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CERN Ideas and Plans for a Neutrino Factory

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Abstract

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Abstract

In view of the physics interest, CERN has decided to engage in the study of a Neutrino Factory. The present paper describes our basic concept, and plans for R&D.

1. The basic concept for a CERN Neutrino Factory

This concept has been worked out by the CERN Neutrino Factory Steering Group with the help of the CERN Neutrino Factory Working Group and outside laboratories.

Our reference scenario (Fig. 1) is based on the specific situation at CERN. It does not pretend to be the best solution or to describe the machine which will finally be built. It is rather intended as a working model.

The Nufact'99 workshop in Lyon resulted in an aim of 10^{22} neutrinos per year, corresponding to a proton beam power of 4 MW. The present CERN accelerators are not suitable for an easy upgrade of this beam power. However, a proposal [1,2.] has been made to replace the injector complex (50 MeV linac and 1.4 GeV Booster) by a linear accelerator as an injector for the LHC beam into the PS, offering a higher brilliance for the LHC beam. The basic idea for building this linac is to re-use the cavities, klystrons and auxiliary equipment from LEP when this machine is shut down. If this linac were built, it could easily be pushed to higher average power ; 4 MW seems quite feasible. For this reason we envisage in our scenario [3] an energy of only 2.2 GeV, which is low compared to other proposals [4,6]. However, this energy may not be a priori too low. The results of the HARP experiment [7], which should produce data next year, will be crucial for the assessment of our choice.

For a Neutrino Factory, short pulses of protons are needed to allow the reduction of the large energy spread of the muons by bunch rotation. The number of these pulses per second must not be too high, because this number is very much related to energy consumption of the subsequent machines. As the linac cannot provide these short pulses directly, it will operate with H^- ions and inject into an accumulator ring, using charge exchange injection to achieve a large circulating proton current. Bunches will be formed in this ring with rf cavities, and transferred to a compressor ring for further reduction of their length. The linac will operate at 75 Hz, a pulse duration of 2.2 ms and a pulse current of 11 mA. Accumulator and compressor rings can be fitted into the old ISR tunnel. The resulting beam pulses of 3.3 µs contain 140 bunches spaced at a 44 MHz frequency and arriving 75 times per second.

