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ELFE at CERN

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Abstract

A conceptual design for a recirculating electron accelerator with a maximum energy of 25 GeV and a continuous beam current of 0.1 mA on target has been prepared by a study group at CERN. The machine makes use of the super-conducting RF system and other components that will become available after the decommissioning of LEP. The beam will be accelerated in seven passes through a linac with an energy gain of 3.5 GeV per pass. The status of the study and the main design features are presented. *

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1 Introduction

The European nuclear physics community has recently published a report about future options for nuclear physics [1]. One of the recommendations for future research facilities is an electron accelerator providing a quasi continuous electron beam with an energy of about 25 GeV, ELFE, an **E**lectron **L**aboratory **F**or **E**urope. Two designs for such a machine have already been published. The first design consisted of a new machine on a “green site” [2]. The second design was an appendix to the linear e^+e^- collider study TESLA at DESY in Hamburg, Germany [3].

The scheduled shutdown of the LEP collider at CERN offers a new opportunity to realize the ELFE project. The superconducting RF-cavities and other equipment will become available after the year 2000. Several uses of the LEP cavities have been proposed:

1. Free Electron Laser [4, 5]
2. Superconducting proton linac as PS injector [6]
3. 2 GeV superconducting linac as a proton driver for muon beams [7]
4. ELFE at CERN [8, 9]

The LEP cavities have been designed to accelerate ultrarelativistic $\beta \approx 1$ electrons in LEP. A 2 GeV superconducting proton linac could reuse about half of the LEP modules and would in addition require new cavities matched to lower β.

All 72 superconducting modules (with four cavities each, 288 cavities in total) could be reused without modifications for a continuous, recirculating electron accelerator. This makes the option of reusing the LEP cavities for ELFE particularly attractive.

Superconducting recirculators have in fact been the choice for the continuous electron machine (CEBAF) operating at the Jefferson Laboratory and for the ’93 proposal of a new machine in Europe [2].

2 Machine design

The design for ELFE at CERN has been based on the following beam parameter specification:

- 25 GeV top energy
- 100 μA quasi continuous electron beam on target, with the possibility of a substantial degree of polarization
- relative energy spread $\sigma_e/E < 0.1\,\%$.
- emittance (1σ Gaussian) $< 100\,\mathrm{nm}$

The present RF system in LEP and its performance is described in other contributions to this conference [10]. Following the recent experience in LEP, we are confident that a gain of 3.5 GeV can be obtained in a single pass through the 72 superconducting RF-modules. An energy close to 25 GeV is obtained by seven passages through the linac.

The injection energy into the main ELFE ring was chosen to be 0.8 GeV. This appeared to be a good compromise between the cost for the injector and β-beating from the energy mismatch between injection and top energy in the main ELFE linac. The optics is matched for the injection energy at constant wavelength, as shown in Figure 1. The maximum β increases from about 85 m in pass 1 to 375 m in pass 7, as can be seen in Figure 2.

The basic choice for the injector was a racetrack microtron similar to MAMI in Mainz [11], see Figure 3.

An alternative solution as injector, using cavities similar to those developed for the TESLA test facility [12], has also been investigated.

The overall dimensions of the machine are mainly constrained by the length of the RF modules from LEP for the linac (1081 m total) and the requirements on the energy spread and emittance. The latter could be met with a bending radius of 60 m for the arc dipoles. Including spreader/recombiner and with conservative assumptions on extra space needed for transitions, equipment and matching sections, the overall length of the straight sections becomes 1491 m. Together with two arcs of 482 m each, the full turn length adds up to $L = 3946$ m. It is in fact possible to fit such a machine on land owned by CERN, connected to the CERN north area.

A schematic view of the machine is shown in Figure 4. A spreader is used to separate the beams of different energies for the arcs. A schematic drawing of the spreader is given in Fig. 5. A recombiner (the mirror image of the spreader) at the end of the second arc combines the beams for their next passage through the linac.

We have also looked into an alternative design with linacs on either side. This allows to reduce the overall dimensions. There is then no need for six separate return lines. On the other hand, the number of spreaders and recombiners is doubled. It also implies some loss in performance (1.75 GeV top energy and an increase in vertical emittance by a factor of two). The saving in overall cost is rather marginal.

Two experimental areas are foreseen. One 55 m diameter hall allowing for a large spectrometer and a 30 m hall suited for a large solid angle detector.

The total capital investment cost to build ELFE using the superconducting cavities from LEP on ground owned by CERN was estimated to be close to 400 MCHF (about 260 million US–dollar) at 1999 prices.

