STATUS OF LINAC4 CONSTRUCTION AT CERN

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Abstract

Linac4 is a 160 MeV normal-conducting H^- linear accelerator which is being built at CERN in the frame of a program for increasing the luminosity of the LHC. The project started in 2008 and delivery of beam to the CERN accelerator chain is foreseen from early 2015. The new linac will be housed in an underground tunnel close to the present Linac2; a surface building will house RF and other infrastructure.

The civil engineering work started in October 2008 will be soon completed. Installation of the infrastructure will take place in 2011, and from 2012 will be installed the main machine elements. The ion source is presently operational on a test stand, where it will be followed in 2011 by a 3 MeV RFQ under construction in the CERN workshops. Prototypes of the three different types of accelerating structures have been tested; construction of the 22 accelerating cavities has started, supported by a network of agreements with external laboratories and institutions.

Commissioning will take place in stages, starting from January 2013. Starting in March 2014 is foreseen a six-month reliability run, in preparation for Linac4 role as the new source of particles for the CERN complex.

HISTORY AND MOTIVATIONS

The present sequence of accelerators used as LHC injectors at CERN 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), by the 26 GeV Proton Synchrotron (PS) and finally by the 450 GeV Super Proton Synchrotron (SPS). The main challenge for using this old chain of accelerators as LHC injectors consists in creating high brightness beams, i.e. in accumulating the highest possible beam current within the small transverse emittances specified for the LHC, 2.5 μm in the PSB and 3 μm in the PS (1σ rms, normalised).

A programme for an upgrade of the injectors aiming at maximum brightness was therefore started in 1993 and completed in 2000, well before the LHC commissioning [1]. However, the task appeared more challenging than expected, and while it was possible to achieve and slightly exceed the intensity of 1.1×10^{11} protons per bunch (ppb) out of SPS required for the LHC nominal luminosity of 10^{34} $cm^{-2}s^{-1}$, the intensity required for the so-called "ultimate" luminosity (1.7×10^{11} ppb, corresponding to 2.5×10^{34} $cm^{-2}s^{-1}$), was out of reach because of the inherent limitations of the injector chain [2]. An analysis of the different options to further increase the brightness out of the injectors indicated that the first ingredient of every solution was a linac of higher energy, the first bottleneck for higher brightness being the limitation to the intensity at injection into the PSB due to space charge induced tune shift at 50 MeV [3].

The PS is the second important intensity bottleneck; for this reason, the first proposals were aimed at constructing a 2 GeV Superconducting Proton Linac (SPL) injecting into the PS at higher energy [4]. Additional motivations for the SPL were, the opportunity to re-use part of the 352 MHz RF hardware recuperated from the decommissioned LEP machine, and the synergy with physics programs alternative to high-energy that were gaining importance, like neutrino and radioactive ions.

However, it turned out that a less ambitious programme with sufficient interest for the LHC consisted in building in a first stage the normal-conducting section of the SPL using it as injector for the PSB at a significantly higher energy, thus eliminating the first intensity bottleneck. The limitations at PS injection could have been tackled in a second stage, extending the new linac to the full SPL. Hence, the 160 MeV Linac4 was proposed as new injector for the PSB. The linac energy was chosen with the goal of increasing the intensity in the PSB by a factor of 2 with respect to the present operation. Space charge induced tune shift scaling as $1/\beta\gamma^2$, the same tune shift as now could be expected with twice the intensity if $\beta\gamma^2$ at injection was increased by a factor of 2, corresponding to an energy increase from 50 to 160 MeV [5].

An R&D programme aimed at Linac4 was therefore started in 2004, partially integrated in the EU CARE Initiative, allowing a finalisation of the design [6]. Construction of the new linac was approved by the CERN Council in June 2007 and the project officially started in January 2008. While the initial proposal considered installing the linac in an existing hall, the constraints on linac design, radiation protection, integration with other machines and the commissioning schedule had led in 2007 to the decision to house Linac4 in a new dedicated building, to be constructed in a location parallel to the present position of Linac2 (Fig. 1).