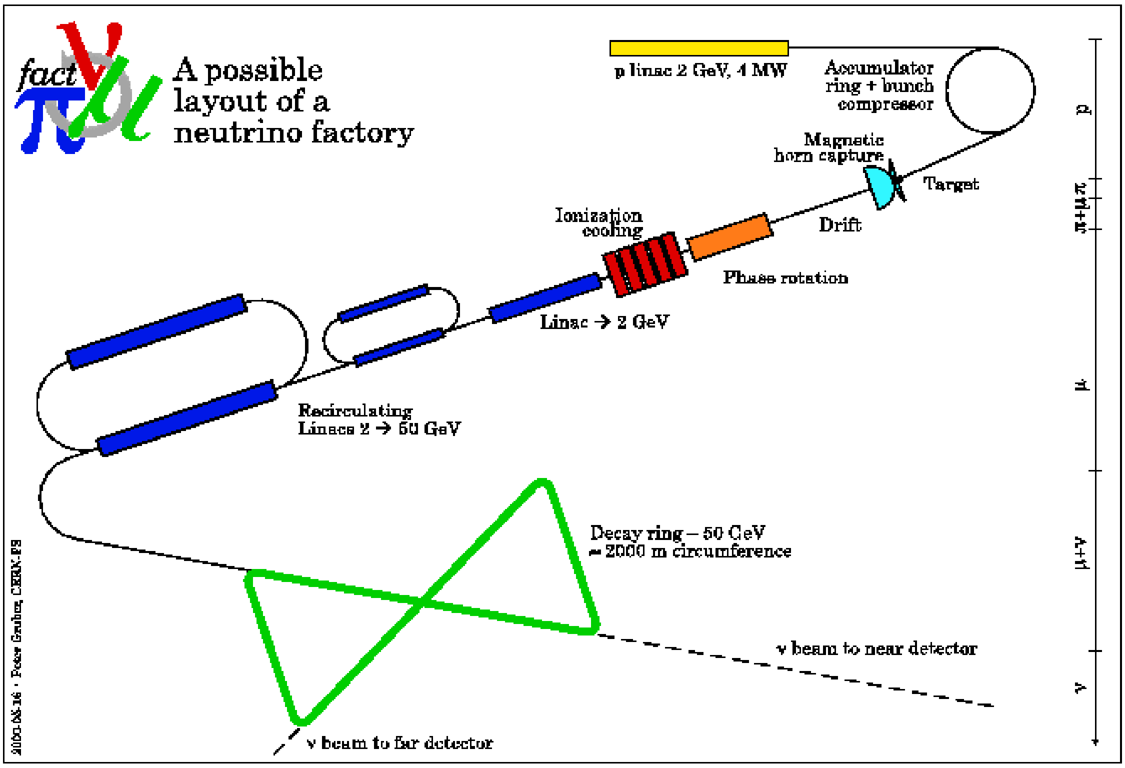

Fig. 1: A Possible Layout of a Neutrino Factory

A target will be bombarded with the short bunches [order of nanoseconds] produced in the compressor ring. In the FNAL study [6] a stationary carbon target has been chosen which has advantages for the beam power (1 MW) assumed in that study and for the energy of their proton driver. In our 4 MW case we need a moving target. Some work has been going on at RAL who propose a toroid made out of solid material. Other experts prefer a liquid metal target on which some experience is available at CERN.

It is necessary to capture the pions produced in the target. The FNAL study has chosen a 20 T solenoidal field for this purpose. This magnet is expensive and has a limited lifetime, especially when used with higher beam power. At CERN there is substantial experience with magnetic horns, be it for the collection of antiprotons, or for the production of (conventional) neutrino beams. It is therefore justified to investigate the possibility of using a magnetic horn also for the Neutrino Factory. It is clear that one problem will be the high repetition rate of 75 Hz, which is likely to reduce the lifetime. It must, however, be noted that a horn is considerably cheaper than a solenoid.

The system to capture the pions produced in the target and the muons resulting from their decay is complicated and requires advanced technology. Our proposal is not to use an induction linac as proposed in the FNAL study, but, especially due to our high repetition rate and the large number of bunches, an rf system to phase-rotate, capture, cool and bunch the muons [8]. With the low energy from our proton driver it is not feasible to reduce the number of bunches to that of the FNAL proposal. The use of rf may yield a substantial reduction in cost and an increase in reliability as compared to an induction linac. Further acceleration of the muons to 2 GeV is performed in a special linac. Up to about 1 GeV, solenoidal focusing will be used. Subsequent acceleration is performed with two Recirculating Linacs (RLA) in two stages to a final energy of 50 GeV. The muons are then injected into a storage ring (decay ring) where they are kept for the duration of their lifetime (1.2 ms at this energy). The muons decaying in the long straight sections of this ring produce the required neutrino beams.

2. Details of the scenario

2.1. The Proton Driver

2.1.1 Scenario based on a 2.2 GeV Linac

In this scenario the SPL, actually an H^- linac [1,2], is based on the idea of re-using the LEP cavities and ancillary equipment after decommissioning of the LEP. The linac accelerates H^- up to 2.2 GeV kinetic in bursts of 2.2 ms, at a rate of 75 Hz. The mean current during the pulses is 11 mA for a mean beam power of 4 MW. The main characteristics of the SPL beam are listed in Table 1. For the Neutrino Factory this beam is accumulated in 660 turns in an accumulator which transforms it into a 3.3 μs burst whose bunches are reduced in length in a compressor before being sent to the pion production target.

Table 1 - The 2.2 GeV Superconducting H^- Linac Parameters

Beam Current	11 mA
Energy	2.2 GeV
Beam Transverse Emittance (normalised)	0.6 μm rms
Beam Energy Spread	±2 MeV
Bunch Length	24 ps
Linac Length	800 m
Overall RF Power	31 MW
Number of klystrons	46

2.1.2 The Linac

The beam from the ion source is bunched at 352 MHz and accelerated to 7 MeV in an RFQ. The RFQ will be split at 2 MeV for the installation of a chopper, necessary for minimising beam losses at the high energy end. Conventional room temperature accelerating structures are used up to 120 MeV. Above this energy, superconducting rf cavities are employed. Up to 1 GeV, new low-beta structures are needed, while 116 LEP-2 cavities in 29 cryostats are used afterwards (Fig. 2).

The entire rf infrastructure and all cavities between 1 and 2.2 GeV can be built from recuperated LEP hardware leading to a cost-effective machine. The main elements to be constructed are (i) the 120 MeV room temperature, (ii) the new low-beta superconducting cavities for the section between 120 and 1000 MeV, (iii) the focusing, diagnostic and control equipment, (iv) the cryoplant, and (v) the civil engineering for the 800 m accelerator tunnel and the technical gallery.

