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The construction of the Large Hadron Collider at CERN is in its final phase, and commissioning with beam is scheduled to begin before the end of 2007. It is now time to prepare for increasing as much as possible the performance of this unique instrument to maximize the benefits for physics. An essential part of the proposed luminosity upgrade plan is the replacement of the CERN PS and its injectors by a 50 GeV proton synchrotron (PS2) and a 4 GeV superconducting linac (SPL). The design of the SPL has recently been updated and the optimization of its high-energy part will continue until ~2010. For the foreseen luminosity upgrade of the LHC a low-power version of the SPL (LP-SPL) is under study, which can be upgraded to a multi-megawatt machine providing beam to high-power proton users such as neutrino facilities and/or radio-active beam facilities. The construction start of the low-energy normal conducting SPL front-end, the 160 MeV "Linac4", is scheduled for January 2008, with the goal of being operational as injector for the PS Booster (PSB) at the beginning of 2012. The design status of Linac4, LP-SPL, and SPL are described, as well as their foreseen implementation into the CERN proton injector chain.

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Abstract

The construction of the Large Hadron Collider at CERN is in its final phase, and commissioning with beam is scheduled to begin before the end of 2007. It is now time to prepare for increasing as much as possible the performance of this unique instrument to maximize the benefits for physics. An essential part of the proposed luminosity upgrade plan is the replacement of the CERN PS and its injectors by a 50 GeV proton synchrotron (PS2) and a 4 GeV superconducting linac (SPL). The design of the SPL has recently been updated and the optimization of its high-energy part will continue until ~2010. For the foreseen luminosity upgrade of the LHC a low-power version of the SPL (LP-SPL) is under study, which can be upgraded to a multi-megawatt machine providing beam to high-power proton users such as neutrino facilities and/or radio-active beam facilities. The construction start of the low-energy normal conducting SPL front-end, the 160 MeV "Linac4", is scheduled for January 2008, with the goal of being operational as injector for the PS Booster (PSB) at the beginning of 2012. The design status of Linac4, LP-SPL, and SPL are described, as well as their foreseen implementation into the CERN proton injector chain.

1. The new proton injector chain

The location of Linac4 [1] and of the SPL [2] on the CERN site has recently been reconsidered with the goal of minimizing beam interruptions for LHC during the construction and commissioning of both machines (see Figure 1). In the old scheme Linac4 was planned to be installed in an existing hall (South Hall) to minimise costs, and then moved to a new site (along the southern border of CERN) when the SPL would be built.

Figure 1: *Layout of the new proton injector complex at CERN.*

For this purpose a long shut down would have been necessary to allow for the move of Linac4 and the commissioning of the SPL. In the new scheme, Linac4 is not moved and can be used as injector for the old proton chain (PSB and PS), while at the same time supplying some of its spare beam pulses to commission the SPL and PS2. The staged approach towards renewing the CERN proton injectors now foresees: i) the replacement of the present Linac2 with Linac4 which will increase the PSB injection energy from 50 to 160 MeV, removing the present space-charge limitation at injection, and allowing to accelerate up to twice as many particles per cycle; ii) starting in 2012, the extension of the Linac4 normal conducting part up to 180 MeV and the construction of the LP-SPL and PS2, which will replace the PSB and the CERN PS; iii) the upgrade of the LP-SPL to a multi-megawatt proton driver whenever that is necessary for an approved physics experiment.

2. Linac4

The low-energy front-end of Linac4 is made up of an H^- source, a LEBT, the IPHI RFQ [3], and a 3 MeV chopper line. It will first be assembled as a 3 MeV test stand [4] where the commissioning of high power RF with a new klystron modulator will start in September 2007 and the beam commissioning will take place at the end of 2008. The vacuum tightness and the electrical characteristics of the chopper structure have already been checked [5]. The RFQ is under construction in the frame of a collaboration between the French CEA, IN2P3 and CERN. The design and construction of the H^- source have started with the help of the DESY laboratory in Germany [6]. For acceleration beyond 3 MeV, three types of accelerating structures are used [7]: a Drift Tube Linac (DTL) up to 40 MeV, followed by a Cell-Coupled Drift Tube Linac (CCDTL) up to 90 MeV and a Side Coupled Linac (SCL) up to the final energy of 160 MeV. Figure 2 shows the overall architecture of Linac4 as a part of the SPL.

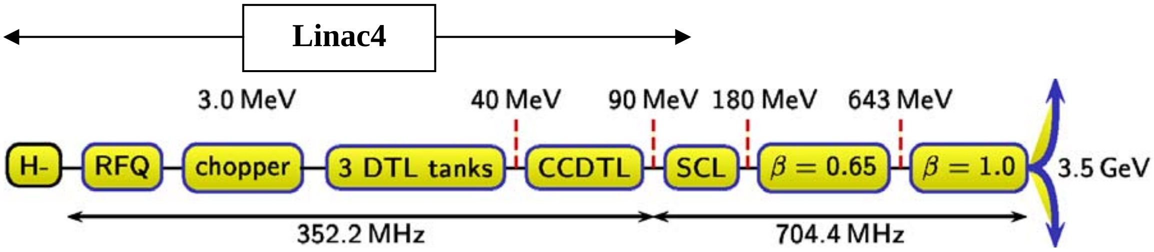

***Figure 2**: Block diagram of Linac4 (<160 MeV) and SPL.*

Prototyping of the DTL tanks has started in Russia with the support of the ISTC (prototype in construction with ITEP Moscow/VNIIEF Sarov under project #2888) and in Saudi Arabia (KASCT, Riyadh) (cold model). One CCDTL hot model (2 half-cavities plus coupling cavity) has been built at CERN and one full module (3 cavities plus 2 coupling cavities) was recently delivered to CERN from Russia (BINP Novosibirsk/ VNIITF Snezinsk) under ISTC contract #2875. Both hot models have been tested successfully at low power and will be high-power tested this spring. For the SCL a low-power prototype is built in France (LPSC Grenoble) and a technical prototype is under construction in Novosibirsk/Snezinsk.