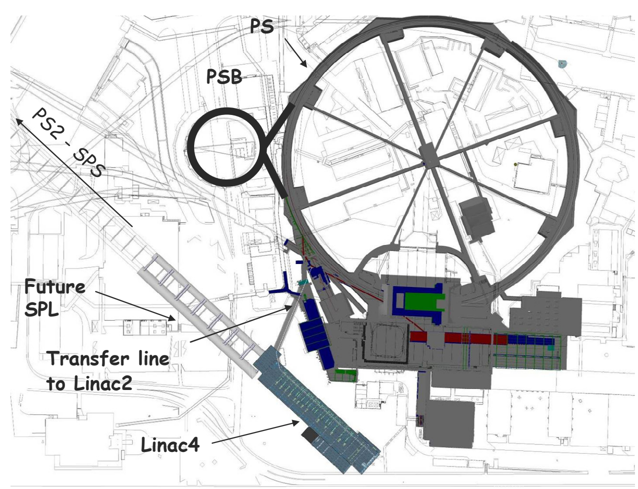

Figure 1: Linac4 location with respect to the LHC injectors

Although driven by the requirement to upgrade the LHC luminosity, the replacement of Linac2 by Linac4 has been as well motivated by the worries on the future reliability of Linac2, which has recurrent vacuum problems due to the peculiar old-fashioned construction of the accelerating tanks, and which is relying on RF tubes of obsolete design due to go out of production. Moreover, a new linac applying modern technologies like chopping at low energy and H^- charge exchange injection should allow reduced beam loss and activation in the PSB, and the higher PSB intensity made possible by Linac4 can be exploited by non-LHC physics users.

More recently, a further revision of the Linac4 goals and parameters has been driven by a redefinition of the CERN medium-term programs following the delay in the LHC start-up and ramping up in energy after the 2008 accident. The initial plans assumed that Linac4 would have been followed by a low duty cycle version of the SPL injecting into a new PS (PS2), aiming for a major improvement in the LHC luminosity [7]. However, the need to keep the present injectors running during a much longer period together with the expected problems in reaching high intensities in the SPS and in the LHC itself suggested to aim for a less ambitious program achievable in the short-medium term [8]. In the present plans, Linac4 will remain as injector to the PSB, which will no longer be replaced by the SPL. The higher intensity made possible in the PSB by the new linac will be transferred to the PS thanks to an increase in the PSB extraction energy from 1.4 to 2 GeV. Moreover, some upgrades to the SPS should allow transporting the higher intensity to the LHC. Linac4 together with these upgrades is expected to increase the intensity to the SPS by a factor 1.8 and correspondingly the LHC luminosity by a factor 3, assuming that the full intensity can be transported through the SPS. This upgrade program should proceed in parallel with a consolidation of the injectors, aiming at keeping their present availability through the lifetime of the LHC.

The SPL study is presently focused towards a possible future high-power facility for neutrinos or radioactive ion beams; Linac4 is designed to be compatible with high-duty cycle operation for the SPL and is oriented in a direction from which it can be extended to the SPL.

DESIGN AND MAIN PARAMETERS

The main Linac4 parameters are reported in Table 1.

Table 1: Main Linac4 design parameters

Output Energy	160	MeV
Bunch Frequency	352.2	MHz
Repetition Frequency	1.1 (max. 2)	Hz
Beam Pulse Length	0.4 (max. 1.2)	ms
Beam Duty Cycle	0.08	%
Chopper Beam-on Rate	62	%
Linac pulse current	40	mA
N. of particles per pulse	1.0	$\times 10^{14}$
Transverse emittance	0.4	π mm mrad
Maximum RF duty cycle	10	%

The Linac4 energy and repetition rate are defined by the PSB, whereas the operating frequency corresponds to that of the old LEP accelerator. The number of particles per pulse and the corresponding pulse length has been defined in order to provide the beam requested by the most demanding users with some operational margin. Chopping at low energy will shape the linac beam pulse at the RF frequency of the PSB (1 MHz).

The basic Linac4 layout is presented in Fig. 2, and an overall view of the machine is shown in Fig. 3. After the ion source, the RFQ and the chopper line, the main accelerator is made of a sequence of accelerating tanks of three different types. Three Drift Tube Linac (DTL) tanks going up to 50 MeV are followed by a sequence of 7 Cell-Coupled Drift Tube Linac (CCDTL) modules to 100 MeV. The last section is made of 12 tanks of the so-called Pi-Mode Structure (PIMS). All accelerating structures are normal conducting, the overall cost for superconducting acceleration being much higher than for normal conducting in this range of energies and at this duty cycle. The structures are all at the same frequency in order to standardise the RF system, reducing cost and simplifying maintenance. All accelerating structures are designed for a possible future use at 10% duty cycle.