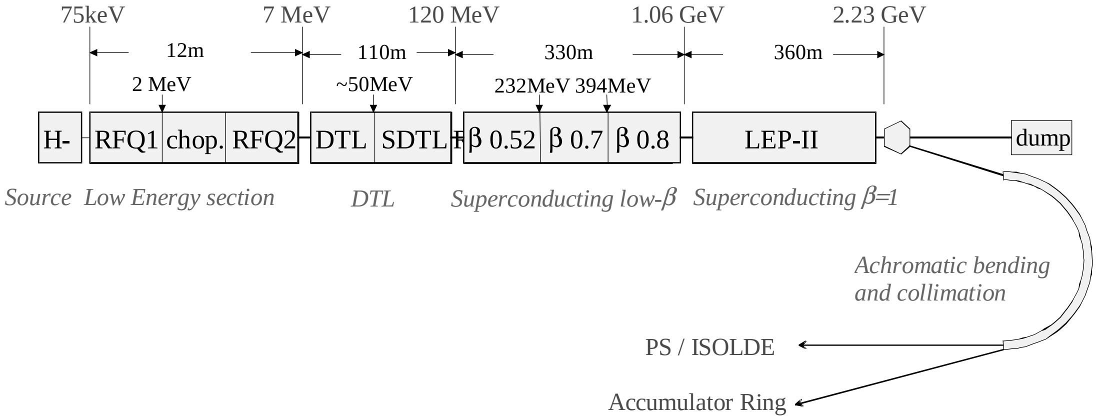

Fig. 2 - Layout of the Superconducting Linac

Radiation management is a key concern at these high beam powers. In order to permit hands-on maintenance, losses must be kept below 1 W/m, a challenging figure that requires an adequate machine design with a careful control of beam halo as well as an effective collimation system. The large aperture of the LEP-2 cavities is a welcome advantage in this respect because most of the halo particles that develop after the initial collimation are transported to the end of the linac and dumped in collimator dumps where radiation is localised and properly addressed.

2.1.3 Accumulator and Compressor

The CERN-specific 2.2 GeV / 75 Hz scenario using the SPL, features an Accumulator and a Compressor ring in the ISR tunnel [9]. Both rings have high-γ_t lattices, ensuring fast debunching of the linac microbunches in the accumulator and very fast bunch rotation (~7 turns) in the compressor. The feasibility of H^- injection, and of the final bunch rotation, has been demonstrated. The Accumulator lattice and the lattice of the intersecting Compressor have been designed. More refined simulations, including the effect of space charge on momentum compaction and of the microwave instability, have given very satisfactory results [10]. The length of the ejected pulses is given by the circumference of the ring: 3.3 μs. It was possible to increase the number of bunches, originally 12, to 140 because of the use of rf cavities instead of an induction linac as in the FNAL study [6]. This helps with space charge problems.

2.1.4 Scenario based on fast cycling synchrotrons

As it may turn out that 2.2 GeV is not an ideal energy for a Neutrino Factory, alternative scenarios [11] to 4 MW proton drivers have been studied.

A collaboration with RAL was established for the design of a site-independent synchrotron scenario. A 5 GeV/50 Hz and a 15 GeV/25 Hz scenario, the latter using the ISR tunnel, were investigated. Each one requires two booster and two driver rings. Lattices have been designed and H^- injection and final bunch compression studied and shown to be feasible. The 180 MeV/56 mA H^--linac is very similar to the existing ESS design and is being adapted to the scenario. The study of this scenario is being pursued at RAL.

In case slow repetition rates should be needed, we would opt for a 30 GeV/8 Hz configuration, using the ISR tunnel for the driver [12]. This high beam energy permits injection into the SPS above its transition energy, thereby increasing the intensity for the LHC and for fixed-target physics. The high-γ_t lattice provides naturally short bunches without compression. The feasibility of this approach has been demonstrated by tracking studies, including high-Q longitudinal impedances of resonance frequencies up to the pipe cut-off. The lattices designed so far are not conventional and need refinements, and it is likely that the extraction energy has to be reduced to 25 GeV which is still useful for the SPS. The 2.2 GeV booster ring delivers 440 kW of beam power at 50 Hz and could be used in an ISOLDE upgrade.

