THE LINAC4 PROJECT: OVERVIEW AND STATUS

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Abstract

Linac4 is the new 160 MeV, 40 mA H^- accelerator which will be the source of particles for all proton accelerators at CERN from 2013. Its construction has started in 2008, as part of a programme for the progressive replacement or upgrade of the LHC injectors during the next decade. Linac4 will initially inject into the PS Booster and at a later stage into a 4 GeV Superconducting Proton Linac (SPL), which could ultimately be upgraded to high duty cycle operation. For this reason accelerating structures, RF infrastructure and shielding of Linac4 are dimensioned for higher duty cycle from the initial phase.

Linac4 is normal-conducting, 80 m long and consists of an RF volume ion source, an RFQ, a beam chopping section and a cascade of three different types of 352 MHz accelerating structures. Its main design requirements are high reliability, high beam brightness and low beam loss. The accelerator will be housed in an underground tunnel on the CERN Meyrin site, which can eventually be extended to the SPL, with equipment installed in a surface building above.

The main parameters, the status of the main components, the planning, the project organisation and the civil engineering infrastructure are presented.

LINAC4 AND THE CERN INJECTOR UPGRADE

The present sequence of accelerators used as LHC injectors starts with a proton linac of a relatively low energy (Linac2, 50 MeV, commissioned in 1978), which is followed by the 1.4 GeV PS Booster (PSB, 1972), by the 26 GeV Proton Synchrotron (PS, 1959) and finally by the 450 GeV Super Proton Synchrotron (SPS, 1976). The performance of this cascade of accelerators in terms of beam brightness for the LHC is limited by several factors, the first bottleneck being the limited intensity that can be accumulated at injection into the PSB because of space charge induced tune shift at 50 MeV energy.

An upgrade of the linac energy is therefore the logical start for any programme aimed at increasing the LHC luminosity beyond what is provided by the present injectors. This in turn means replacing Linac2 with a new linear accelerator, because no space is available at the end of the Linac2 tunnel for a significant increase of the beam energy. For a further luminosity increase, PSB and PS need to be as well replaced by new machines with higher final energies, a programme at much larger scale that can be realised in a second phase after the construction of the new linac injecting into the PSB.

A two-phase programme for the progressive replacement and upgrade of the LHC injectors has been recently defined at CERN [1], having as motivations not only a progressive upgrade in LHC luminosity but also the replacement of the aging injectors with modern machines with simplified operation and maintenance and reduced radiation concerns. One of the main elements in the new injection chain would be the Superconducting Proton Linac (SPL, [2]), which in its low-power version (2 Hz maximum repetition frequency) would replace the PSB and inject a beam at 4 GeV energy into a new Proton Synchrotron, the PS2 of 50 GeV energy. The linear accelerator replacing Linac2, which is called Linac4 because it is the fourth linear accelerator to be built at CERN (Linac3 is the heavy ion linac), could then be the injector to the SPL, provided that the SPL is built in a straight line following Linac4 [3]. Figure 1 shows the scheme of the present (top) and future (bottom) LHC injection chains. Phase 1, to be completed in 2013, foresees the construction of Linac4 and its use as injector for the PSB. In phase 2 (around 2018), SPL and PS2 would replace PSB and PS.

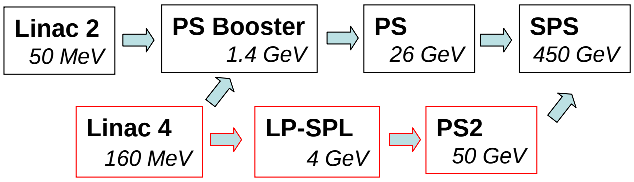

Figure 1: Scheme of the old and new LHC injectors.

The final energy of Linac4, 160 MeV, is defined by the requirement to allow making the nominal LHC beam in a single PSB batch instead of the present double batch, which requires doubling the bunch population in the PSB within constant normalised transverse emittances. The incoherent transverse tune shift at PSB injection being inversely proportional to $\beta\gamma^2$, keeping the present tune shift while doubling the brightness is possible by increasing $\beta\gamma^2$ at injection by a factor 2, corresponding to an increase in injection energy from 50 to 160 MeV. Going back to double batch injection should allow reaching and possibly increasing the ultimate LHC luminosity. Moreover, the new linac will accelerate ions instead of protons, as is done in the large majority of accelerator laboratories, and the flexibility allowed by using charge-exchange H^- injection for painting in the PSB acceptance should allow preserving the higher brightness during the acceleration process. The energy of 160 MeV falls well into the optimum range for transition from normal-conducting to superconducting structures in a modern linac, suggesting that Linac4 can be normal-conducting, whereas the SPL can be entirely made of superconducting accelerating sections.