3 Performance

The bunches are accelerated at the crest of the sine wave. The bunch length of $\sigma_z = 3$ mm introduces a relative energy spread of:

$$\sigma_e/E = \frac{1}{\sqrt{2}} \left(\frac{\omega \, \sigma_z}{c} \right)^2 = 3.4 \cdot 10^{-4}$$

(ω is the angular RF frequency, c the speed of light). Another source of energy variation from bunch to bunch comes from power and phase errors of the RF power delivered to the cavities. There is good experience with a fast RF vector sum feedback in

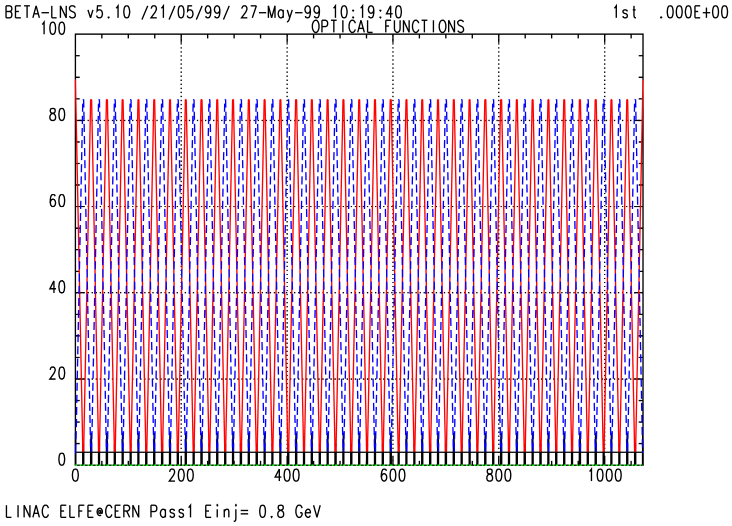

Figure 1: Optical functions β_x in red and β_y in blue during pass No. 1 through the linac.

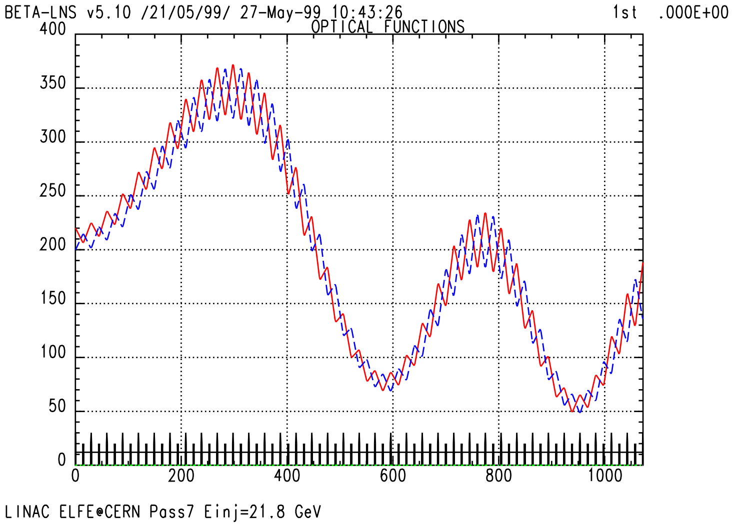

Figure 2: Optical functions β_x in red and β_y in blue during pass No. 7 through the linac

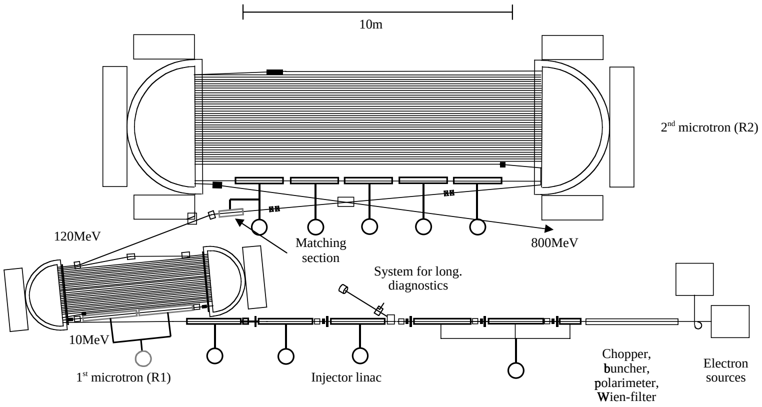

Figure 3: Microtron injector for ELFE, consisting of a 10 MeV linac, and two racetrack microtrons with 120 and 800 MeV top energy.

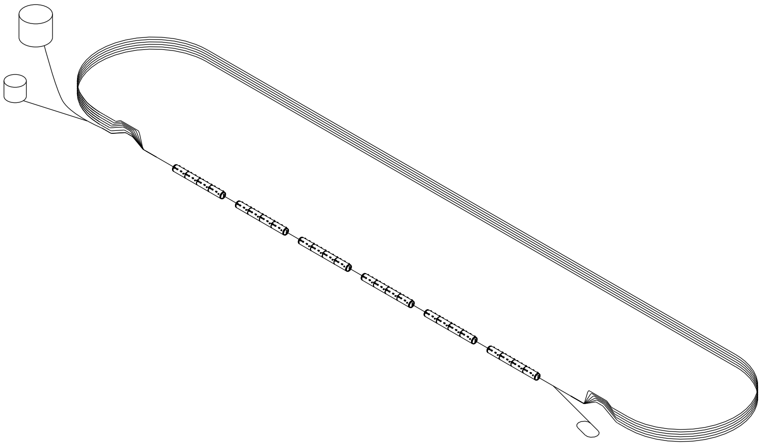

Figure 4: Schematic view of the ELFE machine.