2.2. Target and Horn

2.2.1 Target

This device, which has to survive a 4 MW proton beam, is an extremely critical item, even though only a small fraction of the beam power is lost in the target. For the moment we have kept the specification of a 4 MW beam power as established at the Nufact99 workshop in Lyon. We have not yet designed anything, but model tests are underway [13] for a pulsed liquid metal (Hg) target. So far the model has only operated with water (similar viscosity), but tests are foreseen in the near future with Hg. After successful operation with Hg, tests will be performed by injecting the Hg jet into a high magnetic field (which may be necessary for the collection of the pions) and/or by exposing it to the Booster beam at ISOLDE at CERN. This beam, which has only 1.4 GeV, can however be adjusted to deliver the same power density as in our favoured scenario. The repetition rate will of course be lower by two orders of magnitude. It is worthwhile to point out a few characteristics implied by our scenario (2.2 GeV, 75 Hz operation):

- the energy dumped in the target will be higher than in the case of a proton beam with higher energy (typically by a factor 2),
- the energy density is also likely to be higher,
- however, the energy per pulse is reduced because in our scenario the repetition frequency is higher.

In case a low-Z material can be used (e.g. Li), a substantial gain is expected for the production of positive pions. To profit from this fact, it is, however, necessary to switch from high Z to low Z between runs positive and negative muons.

The HARP experiment [7] will measure the production of pions and their characteristics for different target materials. The results of this experiment may be decisive for the future orientation of our study.

2.2.2 Horn

The pions produced in the target have to be collected to enhance the production of a high-quality muon beam. The FNAL study and most other proposals use a 20 T solenoidal field for this purpose. Since one is interested in the production of one sign of pions for any given proton bunch, one could envisage a pion collection system based on transverse magnetic fields generated by a horn. Although we plan to test our Hg target in a high magnetic field, we shall explore the feasibility of horn focusing, where CERN has considerable experience A major advantage of horns is that the parts exposed to the beam are rather simple, inexpensive and can be radiation-hard. The horn will focus particles emitted at large angle, and with an energy range of 200-400 MeV, from a target typically 2-interaction lengths long. The horn design will be rather different from those used for high-energy beams, such as CNGS and NuMI, and closer to those considered for the antiproton source or the Fermilab mini-Boone beam. Several major questions are unanswered by the preliminary studies performed on the occasion of the Lyon workshop [14], the reallly critical issue being the high operating frequency of 75 Hz.

2.3 44/88 MHz system for phase rotation, cooling and bunching

The decay of the pions would take place in any case in a solenoidal channel where debunching occurs, i.e. there is a correlation between position and energy of the resulting muons. This energy spread will be reduced with rf cavities working with modest gradients in the range of 2-4 MV/m at 44-88 MHz. This scenario [8,15] is well adapted to our high repetition rate (75 Hz) and the large number of proton bunches impinging on the target (12 originally, now 140). Another advantage is that it works immediately with a bunched beam that is adapted to further acceleration in the subsequent linac, instead of needing rebunching as in the case of an induction linac [16]. The characteristics of the rf cavities are similar to the American designs (closed with Be foils or grids in case of the 44 MHz cavities), but have a more modest power consumption. The cooling follows basically the “standard” scheme of ionisation cooling, i.e. reduction of the total momentum of the muons (by ionisation losses of the beam passing through liquid hydrogen, LiH or Li), and reconstitution of the longitudinal momentum component with rf cavities.

After the target, the pions decay in a 30 m long channel focussed by a 1.8 T solenoid. At the end of the decay channel the particles with kinetic energy in the range 100-300 MeV are captured in a series of 44 MHz cavities and their energy spread is reduced by a factor two. At this point, a first cooling stage, employing the same rf cavities, reduces the transverse emittance in each plane to 60% while keeping the final energy constant. After the first cooling stage, the beam is accelerated to an average energy of 300 MeV. The longitudinal bunching achieved with acceleration, as well as the reduced physical dimensions of the beam, allow us to employ an 88 MHz cavity cooling system. The cooling, mixed with acceleration and rebunching, is continued until a sufficient number of particles fit within a 6D volume defined by 1.5π cm rad in the two transverse planes and 0.053 eVs in the longitudinal. The beam is then accelerated to 1 GeV with 80 MHz cavities. Present calculations predict ~10^{21} muons/year delivered to the re-circulator. The main characteristics of the components are given in Table 2.

Table 2: Main Parameters of Front End (SEE ALSO Fig. 2)

		Decay	Rotation	Cooling I	Acceleration	Cooling II	Acceleration
Length	[m]	30	30	46	32	112	≈450
Diameter	[cm]	60	60	60	60	30	20
Solenoid field	[T]	1.8	1.8	2.0	2.0	2.6	2.6
Frequency	[MHz]		44	44	44	88	88-200
Gradient	[MV/m]		2	2	2	4	4-10
Kin. Energy	[MeV]		200		280	300	2000

The motivation for this set-up was to propose a solution that makes use of existing technology or a modest extrapolation of it. The initial value for the gradient of the 40 MHz cavities came from the performance of the existing PS 44 MHz cavity [17]. Some exploratory Superfish runs have been made [18] for a 44 MHz normal-conducting cavity with a bore radius of 30 cm, and the results are encouraging (1.6 MW power required for 2 MV/m). This cavity could accommodate a solenoid around the chamber. A preliminary estimate of the power losses, for 2 MV/m at 44 MHz and 4 MV/m at 88 MHz, gives a figure of 10 MW for the entire phase rotation and cooling system, assuming that the system is pulsed at 75 Hz. The system could equally well work with half the gradient, at the expense of length.

