CERN LINAC UPGRADE ACTIVITIES

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Abstract

In its June 2007 session the CERN Council has approved the White Paper, which includes construction of a 160 MeV H¯ linear accelerator called Linac4, and the study of a 4 GeV Superconducting Proton Linac (SPL). Linac4 will initially replace Linac2 as the injector to the PS Booster, improving its performance up to the levels required for producing the ultimate LHC luminosity. In a later stage, Linac4 is intended to become the front-end of SPL in a renewed injection chain for the LHC, which could be progressively constructed over the next decade. After briefly introducing the motivations and layout of the new injector chain, the talk will present the characteristics of the new linacs and give an overview of their main technical features and the R&D activities pursued within the HIPPI Joint Research Activity.

INTRODUCTION

In its June 2007 session the CERN Council has approved the White Paper "Scientific Activities and Budget Estimates for 2007 and Provisional Projections for the Years 2008-2010 and Perspectives for Long-Term", which includes construction of a 160 MeV H¯ linear accelerator called Linac4, and the study of a 5GeV, high beam power, superconducting proton Linac (SPL).

Both those activities aim at rejuvenating the present proton injectors which –although well-performing for the time being - date from the 60-70s and are working, since some years, well beyond their design intensity and very close to their technical limits.

PRESENT LHC INJECTORS

All the protons at CERN are produced by a duoplasmatron ion source giving in excess of 300 mA of beam current, composed by about 2/3 of protons [1]. The source provides a 100-150 μs beam with a repetition rate of 1.1 Hz. The beam, extracted at 90 keV, is further accelerated by a Linac (Linac2) up to 50 MeV and then injected in the 4 rings of a 25 m radius synchrotron, called the CERN PS Booster (PSB). The PSB, commissioned in 1972, brings the beam energy to 1.4 GeV and injects in another synchrotron, 100 m in radius, called the Proton Synchrotron (PS). CERN PS was commissioned in 1959 and accelerates the beam up to 26 GeV. All the above accelerators are located on the original CERN Meyrin site and serve several experimental facilities like ISOLDE, the antiprotons facility (AD), nTOF and the experiments in the East Area [2].

A fraction of the proton pulses from the PS is sent to the Super Proton Synchrotron (SPS), 1000 m in radius, to be accelerated to 450 GeV and then, amongst other, be injected in the Large Hadron Collider (LHC). The SPS was commissioned in 1976. A sketch of the present CERN accelerator is shown in Fig 1.

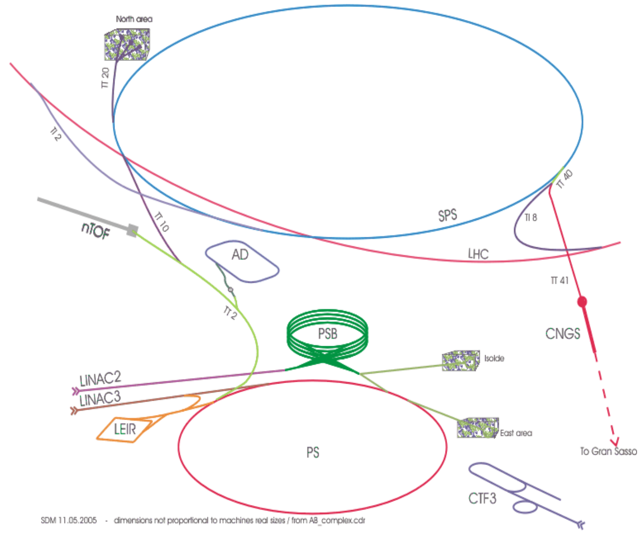

Figure 1: Layout of the present LHC proton injectors.

Linac2 and the Reasons for Its Upgrade

Linac2 [3] was commissioned in 1978 and it consists of a three Alvarez-type Drift Tube Linac (DTL) tanks, operating at the frequency of 202.56 MHz. Electromagnetic quadrupoles are housed inside the 128 drift tubes necessary to bring the beam energy from 0.75 to 50 MeV. Until 1993 the pre-injector was a 750 kV Cockcroft-Walton, which was then replaced by a 4-vane Radio Frequency Quadrupole (RFQ2) [4], capable of delivering almost 200 mA of protons to the DTL. Linac2 is working at a current well beyond its design limit (150 mA) and the RF hardware is working at its technical limit. Besides, the output energy of 50 MeV is too low for any further current increase in the PSB, limited by space charge detuning at injection.

All the above reasons motivate the construction of Linac4 [5], accelerating H¯ to an energy of 160 MeV, which halves the space charge detuning at PSB injection and allows charge exchange injection.