A particular feature of Linac4 and SPL is that they are designed to operate at the higher repetition frequency of 50 Hz if required by the CERN physics programme, acting as proton drivers for the production of large fluxes of secondary particles, such as neutrinos or radioactive ions. The upgrade to high duty cycle would however require some modifications of the machine and the installation of new power supplies and of a new large infrastructure for providing and removing large amounts of power.

Figure 2 shows the layout foreseen for Linac4 and SPL on the CERN Meyrin site. Linac4 will be built at the place of the so-called "Mount Citron", an artificial hill made with the excavation material from the PS, between the PS complex and the IT buildings. This site provides at the same time an easy access, a natural earth shielding, an easy connection to the existing Linac2-PSB transfer line, and finally a straightforward extension to an underground tunnel housing the SPL.

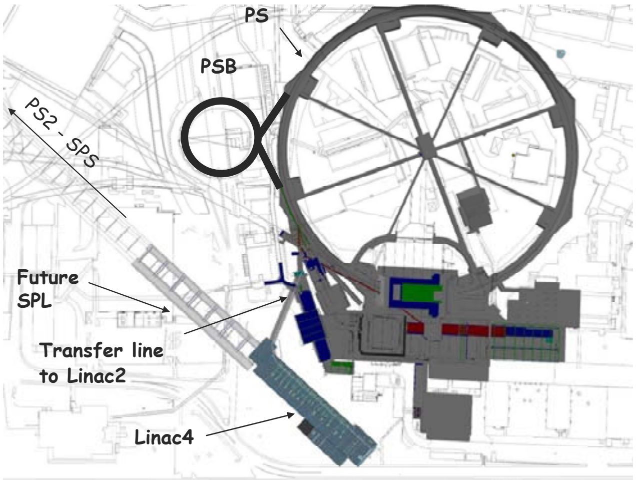

Figure 2: View of the PS Complex at CERN, showing the position of the new Linac4.

Linac4 will be housed in a 12 m deep underground tunnel, connected to the Linac2-PSB line. A surface equipment building will house klystrons and linac equipment. Figure 3 presents the layout of the foreseen Linac4 infrastructure.

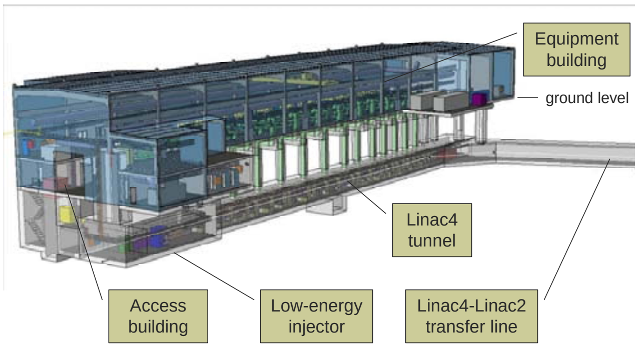

Figure 3: The Linac4 installations.

In June 2007, the CERN Council has approved the construction of Linac4 in the period 2008-2013. The civil engineering works have started in October 2008 with the removal of 40’000 m^3 of earth from the site. The complete building should be delivered at the end of 2010.

LINAC4 DESIGN

The design of Linac4 is dictated by the requirement to operate in three different modes during its lifetime, depending on the characteristics (repetition frequency, pulse current and pulse duration) of the machine that it has to supply with beam:

1. PSB injector, 2013-2018: 1.1 Hz, 40 mA, 400 µs.
2. LP-SPL injector, from 2018: 2 Hz, 20 mA, 1.2 ms.
3. HP-SPL injector, > 2020: 50 Hz, 40 mA, 0.4-1.2 ms.

After a first phase as PSB injector the Linac4 beam pulse length will increase to 1.2 ms, whereas its current will go down by a factor 2. At a later stage, if the high-power programme is approved, Linac4 would operate at 50 Hz with a beam current going up again to 40 mA. Whereas a current of 40 mA is considered at the limit of what can be provided by modern H^- sources, the reduction to 20 mA and the corresponding increase of the pulse length during operation for the low-power SPL is required by the need to minimise the number of klystrons installed in the SPL.