A bending magnet at the end of the linac can send the beam to a transfer line connected to the PSB. A beam dump and some diagnostics are placed in the straight line after the bending. The dump is movable, and could be placed in a parking position in case Linac4 will be extended to the SPL.

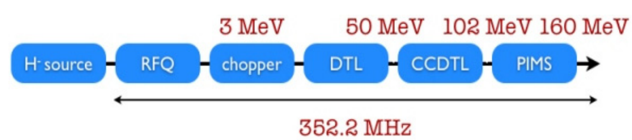

Figure 2: Linac4 layout.

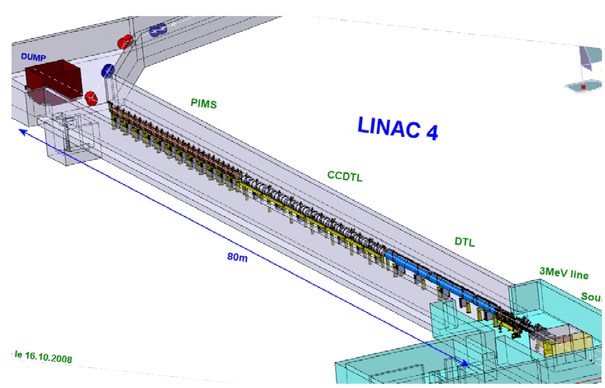

Figure 3: Linac4 in its tunnel.

LAYOUT AND CIVIL ENGINEERING

Linac4 is being built on the CERN Meyrin site (Fig. 1), at the location of an artificial hill made with the excavation spoil from the old PS. This site provides at the same time an easy access, a natural earth shield, an easy connection to the existing Linac2-PSB transfer line, and finally a straightforward extension to an underground tunnel housing the SPL.

The linac will be housed in a 101 m long tunnel located about 12 m underground and connected by a 56 m transfer line to the present Linac2-PSB line (Fig. 4). A surface building above the linac tunnel will house klystrons and other equipment. An access building on the low-energy side connects the two levels and provides access to the underground installations.

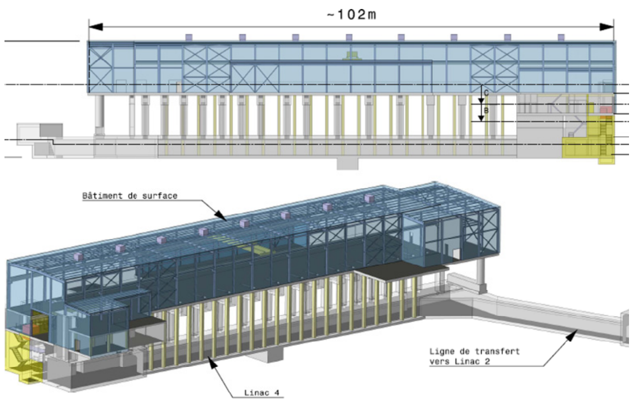

Figure 4: Side and 3D view of tunnel and surface building.

The civil engineering works started in October 2008. The tunnel and the surface hall are presently completed (Fig. 5 and 6), and work is progressing on external and finishing works. The works are on schedule, and delivery is foreseen to take place in October 2010, exactly 2 years after the start.

Figure 5: Linac4 building completed.

Figure 6: Surface equipment hall.

STATUS OF LINAC4 COMPONENTS

The Linac4 H^- source is of the RF volume type, based on the design of the DESY HERA source [9]. This source is preferred for being Caesium free and for its long lifetime thanks to the external antenna. The mechanical design has been revised at CERN and the source has been equipped with a CERN built RF generator delivering 100 kW. The higher power (and longer pulse) achievable with this generator and the higher extraction voltage, 45 kV instead of 35 kV, are expected to provide the factor 2 higher current required for Linac4 with respect to the DESY source. The source has been completely built and assembled, and beam measurements are in progress.

The Low Energy Beam Transport (LEBT) is based on a two-solenoid focusing system. It includes magnetic dipole correctors, beam instrumentation, a pre-chopper deflector and two beam stoppers. The rest gas density in the LEBT can be controlled by a gas injection system, in order to control space charge compensation by rest gas ions. All components of the LEBT have been completed, and will be installed at the end of the source tests.

The Radio Frequency Quadrupole has been designed at CERN, adopting a classic 4-segment brazed copper structure. Thermo mechanical calculations and detailed RF design of the Linac4 RFQ were performed by CEA Saclay in the frame of collaboration with CERN. CEA is also taking care of all RF measurements. The RFQ is 3 m long, the maximum length that was considered as feasible without introducing longitudinal stabilisation circuits. The structure is mechanically divided into 3 modules.