Upgrade of the Injectors

Linac4, which is approved to provide H¯ for the PSB operation in 2013, can be the first stage of a more global injector upgrade, which includes a Superconducting Proton Linac (SPL) [6] delivering a 4 GeV beam to a new synchrotron (PS2). PS2 could inject in the SPS at 50 GeV opening the potential for a higher proton beam flux from the SPS [7]. A technical design study on SPL and PS2 are due to be completed by 2011 when a decision on further upgrades could be taken. The layout on the Meyrin site [8] is shown on Fig.3. In the next two sections the ongoing activities for Linac upgrades will be described.

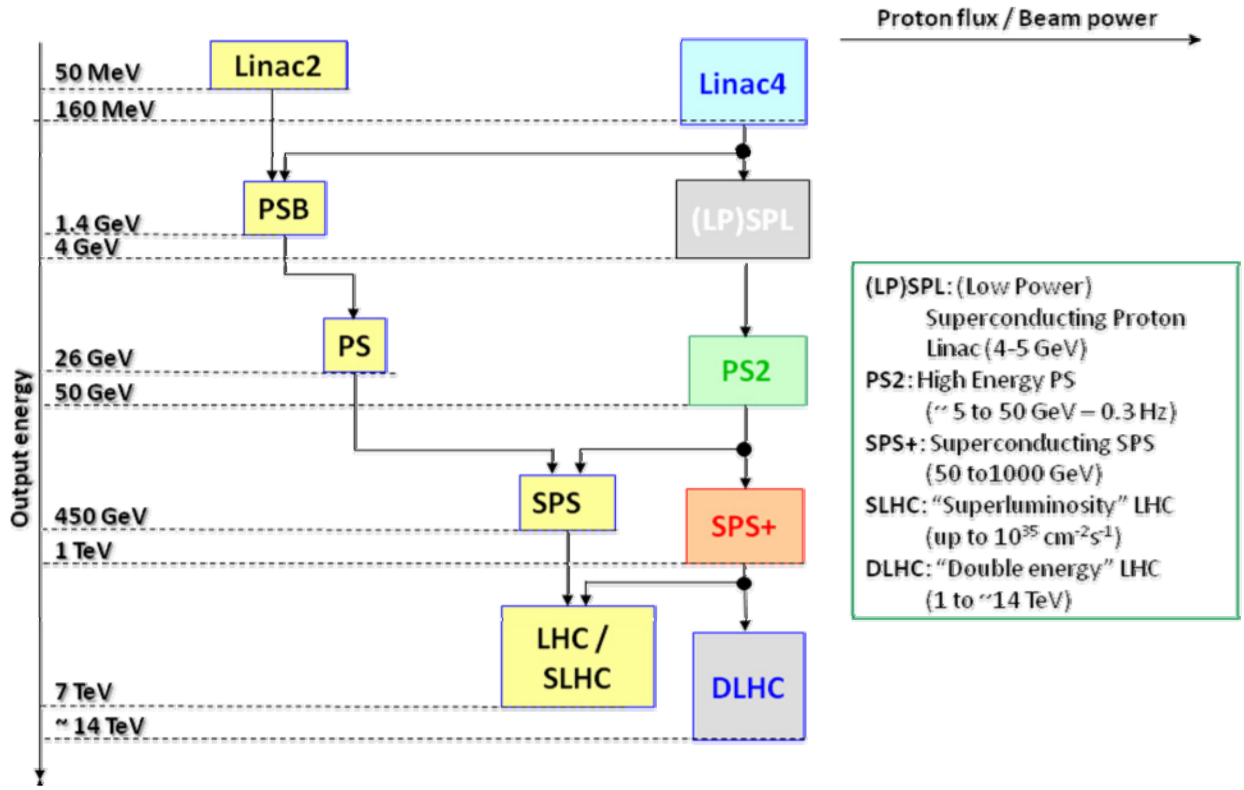

Figure 2: Block diagram of the present CERN proton injectors (left) and the possible staged upgrade (right).