Considering from the beginning the three possible modes of operation, the main consequence on the Linac4 design is that civil engineering and in particular radiation shielding have to be dimensioned for high-power operation, no upgrade being possible at a later stage. Accelerating structures and klystrons will be specified as well for high duty operation, the difference in cost being minor, whereas power supplies, electronics and all electrical and cooling infrastructures will be dimensioned only for low beam power operation and will be replaced or upgraded when required by the SPL at high beam power. Additional space has been foreseen in the surface building for larger power supplies and for the additional SPL equipment.

In the design of machine and infrastructure particular care has been given to solutions providing the high reliability required for the first accelerator in the injection chain. Fault rate should be comparable to that of Linac2, ~1.5% of scheduled beam time. Special attention has been given to the control of transverse and longitudinal emittance growth, for clean PSB and SPL injection, and of losses along the machine, to limit activation for the full-SPL mode of operation [4]. The main Linac4 design parameters are reported in Table 1.

Table 1: Main Linac4 design parameters

Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Max. Rep. Rate	2	Hz
Max. Beam Pulse Length	1.2	ms
Max. Beam Duty Cycle	0.24	%
Chopper Beam-on Factor	65	%
Linac pulse current	40	mA
N. of particles per pulse	1.0	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad

Three different accelerating structures will be used in Linac4 after the RFQ, all at 352 MHz frequency [5]. In particular, the Side Coupled Linac (SCL) at 704 MHz foreseen in previous designs has been replaced with a Pi-Mode Structure (PIMS) operating at the basic linac frequency [6]. The Linac4 scheme with the transition energies is reported in Fig. 4.

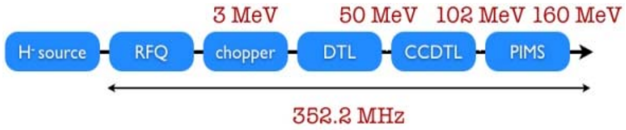

Figure 4: Linac4 layout.

After the 3 MeV Radio Frequency Quadrupole (RFQ) [7], a chopping line can remove selected bunches from the linac pulse, in order to reduce beam loss at capture into the PSB.

The first accelerating structure after the RFQ is a Drift Tube Linac, a standard linac accelerating structure, nonetheless presenting several new features developed for Linac4 [8]. In particular, the drift tube positions will not be adjustable, and precise machining will allow reaching the required tolerances in the position of the drift tubes. As in other modern DTL, focusing will be provided by an array of Permanent Magnet Quadrupoles placed inside the drift tubes. A prototype DTL (Fig. 5) has been recently built by a CERN-INFN collaboration and has allowed validating the drift tube positioning and alignment approach.

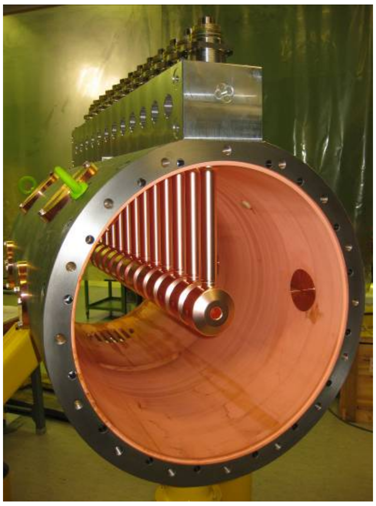

Figure 5: DTL prototype

After the DTL, a Cell-Coupled Drift Tube Linac (CCDTL) will accelerate the beam from 50 to 100 MeV. This new type of structure is a DTL made of short 3-gap tanks connected by coupling cells. The quadrupoles are electromagnetic, and placed outside of the drift tube, between the tanks. In this structure the drift tube alignment tolerances are considerably relaxed, and the quadrupoles are easily accessible for maintenance.

The third accelerating structure, the Pi-Mode Structure (PIMS) brings the beam to the final energy of 160 MeV. The PIMS resonators are made of 7 coupled cells operating in pi-mode, with fields of opposite sign at any moment in two adjacent cells. This structure allows keeping a good accelerating efficiency at high energy with a relatively low number of cells.

Some 352 MHz klystrons and other equipment from the old LEP accelerator will be re-used for Linac4. In the first stage (Fig. 6, top), 13 old LEP klystrons at 1.3 MW and 6 new pulsed klystrons at 2.6 MW will feed the accelerating structures. Most of the LEP klystrons will be connected in pairs to a single modulator, allowing for the progressive replacement of pairs of LEP klystrons with one klystron of the new type. In the final configuration (Fig. 6, bottom) 9 new klystrons will feed two RF cavities each.

