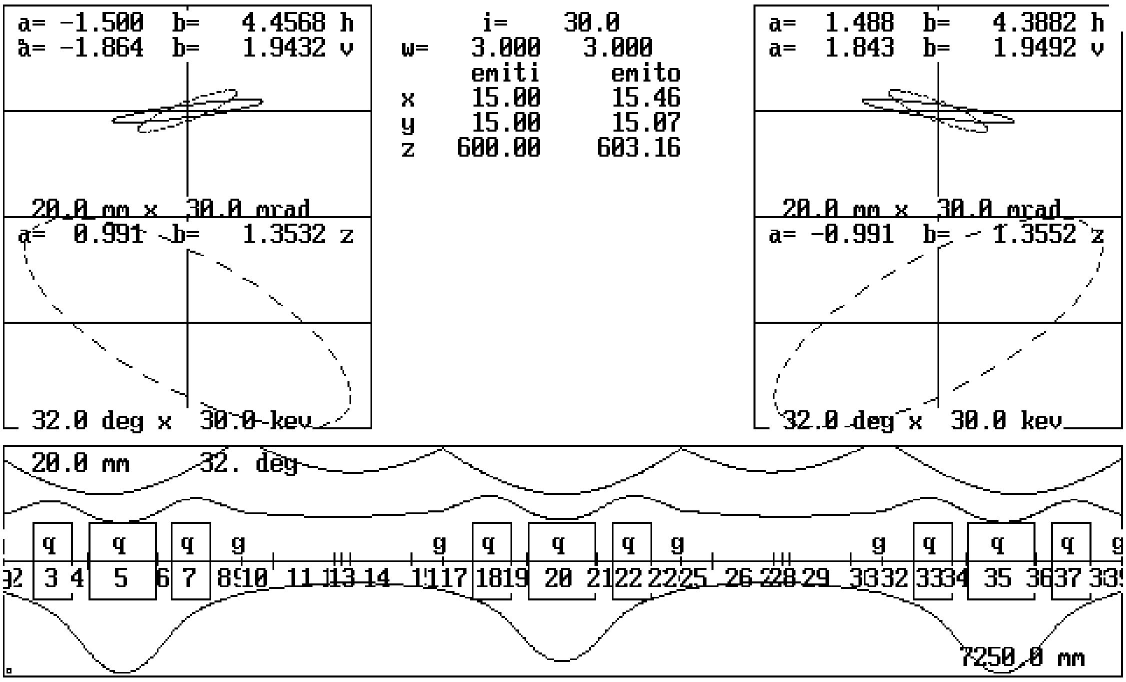

Figure 7: Input and output phase space distributions (top) and beam envelopes (bottom, longitudinal, horizontal and vertical from top to bottom, √5 rms) along the chopping line.

2.6 Diagnostics

The diagnostics for the 3 MeV facility can be divided into two groups: the “on-line” and the “off-line” diagnostics elements.

The “on-line” diagnostics includes all the equipment that will be used during the normal operation of the machine, and is mostly concentrated in the chopper line. The modular construction of the line leaves space for diagnostics in 9 positions (three per each section of the line), which can be occupied by 4 beam current transformers and 5 Beam Profile Monitors (SEMgrids). In the matching sections at input and output of the line can be incorporated two Bunch Shape Monitors (BSM) similar to the ones already in use at Linac2 [16]. They allow measurements of phase distribution with a resolution of ± 2 deg in addition to a measurement of distribution in the transverse planes. In particular, the second BSM can be used to set the chopper timings and to verify that there are no particles in the empty buckets.

The “off-line” diagnostics is concentrated in a movable measurement line that can be mounted after the source, after the RFQ or after the chopping line. This line includes precise measurements that can be destructive, used for an accurate characterisation of the different elements in the facility. The basic components of this line are a transverse emittance measurement (different types can be considered, depending on the repetition rate at which the measurements will be performed), a spectrometer (magnet plus SEMgrid) and a phase probe. By applying different voltages to the bunchers in the line it would be possible to reconstruct the longitudinal emittance out of the phase and energy distribution measurements.

For the measurement line it is also considered to have a “halo measurement” device, capable to explore the tails of the beam distribution with a resolution in the nA range. An option would be to use a movable polarised target to stop most of the beam and a Faraday cup downstream to measure the current outside of the target. This device would show differences in the distribution created by the RFQ or by the chopper line, while it would be more difficult to have an absolute value of the halo current. Another option would be to use a wire scanner coupled with a set of graphite scrapers as used at the Halo Beam Experiment at LANL [17].

2.7 Radio Frequency and Infrastructure

The RFQ will be fed by one LEP klystron. The RF power is split once via a magic-Tee and then two half-height waveguides bring it to two opposite RFQ quadrants. For each branch, a doorknob waveguide-to-coaxial transition will allow to use a coaxial RF window and a power loop of the same design as in the LEP-1 copper cavities. The total power to the RFQ, for the maximum beam current, would be about 500 kW peak, i.e. 250 kW per window (50 kW average). A LEP-type circulator will protect the klystron.

A complete HV power supply from LEP has to be used for the 3 MeV test stand. The same power supply would be able to supply more klystrons (up to 6) if the facility will be later on upgraded to a full 120 MeV linac, while for the test stand it will deliver a much lower current. The main circuit breaker, the transformer and the thyristor controller will be placed outside of the building, while inside the Hall will be placed the HV interface, the klystron and the RF control. The klystron is housed in a shielded cabin, thus access to the klystron area will be possible during operation.

