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SPL at CERN

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Abstract

The existing complex of accelerators at CERN is capable to provide the Large Hadron Collider (LHC) with the beam required to reach its nominal characteristics. Higher performance injectors will however be necessary to exceed this limit and maximize the physics reach of the LHC. As a first step, the construction of a new 160 MeV H^- linac (Linac4) has started, and the study of a 4 GeV Superconducting Proton Linac (SPL) is being pursued in view of submitting a project proposal by mid-2012. The basic design choices of the SPL are described, as well as its potential interest for other physics programmes. The goals and plans of the on-going study are explained.

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The existing complex of accelerators at CERN is capable to provide the Large Hadron Collider (LHC) with the beam required to reach its nominal characteristics. Higher performance injectors will however be necessary to exceed this limit and maximize the physics reach of the LHC. As a first step, the construction of a new 160 MeV H^- linac (Linac4) has started, and the study of a 4 GeV Superconducting Proton Linac (SPL) is being pursued in view of submitting a project proposal by mid-2012. The basic design choices of the SPL are described, as well as its potential interest for other physics programmes. The goals and plans of the on-going study are explained.

NEW PROTON INJECTORS FOR LHC

The different options foreseen for increasing the luminosity of the LHC require new injectors that can satisfy the needs of the most demanding scenario [1]. Simplicity and performance margin are necessary features of these new accelerators which are also expected to operate with the very high reliability required to achieve an integrated luminosity per day an order of magnitude larger than nominal. The proposed future LHC injector complex [1] is sketched in Fig. 1, together with the present machines.

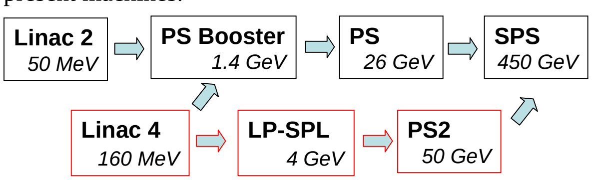

Figure 1: Present and future LHC injector complex.

Because of its superiority in terms of beam performance and potential for future applications, a superconducting linac (the LP-SPL) has been selected as the injector for the 50 GeV proton synchrotron PS2 [2]. The construction of Linac4 [3], the LP-SPL front-end, has been approved by the CERN Council at the end of 2007, as an efficient means to double the brightness of the beam delivered by the PSB and to prepare for the LP-SPL itself. The study of the LP-SPL, PS2 and SPS upgrade have been approved at the same time, with the goal of presenting a project proposal by mid-2012, and starting construction the following year. The layout of these new accelerators on the CERN site has been decided [4] and Linac4 is being built at its final location (Fig. 2).

For the needs of the LHC, only a 4 GeV low power version of the SPL is needed (the "LP-SPL"). For future possible applications like a neutrino facility or a Radioactive Ion Beam facility of the next generation [5], it would have to be upgraded to 4 MW of beam power at

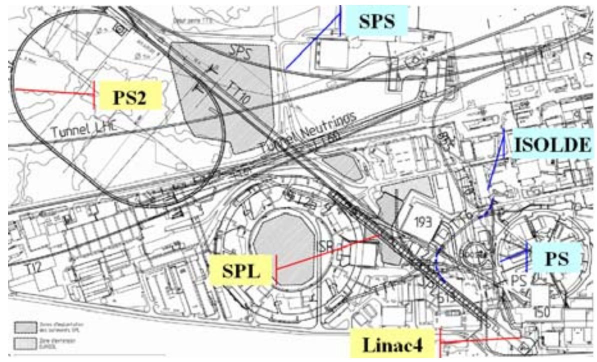

Figure 2: Layout of the new accelerators.

respectively 5 or 2.5 GeV or at both energies simultaneously. The specifications of the accelerator in its different phases of implementation are summarized in Table 1.

Table 1: Successive phases of implementation of the SPL

	LP-SPL	**SPL (5? GeV)**	**SPL (2.5 GeV)**
Users	PS2 ISOLDE	+ ν facility	+ RIB facility
Kinetic energy [GeV]	4	5 ?	2.5
Beam power [MW]	0.14	4	4
Repetition rate [Hz]	2	50	50
Source current [mA]	40	40 (80)	40
Chopping	yes	yes	no
Average pulse current [mA]	20	20 (40)	40
Pulse duration [ms]	0.9	0.8 (0.4)	0.8

LINAC4

Design

The planned evolution of the accelerator complex imposed Linac4 to be designed for operating successively in three different modes:

- as a PSB injector (1.1 Hz rate, 40 mA, 400 μs),
- as the front-end of the LP-SPL (2 Hz rate, 20 mA, 0.9 ms),
- and finally as the front-end of the high power SPL (50 Hz rate, 20 to 40 mA, 0.4 to 1.2 ms).