The present simulations use ideal rf and solenoidal fields and do not yet include the material for the windows of the cavities, nor the necessary material for the containers of the liquid hydrogen required for ionisation cooling. These issues need refinement of the data for the simulation programs and will be addressed in the near future. The current bottleneck of the system can be seen in Fig. 3.

With the manpower presently available it is estimated that a more detailed study, including engineering constraints, can be achieved by early next year. This time scale relies on the strengthening of the team as foreseen for the near future. The optimisation of the system will continue at least till mid-2001.

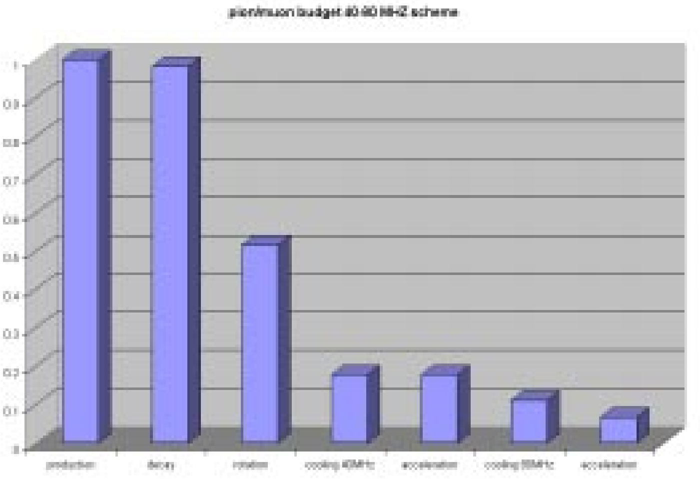

Fig.3: Particle budget along the 44-88 MHz system

2.4 Muon Linac

The muon linac will have solenoid focussing up to around 1 GeV, before acceleration to 2 or 3 GeV. It will operate at a multiple of the frequency used in the first part of the cooling channel [19].

2.5 Recirculating Linear Accelerators

Two RLAs take the muons from the muon linac to a final energy of 50 GeV, an energy favoured by most of our possible future clients. RLAs are used because acceleration has to be fast, in view of the limited lifetime of the muons. Acceleration with a normal linac would be even faster but very expensive.

Two recirculating linear accelerators RLA1 and RLA2 accelerate the muon beams from 2 to 10, and from 10 to 50 GeV. Their design [20] has some similarities with that of ELFE at CERN [21]. Their shape is that of a racetrack. Their circumference is about 1 and 5 km, respectively. The straight sections are occupied by superconducting linear accelerators with a total voltage round the circumference of 1 and 5 GV, respectively, consisting of LEP cavities with 7 MV/m gradient. The muon beam passes through each of them four times. The muons are accelerated on the crest of the rf wave. The transverse focusing in the linear accelerators is arranged to have constant betatron wavelength on the first pass in spite of gaining energy. "Spreaders" at the output end of the linear accelerators feed the muon beams into four separate, vertically-stacked arcs. Combiners merge the four beams into the input end of the next linear accelerator. The lattice of the arcs is achromatic, modified such that all passes through spreader, arc, combiner and linear accelerator are isochronous. Detailed parameters are listed elsewhere in this document.

The optical design of the linear accelerators and of the arcs is straightforward and poses no particular problems. This is not true for the spreaders and combiners, in particular in the first recirculating linear accelerator RLA1 that must handle a muon beam with an initial energy spread of approximately 12.5%. This large energy spread is one of the reasons why the number of passes is limited to four.

The concept of recirculating linear accelerators, operating isochronously at the crest of the rf wave, implies that there are no synchrotron oscillations, and that the bunch length and the absolute energy spread in the muon beam remain constant. Hence, the relative energy spread is adiabatically damped like 1/E. The concept also imposes an upper limit on the bunch length that is given by the shape of the rf wave, and is indeed tighter than that resulting from the size of the rf buckets in the muon storage ring. The muon collection and cooling systems, and the linear accelerator for the muons up to 2 GeV, can deliver suitable beam [19]. It remains to be demonstrated that this concept works. If not, concept adopted in the FNAL study [6] is an alternative. There, the muons are accelerated off the crest of the rf wave, the arcs are not isochronous, and the synchrotron tune does not vanish.