3. LP-SPL and SPL

3.1 Basic parameters

The maximum beam energy for the SPL (5 GeV) is governed by the needs of muon production for a neutrino factory. Its final value remains to be firmly established with additional experimental results and a refined design of the neutrino facility. In the case of the LP-SPL, the top energy of 4 GeV results from space-charge considerations at injection in PS2, the planned successor of the present CERN PS with twice the energy (50 GeV) and twice the brightness. The full SPL aims to deliver high beam power within short pulses to accumulator/compressor rings, needed to produce the short beam bursts required by neutrino applications [8]. For that purpose, a high pulse current of 40 mA and a high repetition rate (50 Hz) are needed, while, for the needs of PS2 and LHC only, savings can be made by reducing the pulse current to 20 mA and the repetition rate to 2 Hz (LP-SPL option). To be able to supply 1.5×10^{14} particles per pulse to the PS2, the

LP-SPL must have a beam pulse length of 1.2 ms, while 0.6 ms are sufficient for the full performance SPL. Table 1 lists the main parameters of both machines.

***Table 1**: Parameters of the "nominal" SPL and of the low-power LP-SPL.*

	unit	*SPL*	*LP-SPL*
Energy	[GeV]	5.0	4.0
Beam power (for ν factory)	[MW]	4.0	0.192
Repetition rate	[Hz]	50	2
Average pulse current	[mA]	40	20
Peak pulse current	[mA]	64	32
Chopping ratio	[%]	62	62
Beam Pulse length	[ms]	0.6	1.2
Protons per pulse for PS2	[10^{14}]	1.5	1.5
Beam duty cycle	[%]	2.0	0.24
Number of klystrons (LEP)		14	14
Number of klystrons (704 MHz)		57	28
Peak RF power	[MW]	219	100
Average power consumption	[MW]	38.5	4.5
Cryogenics av. power consumption	[MW]	4.5	1.5
Cryogenic temperature	[K]	2.0	2.0
Length	[m]	534	459

3.2 Design approach

The general design approach for the LP-SPL, is to build the initial infrastructure such that the nominal SPL can be installed at limited cost. A typical consequence is that the tunnel diameters are large enough to accommodate the installation of the nominal SPL (e.g. water pipes, klystrons, power supplies), while the surface buildings, cooling towers, cryo-plant, and electrical infrastructure are only designed to cover the needs of the LP-SPL. Due to the lower current of 20 mA, further savings are made on the number of klystrons and power supplies. While the klystrons are capable of high-duty cycle operation, the power supplies will have to be exchanged when upgrading the LP-SPL to 50 Hz operation. Additional savings are made by having an initial top energy of 4 GeV instead of 5 GeV. All normal and super-conducting accelerating structures including water/cryogenic cooling are designed for high duty cycle.

Above 180 MeV two families of five-cell bulk-niobium superconducting cavities (elliptical shape with geometric β=0.65/1.0) accelerate the beam to its final energy (see Table 2). The electric gradients of 19 and 25 MV/m are based on electric/magnetic peak surface fields of 50 MV/m and 100 mT, values which are consistent with test results of bulk niobium structures in CW operation [9, 10]. The cryogenic temperature is therefore chosen to be 2 K. Future R&D will show if the same gradients can be reached in pulsed mode at 4.5 K [11], which could result in a saving of ~30% on the costs of the cryo-modules and the cryogenic distribution lines. A recent costing exercise showed that operating at 4.5 K a cryo-system (cryo-modules and distribution lines) designed for 2 K, does not result in reduced costs for the cryo plant. For this reason 4.5 K operation is not considered for the LP-SPL. The design of the cryo-modules benefits from the LHC experience [12] and is based on the TESLA/ILC modules [13, 14], featuring internal Helium distribution lines and SC quadrupoles within the modules. This principle results in long inter-connected cryo-modules with a high filling factor and low static losses. It makes it possible to accelerate from 180 MeV to 4 or 5 GeV within 372 or 447 m, respectively. For both linac versions a maximum of 8 cavities are fed by one 704 MHz 5 MW klystron, making use of fast phase and amplitude shifters [1] to stabilize the electric field in the cavities. Piezo tuners will be implemented to counteract the effects of Lorentz force detuning.

Extensive end-to-end beam dynamics studies have been made for a 3.5 GeV SPL, including the effects of random errors. The error studies were used to define the alignment and field tolerances of quadrupoles and accelerating structures [2] and revealed no performance limitations even for the nominal duty cycle. As a consequence we expect a very short commissioning time for the LP-SPL to reach its design performance.

***Table 2**: Main parameters of all sections for the "nominal" SPL and the low-power SPL (LP-SPL)*.*

Section	*Energy* *[MeV]*	*Cavities*	*SPL: $P_{RF,peak}$* *[MW]*	*LP- SPL: $P_{RF,peak}$* *[MW]*	*Length* *[m]*
Source	0.095	-	-	-	3
RFQ	3	1	1.0	1.0	6
Chopper	3	3	0.1	0.1	3.7
DTL	40	3	3.8	3.1	13.6
CCDTL	90	24	6.4	5.4	25.5
SCL	180	24	15.1	13.7	34.9
$\beta = 0.65$	643	42	18.5	9.3	86
$\beta = 1.0$	4000	152	134	67.1	286
$\beta = 1.0$	5000	40	40	-	75
Total		289/249*	219	100	534/459*

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