This requirement had consequences on items which cannot be easily upgraded, like civil engineering for radiation shielding reasons and accelerating structures which shall be able to withstand the maximum foreseen duty factor. The main beam characteristics of Linac4, as it is initially being built, are given in Table 2. The frequency of 352.2 MHz has been selected because it is very convenient for accelerating protons in this energy range, and because of the availability of a large inventory of LEP RF equipment.

Table 2: Linac4 beam characteristics

Kinetic energy	160	MeV
Bunch frequency	352.2	MHz
Maximum repetition rate	2	Hz
Maximum beam pulse duration	1.2	ms
Chopper beam-on factor	65	%
Average pulse current	40	mA
Transverse emittances	0.4	π mm.mrad

A block diagram of the accelerator is sketched in Fig. 3. Thirteen former-LEP klystrons and six new pulsed devices are used to excite the four different types of normal conducting accelerating structures. A 4 vane RFQ bunches and accelerates the beam up to 3 MeV where a wideband / high speed chopper (rise and fall time <2 ns) tailors the bunch train to the needs of the following synchrotron. An Alvarez DTL equipped with permanent quadrupole magnets brings the energy up to 50 MeV. Cavity-Coupled DTL (CCDTL) structures are used in the energy range from 50 to 102 MeV followed by Pi Mode Structures (PIMS) for acceleration up to 160 MeV.

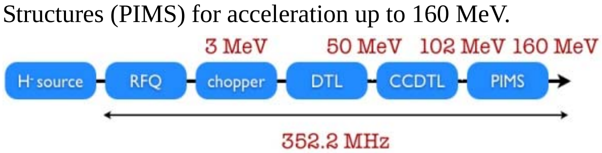

Figure 3: Block diagram of Linac4.

Schedule

Started in 2008, Civil Engineering will finish at the end of 2010. Installation of the infrastructure will then take place in 2011, followed by the installation of the accelerating structures in 2012. Linac beam commissioning will start in the middle of 2012 and last until the third quarter of 2013, when all accelerators will be stopped and the PSB will be modified. After 3 months of commissioning with Linac4, operation for physics will resume in April 2014.

LP-SPL AND SPL

Basic design

The main beam characteristics of the different phases of implementation of the SPL are listed in Table 1. To meet these requirements, the SPL is made up of 2 sections of superconducting cavities accelerating the H^- beam from 160 MeV to 4 GeV [6]. As a result of a recent review of the main design parameters [7], both sections operate at 704 MHz and use 5-cell elliptical cavities having a geometric β of 0.65 and 1.0 [8], respectively. Assuming peak surface fields of 50 MV/m (and 100 mT), accelerating gradients of 19.3 and 25 MV/m are expected for the chosen geometric betas. Although the cavities will operate at 2 K, these gradients are considered as challenging. The present estimate is that approximately 90% of all cavities will reach 22-23 MV/m without re-processing [7]. At the present stage of the design, medium β (resp. high β) cavities are grouped by 6 (resp. 8) in a 11.5 (resp. 14.3) meter long cryomodule, together with 2 (resp. 1) quadrupole doublets. The main SPL parameters are summarised in Table 3, and the resulting real estate gradient is shown in Fig. 4.

Table 3: Main SPL parameters in its successive phases of implementation

	LP-SPL	SPL (ν)	SPL (RIB)
Kinetic energy [GeV]	4	4 (5 ?)	2.5
Beam power [MW]	0.14	4	4
Length [m]	427	427 (502 ?)	502
Nb. of cryo-modules with β=0.65	9	9	9
Nb. of cryo-modules with β=1.0	19	19 (24)	19
Maximum peak power per cavity [MW]	0.5	1.0	1.0

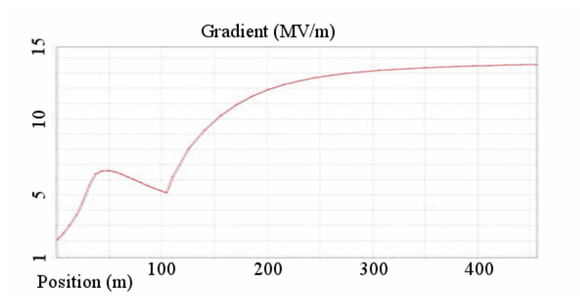

Figure 4: Real estate gradient along the SPL.