LINAC4 STATUS

The pre-integration of machine components required for the definition of the building has started in May 2007 and has allowed tendering of the civil engineering works in April 2008. Construction work has started in October 2008; building and tunnel should be delivered end of 2010. In parallel, safety requirements have been addressed, and a preliminary Safety File has been submitted in June 2008 to the CERN Safety Authorities.

Construction of the ion source and of the RFQ [7] is progressing. The chopper line has been built in the frame of the European Joint Research Activity HIPPI and is presently completely assembled and under vacuum in the Linac4 Test Stand (Fig. 7). The RF volume ion source should deliver its first beam at the beginning of 2009, and after a testing period will be progressively installed in the Test Stand the Low Energy Beam Transport and in 2010 the RFQ. Commissioning of the RFQ is foreseen in 2010, followed by beam commissioning of the chopper line.

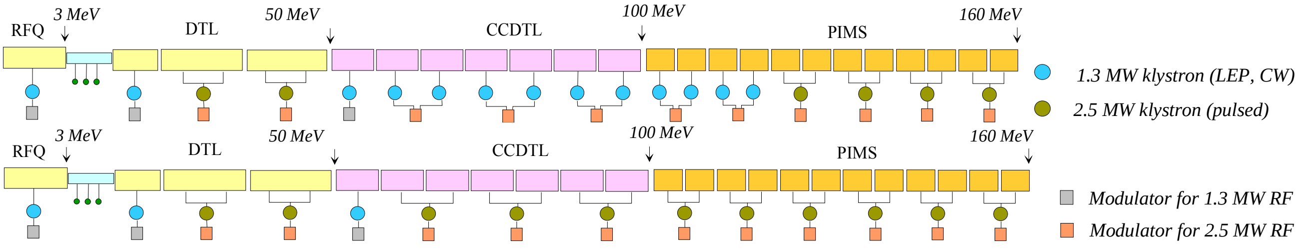

Figure 6: RF power distribution at installation (top) and after the end of the stock of LEP klystrons (bottom).

Figure 7: The Test Stand with klystron and modulator (right), ion source cage (top), chopper line (left).

The prototype modulator and a LEP klystron operating in pulsed mode have been already successfully tested in the Test Stand.

The mechanical design of the Drift Tube Linac (DTL) is now completed. High-power RF tests of the prototype are foreseen for the beginning of 2009 and construction of the first tank will start immediately afterwards. Two prototypes of the first Cell-Coupled DTL (CCDTL) module have been successfully tested at high power and the construction of the complete CCDTL will be carried on by a collaboration with two Russian Institutes jointly funded by the International Science and Technology Centre (ISTC) and by CERN [9]. The design of the PIMS structure has been completed, and construction of a full prototype of the first module is presently starting in the CERN Workshops [6]. The 70 m long transfer line connecting to the Linac2 line is in the detailed design phase. Procurement of RF and other equipment is starting.

PROJECT SCHEDULE

The planning of the project (Fig. 8) is mainly based on the schedule of the civil engineering works. After delivery of the building at end 2010, parallel installation of infrastructure and machine components will take place in 2011.

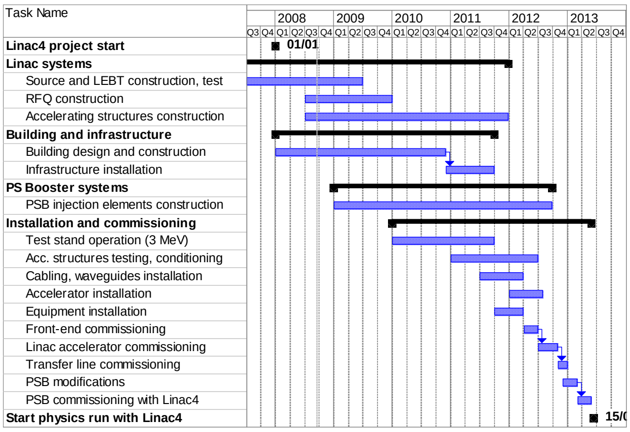

Figure 7: Linac4 Masterplan.

In 2012 the different linac sections will be progressively commissioned. The connection of the transfer line and the modifications to the PSB for H^- injection will take place during a long shut-down foreseen for 2012/13. A total of 7 months will be required for cooling down of the PSB injection region, for the modifications to the PSB and for its commissioning with the Linac4 beam. It is presently foreseen that Linac4 will provide particles to all CERN users from June 2013.

ACKNOWLEDGEMENTS

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