The seven RF cavities in the chopper line (single-gap bunchers) require a power of less than 20 kW peak, which can be easily provided by individual tetrode amplifiers.

The floor space required for the RF infrastructure is about 100 m^2 outside the Hall, and 30 m^2 inside for the klystron, the circulator and the HV interface. The klystron requires 300 l/min of cooling water.

3 RESOURCES

If the project is authorised early in 2002, the 3 MeV facility is expected to be finished and operate with beam before the end of 2005. The detailed cost estimates are given in Table 3. The construction cost of the RFQ is not included because it will depend upon an agreement still under discussion with another European laboratory.

Table 3: Cost estimates

	2002	**2003**	**2004**	**2005**
H^- source	400	400	200	200
RFQ	0	0	0	40
Chopper	100	200	300	200
Bunchers	80	150	170	20
RF amplifiers	100	150	180	500
Magnets		100	300	200
Beam diagnostics	10	20	100	20
Vacuum	30	100	50	20
Infrastructure	40	80	100	20
Travels & visitors	40	40	40	40
TOTAL (kCHF)	**800**	**1240**	**1440**	**1260**

The total resources in staff manpower and budget add up to 14 man.years and 4.74 MCHF, as shown in Table 4, together with the main milestones.

Table 4: Planning and resources

	2002	**2003**	**2004**	**2005**
CERN Milestones		First chopper set-up	H^- source & RF bunchers	3 MeV pre-injector
Manpower (FTE/y)	2.5	3.5	4.5	4.5
Budget (MCHF/y)	0.8	1.24	1.44	1.26

4 PERSPECTIVES

The proposed 3 MeV H^- facility is a direct investment in future accelerators which can improve the proton complex at CERN beyond its present level of performance, benefiting to the approved physics experiments and making new ones possible.

Moreover, this project is an effective opportunity to provide our organisation with proper expertise to compete for external funding and coordinate future realisations in this field.

REFERENCES

[1] M. Vretenar (editor), Conceptual Design of the SPL, a High Power Superconducting H^- Linac at CERN, CERN 2000-012.

[2] R. Cappi (editor), K. Cornelis, J.P. Delahaye, R. Garoby, H. Haseroth, K. Hubner, T. Linnecar, S. Myers, K. Schindl, C. Wyss, Increasing the Proton Intensity of PS and SPS, CERN/PS 2001-041 (AE).

[3] R. Thomae, R. Gough, R. Keller, M. Leitner, K. Leung, D. Meyer, M. Williams, Measurements on H^- sources for spallation neutron source application, Rev. Sci. Instr. 71 (2000) 1213-1215.

[4] R. Keller, Ion-Source and LEBT Issues with the Front-End Systems for the Spallation Neutron Source, 9th International Conference on Ion Sources 2001, Oakland/California, to be published.

[5] J. Peters, The status of DESY H^- sources, Rev. Sci. Instr. 69 (1998) 992-994.

[6] J. Peters, The transition between plasma and vacuum in RF sources for negative hydrogen ions, 9th International Conference on Ion Sources 2001, Oakland/California, to be published.

[7] J.W.G. Thomason, R. Sidlow, M.O. Whitehead, H^- ion source test and development capabilities at ISIS, 9th International Conference on Ion Sources 2001, Oakland/California, to be published.

[8] J. Peters, Negative ion sources for high energy accelerators, Rev. Sci. Instr. 71 (2000) 1069-1074.

[9] Proposal HPRI-2001-50044, European Commission, Brussels.

[10] R. Ferdinand, P-Y. Beauvais, R. Duperrier, A. France, J. Gaiffier, J-M. Lagniel, M. Painchault, F. Simoens, P. Balleyguier, Status report on the 5 MeV IPHI RFQ, Proc. Linac2000, Monterey.

[11] A.Pisent, M. Comunian, A. Palmieri, G.V.Lamanna, D.Barni, Trasco RFQ, Proc. Linac2000, Monterey.

[12] R.K. Hoffmann, Integrierte Mikrowellenschaltungen elektrische Grundlagen, Dimensionierung, technische Ausführung, Technologien, Springer, Berlin, 1983.

[13] S.S. Kurennoy, Private communication, September 2001.

[14] S.S. Kurennoy and J.F. Power, Development of meander-line current structure for SNS fast 2.5-MeV beam chopper, Proceed. EPAC'00, Vienna, p.336.

[15] J. Staples, D. Oshatz, T. Saleh, Design of the SNS MEBT, Proc. of Linac2000, Monterey.

[16] S.K. Esin, V.A. Gaidash, A.V. Feschenko, A.V. Liiou, A.N. Mirzojan, A.A. Menshov, A.V. Novikov, P.N. Ostroumov, O. Dubois, H. Kugler, L. Soby, D.J. Williams, A Three Dimensional Bunch Shape Monitor for the CERN Proton Linac, Proc. of the Linac 1996, Geneva, Switzerland.

[17] R. Valdiviez, N. Patterson, J. Ledford, D. Bruhn, R. LaFave, F. Martinez, A. Rendon, H. Haagenstad, J. D. Gilpatrick, J. O'Hara, Intense Proton Core and Halo Beam Profile Measurement: Beam Line Component Mechanical Design, Proc. of Linac2000, Monterey.