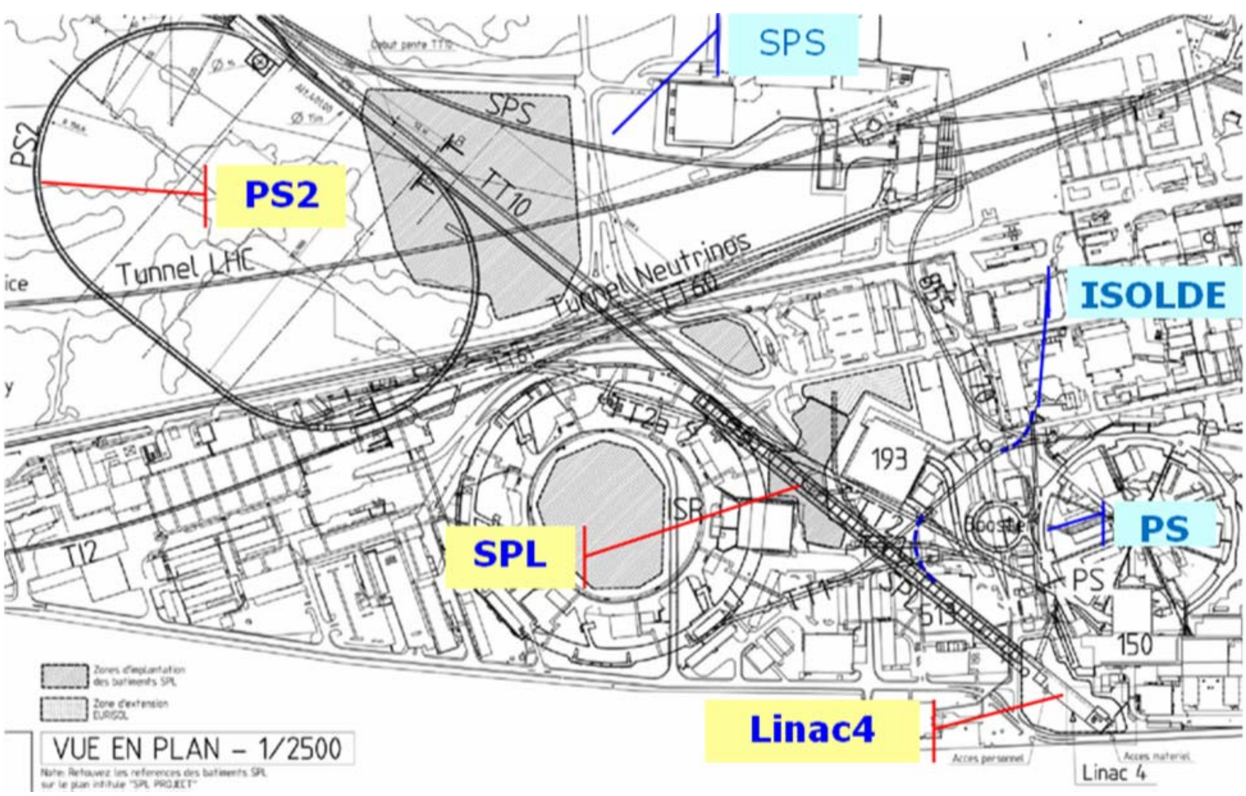

Figure 3: Layout of the new injector on the CERN Meyrin site.

LINAC4

The Linac4 project started officially in January 2008 with the goal of having a Linac injecting 160 MeV H^- beam in the PSB by 2013. The main characteristics of the beam from Linac4 are summarised in Table 1. In brackets the values to be achieved for future (Low Power-)SPL operation.

Table 1: Linac4 Beam Characteristics

Ion species	H^-
Output kinetic energy	160 MeV
Bunch frequency	352.2 MHz
Max. repetition rate	1.1 (2) Hz
Beam pulse duration	0.4 (1.2) ms
Chopping factor (beam on)	65%
Source current	80 mA
Linac current	64 mA
Average current during beam pulse	40 mA
Average beam power	2.8 kW
Particles / pulse	$1.0\ 10^{14}$
Transverse emittance in -rms	0.25 mm mrad
Transverse emittance out - rms	0.4 mm mrad

Linac4 Layout

Linac4 is a normal conducting linear accelerator operating at the frequency of 352MHz. The first element of Linac4 is a 2MHz RF volume source [9] which provides a 400 µs 80 mA H^- beam at 45 keV with a repetition rate of 2 Hz. The first RF acceleration (from 45 keV to 3 MeV) is done by a 3 m long Radio Frequency Quadrupole [10]. At 3 MeV the beam enters a 3.6 meter long chopper line, consisting of 11 quadrupoles, 3 bunchers and two sets of deflecting plates. The beam is then further accelerated to 50 MeV in a conventional Drift Tube Linac (DTL). The DTL, subdivided in 3 tanks, is 19 meters long. Each of the 111 drift tubes is equipped with a Permanet Magnet Quadrupole (PMQ). The acceleration from 50 to 100 MeV is provided by a Cell-Coupled Drift Tube Linac (CCDTL). The CCDTL is made of 21 tanks of 3 cells each for a total length of 25 meters. Three tanks are powered by the same klystron, and constitute a module. The focusing is provided by electromagnetic quadrupoles placed outside each tank, with the option of using Permanet Magnet Quadrupoles between coupled tanks. The acceleration from 100 to 160 MeV is done in a π-Mode structure. The PIMS is made of 12 tanks of 7 cells each for a total of 22 m. Focusing is provided by 12 Electromagnetic Quadrupoles (EMQ). A 60 m long transfer line, composed of 2 horizontal and 2 vertical bendings, 15 quadrupoles and a debuncher cavity connects the Linac4 tunnel to the present Linac2 to PSB transfer line.