Construction of the RFQ is taking place entirely in the CERN Workshops. The most challenging step in the construction procedure is the brazing in the horizontal position of the four segments, where tight mechanical tolerances have to be respected. A detailed procedure for stress release and preparation for the brazing has been prepared, and the recent brazing of the first module (Figs. 7 and 8) has shown that deformations can be contained within 25 μm, for a given tolerance of 30 μm [10].

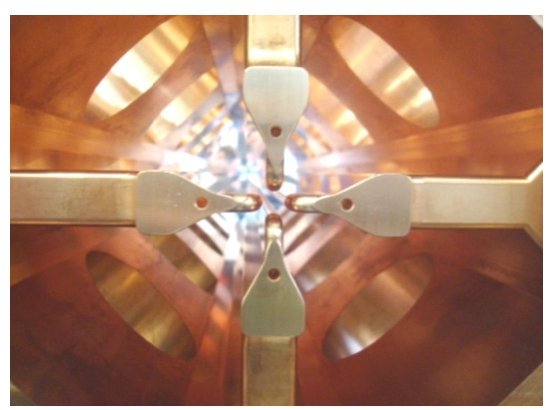

Figure 7: Initial section of the Linac4 RFQ.

After the RFQ a 3.6 m line equipped with two fast choppers and a collimator-dump can remove selected bunches from the linac pulse. The line has already been built and assembled (Fig. 9).

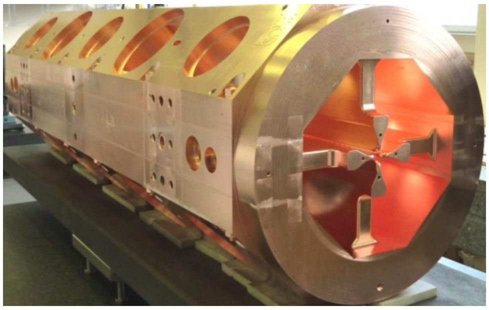

Figure 8: First module of the Linac4 RFQ after brazing.

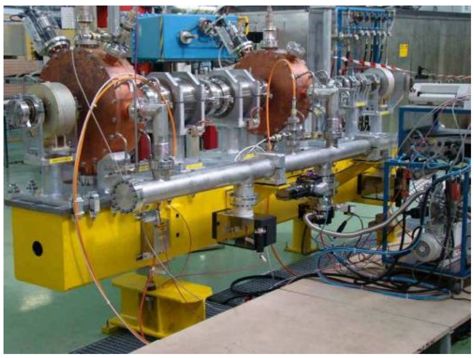

Figure 9: The Linac4 chopper line.

The low-energy part of Linac4, consisting of ion source, LEBT, 3 MeV RFQ and chopper line, is being progressively assembled in a dedicated Test Stand (Fig. 10) equipped with a movable beam diagnostics line. The Test Stand will be used to fully characterise the beam before installation of the 3-MeV section in the Linac4 building. Additionally, the Test Stand is used to test and commission other equipment like klystrons, modulators and low-level electronics.

Figure 10: The Linac4 Test Stand.

The RFQ is followed by a 50 MeV DTL, divided into 3 tanks. The basic DTL design is derived from that of SNS [11], characterised by a rigid cylindrical tank supporting drift tubes equipped with Permanent Magnet Quadrupoles (PMQ) in vacuum. The main modifications concern the tanks, which are in stainless steel to simplify the copper plating process that will take place at CERN, and the supporting mechanism of the drift tubes. The drift tubes are not connected directly to the tank, but rest on an aluminium girder, and contrarily to most DTL designs they are not adjustable after mounting. The required tight tolerances are provided by precision machining of reference surfaces on the stem and the girder (Fig. 11). In particular, this system permits using only metallic vacuum joints, whose correct compression is guaranteed by a particular mechanical arrangement.

A prototype DTL tank of 1.2 m length (Fig. 11) has been built to test the DTL construction technique and the RF properties. It has successfully achieved the required alignment tolerance; the design RF gradient has been reached during high-power tests after a very short conditioning time. Construction of the DTL components is presently starting, with completion of the first tank expected for June 2011 [12].