2.6 Storage (Decay) Ring

To allow the muons to decay in a “useful” way, i.e. by producing neutrino beams in the desired direction and with a good quality, two versions of a muon storage rings operating at 50 GeV, one with a triangular, and one of bow-tie shape have been designed (Figs. 4 and 5). To optimise the number of neutrinos decaying in the straight section, the curved section will use superconducting magnets. Note that these rings have unusual shapes and are not in the longitudinal plane. They send neutrino beams from two long straight sections (in which muon beam divergence is small), to two distant detectors at 1000 km and 3000 km distance. They are designed for a normalised emittance of 1.67 mm and an r.m.s. momentum spread of 0.5%. The verification of the optical design included the tracking of many thousands of muons during their lifetime. The total height of the ring is less than 250 m (Fig. 5) and hence smaller than the thickness of the molasse near the CERN site.

The first design [22] to meet the requirements, (i.e. 50 GeV muon energy, 10^{14} muons/s arriving in the storage ring for 10^7 s/year) has the shape of an equilateral triangle with rounded corners (Fig. 4). It has two long straight sections feeding neutrinos to detectors at 1000 and 3000 km distance, with a muon beam divergence of less than 0.2 mrad. A third long straight section closes the machine and is used for tuning. The machine is installed in a plane that is inclined such that the pitch angles in the long straight sections are -78.9 mrad, -237.9 mrad and +319.6 mrad. The triangular shape fixes the relative directions pointing towards the two detectors. Small deviations from the assumed shape are easy to accommodate. Large deviations are undesirable because they imply steeper slopes. Several 10^4 muons were tracked for the full muon lifetime. Collimators at 3 r.m.s. beam radius in almost all quadrupoles limit the physical aperture. Muons with initial amplitude of 2.4 r.m.s. beam radii in both horizontal and vertical directions survive. A dynamic aperture problem caused by the fringe fields of six quadrupoles was overcome by doubling their length [23]. The average energy deposition around the circumference of the muon storage ring, due to decay electrons, is about 140 W/m. Its enhancement, caused by electrons originating in the long straight sections and getting lost at the beginning of the arcs, has been investigated [24,25]. Another muon storage ring with the shape of a symmetrical bow-tie [26] (Fig. 5) was also studied. Its parameters are close to those of the triangular machine.

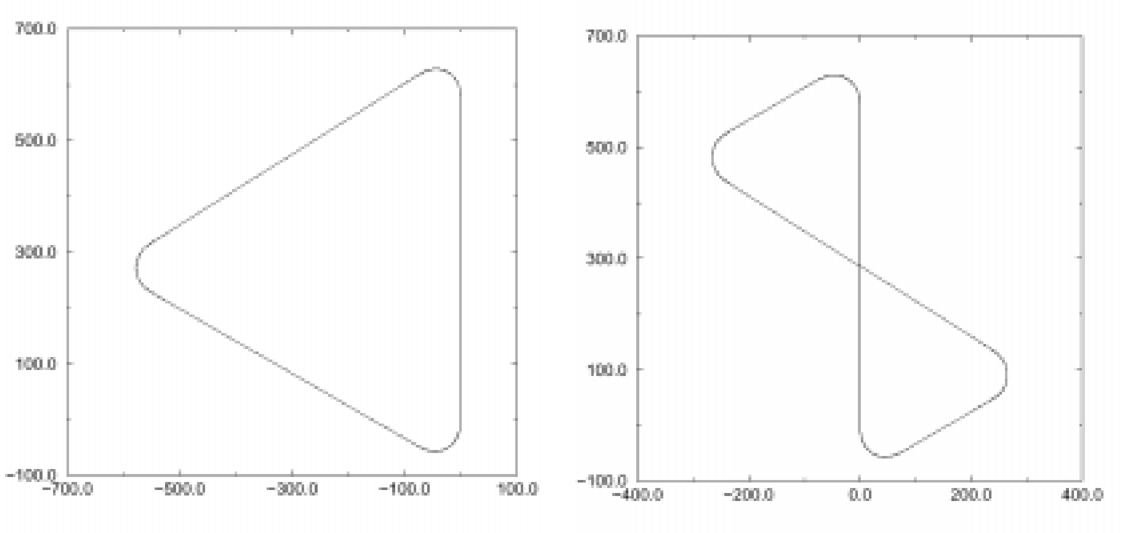

Fig. 4: Triangular and bow-tie shape of muon storage ring (horizontal projection)