Prototyping Activities

Prototyping activities have been going on since 2004, in order to prepare the Linac4 technical design report and to help choosing the most reliable technology and the best engineering solution for the components of Linac4. Prototyping activities include the realisation of a chopper device complete with its driver; two prototypes for the DTL; three prototypes of PMQ for the DTL; two prototypes for the CCDTL and a cold model of the PIMS structures. A list of the issues addressed and the achievements of the past and ongoing prototyping activities is given in the following:

- Chopper structure: a meander type structure printed on alumina substrate has been realised in collaboration with industry. Electrical and vacuum tests have confirmed the final choice of material and geometry. Assembly in a quadrupole has been demonstrated. [11]
- A driver for the chopper plates has been realised in house and a commercial amplifier has been bought and tested. Both solutions present advantages and disadvantages. The required voltage and repletion rate for LP-SPL operation has been achieved. The ultimate repetition rate operation (40 MHz) is still to be fully demonstrated. [12]
- A cold model of the DTL has been realised to test the tuning capability [13]
- A mechanical model of the DTL has been realised to test the mechanical tolerances achievable with the chosen assembly procedure [13]
- Two models (1 and half cell) of CCDTL have been tested at high power [14]
- A cold model for the PIMS is undergoing RF measurements[15]
- A klystron test stand has been set-up to demonstrate the operation of decommissioned LEP klystron in pulsed mode.

The 3 MeV Test Stand

Experience with other Linacs and dedicated beam dynamics studies [16] show that the most difficult part to master in a high intensity Linac is the low energy part, where the beam is slow and under the influence of strong space charge. Besides, issues like neutralisation at the lowest energy and non-standard beam distribution can result in beam parameters that severely differ from computational prediction. In order to have enough time to study and master the low energy beam a test stand including the source, the Radio Frequency Quadrupole and the chopper line is being put in place in the PS south hall, with the aim of being operational by 2010, before the final Linac4 building will be available. The 3 MeV test-stand will be equipped with a dedicated diagnostics line and a state-of-the-art device capable of detecting the population of adjacent microbunches (spaced by 2.8 ns) with a dynamic range of 10^6[23]. The goal of the 3 MeV test stand is to demonstrate the capability of delivering a 70 mA , 400 µs long, beam at 3 MeV of energy, matched to the DTL and adapted to the 1 MHz PSB bucket, i.e. with 123 over 352 pulses removed and intercepted by the in-line beam dump [17].

SUPERCONDUCTING PROTON LINAC

The location [8] of Linac4 has been chosen to allow using Linac4 as the front end of a Superconducting Proton Linac delivering a 4-5 GeV beam. The SPL could initially be configured for "low power" and serve as injector for a new 50 GeV Synchrotron (PS2) and later be configured for high power and serve as a multi-megawatt proton facility for future physics needs, e.g. a neutrino factory. The LP-SPL (and PS2) would complete the re-juvenation of the CERN LHC injectors while leaving 50% of the pulses available for nuclear physics experiments, e.g. an upgraded ISOLDE. Linac4 can work as front end for the LP-SPL without major modification, whereas for the SPL a new source and new electronics and power supplies should be procured. The shielding, the alignment and the correction system of Linac4 is designed to work at the highest possible beam duty cycle, 6%.

The goal of the SPL activities is to complete a Technical Design Report by the year 2011 when a decision on the construction of the SPL and PS2 could be taken. Should this decision be positive a LP-SPL could be available in 2017.

The main parameters of LP-SPL and SPL are listed in Table 2.