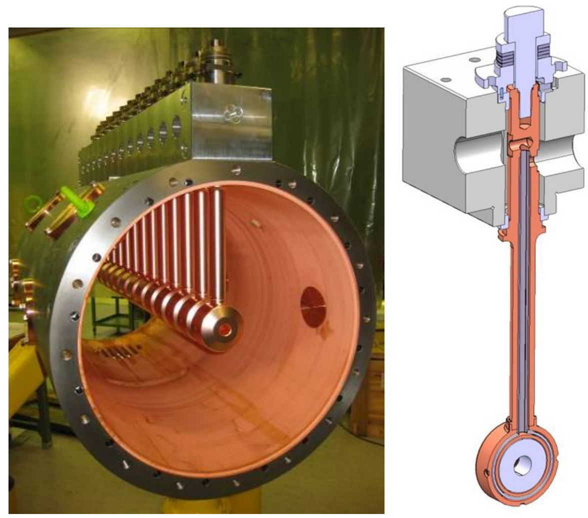

Figure 11: DTL prototype and drift tube assembly.

A Cell-Coupled Drift Tube Linac (CCDTL) will accelerate the beam from 50 to 100 MeV [13]. This new type of structure is a DTL made of short 3-gap tanks connected by coupling cells. Focusing is provided by a combination of PMQs, placed between tanks, and electromagnetic quadrupoles, placed between modules. The CCDTL is presently in construction at the VNIITF, Snezhinsk and BINP Novosibirsk Laboratories in Russia. Completion of the first pre-series module is foreseen for the end of 2010.

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 π-mode. The first PIMS cavity (Fig. 12) has been recently completed at the CERN Workshops. Vacuum and low-power RF tests gave very satisfactory results, and high-power RF tests are expected to follow in October [14]. Construction of the remaining 11 cavities and of the debuncher, which is of a PIMS-like design, will take place in the frame of a collaboration between the Soltan Institute of Warsaw (Poland), that will make the machining and pre-tuning of the cells, the KF Jülich (Germany), that will provide the EB welding of ports, and CERN, that will take care of the final EB welding.

Figure 12: The PIMS cavity vertically assembled at the CERN Workshop.

The specification and procurement of the RF equipment is well advanced. In the initial stage, thirteen 1.3 MW klystrons recuperated from the LEP accelerator will be used to feed the Linac4 accelerating structures, together with 6 new 2.8 MW pulsed klystrons. In a later stage, pairs of LEP klystrons will be progressively replaced by these new and more powerful devices. A large fraction of the high-power RF equipment will also come from the old LEP inventory. A prototype modulator for the LEP klystrons is operating reliably in the Linac4 test stand, whereas a new prototype for the higher power klystrons is being assembled. The layout of a 2.8 MW RF station feeding two cavities is presented in Fig. 13 [15]. The order for the 2.8 MW klystrons has been recently placed, shared between two different suppliers.

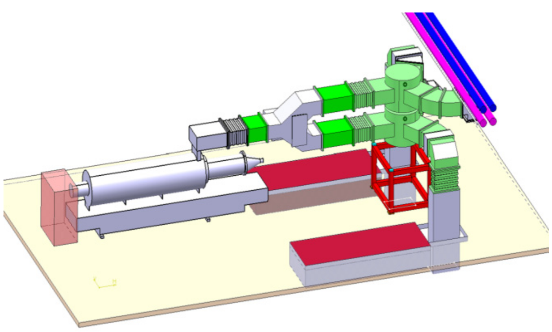

Figure 13: Layout of a 2.8 MW RF station.

The design of the beam diagnostic devices is completed and procurement is in progress. Most of the equipment is derived from existing linac or LHC devices.

PROJECT SCHEDULE

After delivery of the building the installation of electrical, cooling and ventilation infrastructure will be completed by September 2011. Installation of machine equipment will take place between end of 2011 and beginning of 2013. At the end of 2012, the 3 MeV test stand equipment will be transferred into the new building. Beam commissioning at 3 MeV is foreseen to start in March 2013, followed by the progressive commissioning of the different Linac4 sections (DTL, CCDTL, PIMS) during 2013 and the first months of 2014. Dedicated commissioning runs of about one month duration will be interlaced with installation periods, to allow improving the hardware and completing the installation of the next section.

In the present schedule, the commissioning of the linac is followed by a 6 month reliability run in 2014, intended to assess potential reliability problems before connecting Linac4 to the CERN injector chain. From the end of 2014 Linac4 will be ready to be connected to the PSB. A PSB shutdown of 7 month duration will be required for the connection, divided into one month for commissioning of the transfer line, three months to modify the PSB injection region, and finally three months for commissioning the PSB with the Linac4 beam.

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