As shown in the block diagram of Fig. 5, beam extraction at ~1.4 GeV is foreseen in the layout of the LP-SPL, for supplying particles to the ISOLDE experimental area (Fig. 2). The length of one cryomodule is assumed for this extraction section. To minimize irradiation close to the main linac, stripping of the H^- ions has to be avoided in the extraction and in the first part of the transfer line, where low field bending magnets have therefore to be used.

For the needs of an RIB facility of the next generation, the high power version of the SPL is planned to have an extraction at 2.5 GeV which is assumed to fit within the length of one cryomodule. Low field magnets must also be used for extraction and transfer to this facility which requires H^- ions for splitting the beam onto multiple targets.

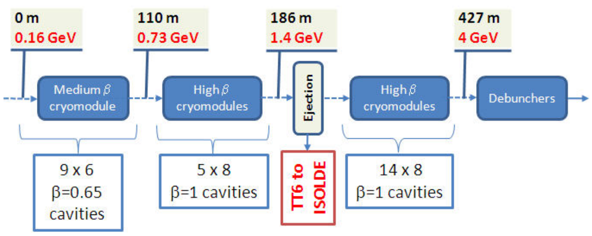

Figure 5: Block diagram of the LP-SPL.

For a neutrino factory, the high power SPL has to be complemented with an accumulator and a bunch compression ring to give an adequate time structure to the beam [9]. According to a recent investigation [10], the initial requirement of 5 GeV kinetic energy for the proton beam producing pions seems not justified and 4 GeV might perfectly be used.

Goals and means of the SPL study

The goal of the SPL study is to prepare for a start of construction of the LP-SPL optimized for PS2 and LHC at the beginning of 2013. For that purpose, a detailed Conceptual Design Report and a cost estimate will be published in May 2012. The cost of leaving the possibility of a later upgrade to high beam power will also be quantified. To arrive at a sufficiently accurate design and to be able to estimate cost:

- enough cavities must be designed, built and tested for a reliable assessment of the reasonably achievable gradient,
- a full size prototype cryomodule must be designed and assembled,
- the SM18 test place at CERN must be upgraded to allow for exercising multiple cavities in the prototype cryomodule at the nominal RF power,
- Civil Engineering and Integration must be studied, including safety and environment concerns.

These tasks are accomplished in the context of the SPL Collaboration by multiple laboratories and institutions worldwide (including CERN) and with the support of the European Community in the context of its 7th Framework Programme. Contacts are established with the ESS project team, in view of maximizing synergy and sharing efforts. Two SPL collaboration meetings have already taken place since the start of the study in 2008, and the third one is planned in November 2009 at CERN [11].

Status and plans

As reported before, the first subjects addressed in 2008 have concerned the cavities frequency, gradient and cooling temperature. The effects of the cavities' HOMs on the beam and on the cooling system have been investigated more recently [12, 13], the outcome being that a weak damping of these resonances is sufficient to prevent beam break-up and keep a low heat load [14]. It is planned to be obtained by a careful design of the inter-cavity sections, where normal conducting elements are located (e.g. stainless steel bellows).

The architecture of the high power RF distribution is an important subject where decision is required soon because of the long lead time for getting high power RF amplifier(s) (e.g. klystron) and power supplies for the test place. The initial choice was to use multi-MW klystrons, each one feeding 4 cavities in the high β region and more in the medium β part. However, due to the difficulties of stabilizing the field in pulsed superconducting cavities using high power vector modulators, the economical advantage of this choice is being revisited, in view of reducing the number of cavities per klystron.

The possible options for the sectorization of cryogenics will be debated during a workshop organized in November 2009 [15]. Impact on construction and operational costs as well as on maintenance and repair will be analysed. The outcome of this workshop will provide the information required to decide on multiple issues, like the number of cavities and quadrupoles per cryo-module and the need for a separate cryo-line.

The major milestones in 2010 will concern the detailed design and the start of construction of cavities and of cryomodule components. Moreover Civil Engineering will be have to defined and orders for the upgrade of the CERN test facility will have to be made. All these subjects will be addressed during the 3rd SPL collaboration meeting [11].

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