Table 2: SPL Parameters

	LP-SPL	**SPL**
Energy [GeV]	4	5
Beam power [MW]	0.192	>4.0
Repetition rate [Hz]	2	50
Average pulse current [mA]	20	40
Source current [mA]	40	80
Chopping ratio [%]	62	62
Beam pulse length [ms]	1.2	0.4-1.2
Beam duty cycle [%]	0.24	2.0- 6.0
Number of klystrons (704 MHz, 5 MW)	24	53
Geometric cavity beta	0.65/1.0	0.65/1.0
Number of cavities	42/160	42/200
Cavities/klystron	8 - 16	4-8
Cavities/cryostat	6/8	6/8
Length including Linac4 [m]	459	534

Nominal Layout

The layout of the SPL is based on 704 MHz 5-cell elliptical cavities. Two building blocks are used in the layout: a low-beta module (beta=0.65, Eacc=19MV/m) and a high-beta module (beta=0.92, Eacc=25 MV/m), see Fig. 4 and 5. A low beta module contains 6 cavities and two quadrupole doublets (2 periods), a high beta module contains 8 cavities and one doublet. Seven low beta modules are used to bring the energy from 160 MeV to 589 MeV and 20/25 high beta modules bring the energy to 4/5 GeV. Special attention has been paid in the beam dynamics design to achieve a proper matching between the two sections.

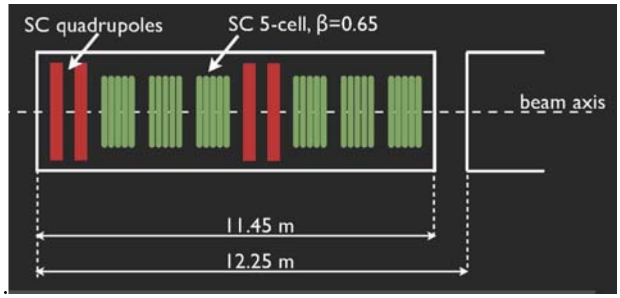

Figure 4: Low beta module.

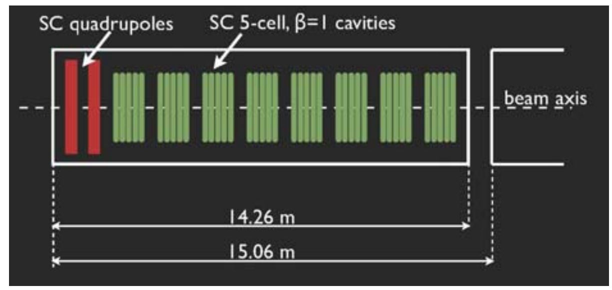

Figure 5: High beta module.

Research Activities

Several themes have been identified for the R&D necessary to complete a Technical Design Report for the SPL. The main activities are listed in the following:

- Tests of surface treatment techniques on a 704 MHz, low beta single cell cavity from CEA are expected for 2009. The goal of this test is to verify the efficiency of electro-polishing low beta cavities.
- Prototypes of β=0.65 and β=0.92 5-cell cavities are to be developed with the aim to demonstrate the gradients of 19 MV/m and 25 MV/m, which have so far been assumed in the beam dynamics design.
- The design of a cryostat adapted to house 704 MHz cavities.
- Ideally, equip a cryostat with 8 cavities 5-cell Beta=0.92 and perform for high power RF tests.
- Development of a plasma generator for the 2 MHz RF source as a part of the European FP7 activities.
- Development of a low level RF system.

ACTIVITIES WITHIN HIPPI

HIPPI (High Intensity Pulsed Proton Injector) is a Joint Research Activity in the framework of CARE [18] (Coordinated Accelerator Research in Europe), within the 6th European Framework Program (2004-2008). Ten European laboratories participate in HIPPI and the projects supported within HIPPI are Linac4, FAIR and the ISIS upgrade.

The scientific work in HIPPI is organized in 4 work packages addressing the issues of normal conducting structure (WP2), superconducting structures (WP3), chopping (WP4) and beam dynamics (WP5).

A lot of the prototyping work for Linac4 was fostered by HIPPI. In particular in the work package normal conducting structure activities on CCDTL prototyping were very instrumental to the choice of an optimised design for the structure [19].

The original design of Linac4 considered a 704 MHz Side Coupled Linac Structure for the energy 90-160 MeV. Prototyping work and studies were carried out on this structure which wasn't eventually retained [20].

Part of the work in WP3, the study of superconducting spoke cavities [21], was the basis for the study of an alternative Superconducting layout for the high energy part of Linac4. This solution was also discarded with the reason that a short superconducting section added unnecessary complexity for Linac4 itself, but it allowed to explore all possibilities.

For the chopper prototyping, the work within HIPPI was fundamental for the developing of a meander structure adapted to 3 MeV and its integration in the 3 MeV beam line. The prototyping activity was fully covered by HIPPI [22]. The system is ready to be tested at the 3 MeV test-stand.

The work within WP5 included beam dynamics and instrumentation. The development of a time resolved device [23] able to access the efficiency of the chopper is instrumental to the measurement program of the 3 MeV test stand.

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