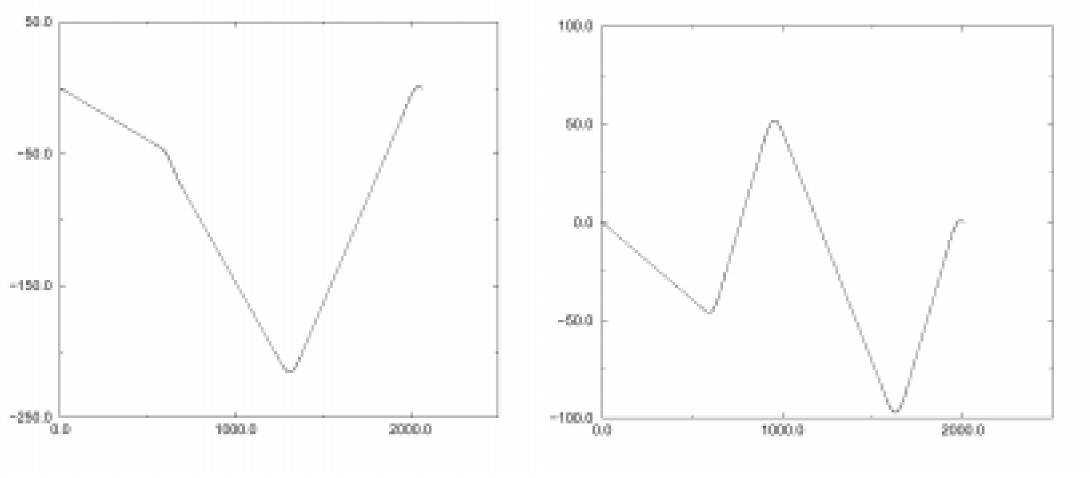

Fig. 5: As Fig. 4, but vertical level as function of distance round the ring

The design of the muon storage ring [22] is based on a number of assumptions concerning its engineering and the parameters of the injected muon beam. The next steps should put these issues on a firmer footing. For the arcs, engineering concepts for all magnets need to be developed.

The long straight sections should contain the smallest possible number of active components. One possibility is the use of permanent-magnet quadrupoles [27]. Two extreme possibilities for the removal of the heat due to decay electrons (about 70 kW in a straight section of 500 m length) are a shielded vacuum chamber with water cooling at room temperature or a transparent (to the decay electrons) vacuum chamber and regularly spaced, water cooled absorbers.

3. R&D Activities

Some of the R&D activities have been mentioned above. Computer simulations were performed on almost all of the subsystems although most remain to be done. Hardware design has started on a few components. Experimental activities have been going on in the field of superconducting cavities, on the target model and on an irradiation test of a 200 MHz cavity in the AD (Antiproton Decelerator) target area [28]. The HARP experiment should have its first technical run this year. At TRIUMF the MUSCAT experiment is producing data with some modest participation from CERN [29].

Our plans, for the not-too-distant future, can be summarised as follows.

SPL

1. the β=0.52 and 0.7 superconducting rf structures (an adequate solution has been found for β=0.8) [30],
2. the room-temperature DTL,
3. the H- source,
4. the design of field regulation servo-loops for the SC cavities,
5. the 2 MeV chopper, and especially its driving amplifier.

Target

For the liquid metal target:
1. Identify the parameters of liquid metal targets that should be experimentally determined and the equipment needed for their measurement. Identify the theoretical basis that the experimental results should benchmark.
2. Set up liquid jet equipment in the ISOLDE chemistry laboratory and demonstrate its use with mercury.
3. Organise a test in Europe of the injection of a mercury jet into a strong magnetic field.
4. Start planning the in-beam tests of the Hg-jet in the ISOLDE target area.

In addition, calculations and irradiation tests for the toroid shaped target proposed by RAL are planned.

Horn

Several major questions are unanswered by the preliminary studies performed on the occasion of the Lyon workshop [14]

:

1. Can a horn be designed to provide focusing for particles emitted at large angle (approaching 90 degrees) from a long target?
2. What would be its performance compared to the 20 T solenoid option?
3. Can a horn be operated at a repetition rate of 75 Hz, with short pulses of typically 3 μs “flat” top?
4. At what peak current can such a horn be operated for a reasonable lifetime?
5. What design of power supply could be envisaged?

For the moment this is mainly simulation work which might result in some model tests.