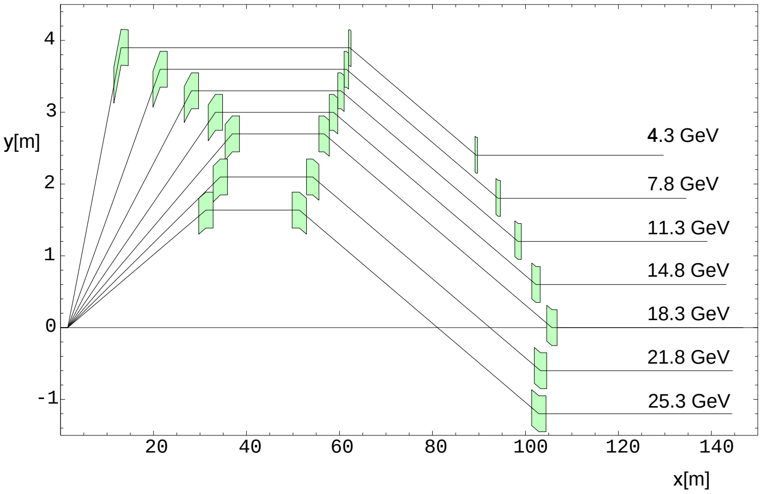

Figure 5: Schematic view of the spreader.

LEP. In addition, in order to minimize the energy spread introduced by the RF system, a feedback on beam energy is planned.

Table 1 summarizes the results for the synchrotron radiation losses U_s and the contribution of the synchrotron radiation losses to the relative RMS momentum spread $\sigma_e^{\rm SR}/E$ for each of the seven passes. Table 1 also shows the mean momentum offset $\Delta p/p$, the accumulated relative RMS momentum spread σ_e/E, and the transverse emittances ϵ_x and ϵ_y, that can be deduced from the particle coordinates in six-dimensional phase space, for all seven passes. Both $\Delta p/p$ and σ_e/E include the contribution of the bunch length $\sigma_z = 3$ mm. The energy spread and emittances are well within the beam specification. We recall that the goal of this study has been to demonstrate the feasibility of the project and to provide a cost estimate for the beam parameters as agreed initially with the physics group. The beam quality in terms of energy spread and emittance could be further increased by scaling (increased bending radius) and optimization if this would be of importance.

Table 1: Final energy E_f, contributions of the passes to the energy loss due to synchrotron radiation U_s, and to the relative momentum spread $\sigma_e^{\rm SR}/E$, and to the mean momentum offset $\Delta p/p$, accumulated relative RMS momentum spread σ_e/E, and transverse emittances ϵ_x and ϵ_y for the seven passes. Both $\Delta p/p$ and σ_e/E include the contribution of the bunch length $\sigma_z = 3$ mm.

Pass	E_f/GeV	U_s/MeV	$\sigma_e^{\rm SR}/E$	$\Delta p/p$	σ_e/E	ϵ_x/nm	ϵ_y/nm
1	4.3	1.28	3.365E-5	-4.916E-04	2.780E-04	0.0032	0.723
2	7.8	8.29	7.605E-5	-1.171E-03	3.161E-04	0.0891	2.965
3	11.3	30.59	1.484E-4	-2.783E-03	3.555E-04	0.722	4.337
4	14.8	82.92	2.571E-4	-5.660E-03	4.292E-04	3.247	6.806
5	18.3	185.14	4.144E-4	-1.016E-02	5.733E-04	10.58	10.33
6	21.8	362.46	6.194E-4	-1.666E-02	8.035E-04	27.84	14.44
7	25.3	22.51	1.717E-4	-9.233E-04	7.354E-04	23.96	18.83

4 Status

A joint CERN–NuPECC study group prepared the detailed technical design report, demonstrating the feasibility of the project. The report is very close to completion and is expected to go into print before the end of the year. The study group included accelerator specialists from several labs in Europe and a physics working group with about 30 nuclear physicists.

Starting from the initial “green light”, the total duration of the civil-engineering design and work implementation have been estimated at 6.5 years. This includes the time needed for authorization, tendering and contract-awarding procedures.

CERN provides the superconducting RF and other hardware that will become available from LEP, its expertise and the ground to build ELFE. It is now mainly the task of the nuclear and hadronic physics community as represented by NuPECC, to assign the necessary priorities and to find the extra resources in funding and manpower needed to realize the project.

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