44/88 MHz scheme

The fundamental components of the 44/88 MHz system for phase rotation and cooling are the 44 MHz cavities. Design work for the 44 and 88 MHz cavity is to be continued. Some of the open questions are:

1. Study and test of different technological solutions for the beam windows. What is the minimum thickness of the window?
2. What is the maximum gradient that can be achieved in the cavity (anything above 1 MV/m is acceptable, but a higher gradient would reduce the length of the system)?
3. Test of the maximum gradient capability in the presence of a solenoid field.
4. Design, construction and test of the 1.8 T superconducting solenoid.

In addition, the future beam dynamics simulation work will include:

1. The dependence of the muon yield from the proton beam characteristics and the target material and geometry (limit on the upstream parameters).
2. Optimisation of each section (minimise emittance growth during decay, optimise cooling, a more refined design of the final accelerator).
3. In parallel, a revision of the beam dynamics in view of engineering constraints.

Finally, a study of sensitivity to the rf and mechanical parameters need to be done to assess and optimise the stability of the system.

Basic rf tests

Irradiation of 200 MHz cavity with (pulsed) magnetic field.
Tests of cavity with pressurised H_2 or He.
Tests with cavity closed by Li window (cooled).

Cavities for Linac (and RLA1)

Design of 200 MHz Nb sputtered Cu cavity relevant for the muon linac and in case of beam loading problems in RLA1 (using now 356 MHz LEP cavities). Possible collaboration with Cornell [29].

Recirculating linear accelerators

As is the case with the muon storage ring, the design of the recirculating linear accelerators is based on a number of assumptions concerning their engineering and the parameters of the muon beam. Once the feasibility of one or the other concept for RLA1 and RLA2 is established, all these assumptions ought to be verified. If the assumed accelerating gradient were higher than 7 MV/m, the circumference of RLA1 and RLA2 would be reduced almost in proportion, and so would the decay losses

Muon storage ring

The design of the muon storage ring is based on a number of assumptions concerning its engineering and the parameters of the injected muon beam. The next steps should put these issues on a firmer footing. For the arcs, engineering concepts for all magnets need to be developed. Furthermore the following questions should be addressed:

1. Determine the inside dimensions of the vacuum chamber.
2. Determine the material, temperature and shape of the shield that absorbs most of the power from the decay electrons and lets only a few W/m penetrate into the coils of the superconducting magnets at liquid He temperature. This can be done using computer simulation with programs such as MARS.
3. Determine the number of layers and the dimensions of the coils, and propose better values for the magnetic field. In particular, answer the question up to what field can the magnets be built with a single coil layer.
4. Determine the shape of the coils at the ends of the magnets.
5. Determine the dimensions of the collars and steel yokes.
6. Study the installation of the magnets in cryostats, considering the pitch and roll angles, installation, alignment, and maintenance in the tunnel.

Muon Test beams and Front-End Instrumentation

It has become evident that beam tests of the most critical elements are needed for development of credible neutrino factory designs, in particular for the muon capture and cooling sections. An international working group is being set up to investigate the needs (energy, time structure, beam size) and possibilities of muon test beams. At CERN, an evaluation of possible muon beams is being undertaken, including a possible reshuffling of a former neutrino beam line, from which a moderate-intensity pulsed muon beam could be obtained. The International Working Group is expected to give a first report at the end of 2000.

At the same time, the instrumentation necessary to commission and run the aforementioned beam tests, as well as the Neutrino Factory itself needs to be considered. Mini-workshops are taking place to define the parameters that need to be measured to evaluate the performance of the considered systems and to evaluate the precision with which they can be measured. The size and cost of the prototypes to be tested will depend on the outcome of these studies.

5. Conclusion

A preliminary scheme for a CERN Neutrino Factory has been proposed. It is intended to continue this study and future work may well show that some elements of this scenario need substantial modification or even replacement by other components. The results of the HARP [7] experiment expected for next year may also provoke some modifications. The ongoing R&D effort will be crucial for the final choices.

4. Acknowledgements

The present work is the result of the effort of the Neutrino Factory Working Group at CERN. The help of other laboratories, in particular RAL, but also GSI, FZI and CEA, and of members of the American Neutrino Factory and Muon Collider Collaboration is gratefully acknowledged.

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Appendix

Members of the CERN Neutrino Factory Steering Group:

Helmut Haseroth	(Chairman)
Bruno Autin	(Deputy Chairman)
Colin Johnson	(Secretary)
Roland Garoby	(2.2 GeV Linac)
Eberhard Keil	(RLAs, Decay Ring)
Alessandra Lombardi	(Frontend, Muon Linac)
Helge Ravn	(Target)
Horst Schönauer	(Accumulator, Compressor, RCSS)

The mailing list of the CERN Neutrino Factory Working Group can be found at:

http://muonstoragerings.cern.ch/Welcome.html