PROGRESS IN THE CONSTRUCTION OF LINAC4 AT CERN

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Abstract

As first step of the LHC luminosity upgrade program CERN is building a new 160 MeV H^- linear accelerator, Linac4, to replace the ageing 50 MeV Linac2 as injector to the PS Booster (PSB). Linac4 is an 86-m long normal-conducting linac made of a 3 MeV injector followed by 22 accelerating cavities of three different types.

The general service infrastructure has been installed in the new tunnel and surface building and its commissioning is progressing; high power RF equipment is being installed in the hall and installations in the tunnel will start soon. Construction of the accelerator parts is in full swing involving industry, the CERN workshops and a network of international collaborations. The injector section including a newly designed and built H^- source, a 3-m long RFQ and a chopping line is being commissioned in a dedicated test stand. Beam commissioning of the linac will take place in steps of increasing energy between 2013 and 2015. From end of 2014 Linac4 could deliver 50 MeV protons in case of Linac2 failure, while 160 MeV H^- could be injected into the PSB from 2016; connection to the PSB will take place during a long LHC shut-down foreseen to begin end of 2017.

MOTIVATIONS AND PARAMETERS

The peak luminosity of the LHC has been constantly increased during its first years of operation and the nominal value of 10^{34} cm^{-2}s^{-1} is now expected to be reached after the 2013-14 shut-down in parallel with the increase in energy. In this way, the LHC could provide to its experiments about 40 fb^{-1}/year, a value sufficient for Higgs physics but most likely too low for new physics discoveries. Extending the physics reach of the LHC during the next decade is therefore a priority for CERN: specific projects have been launched to overcome the present luminosity limitations, related both to the LHC interaction regions and to its injector chain, with the goal of achieving a levelled luminosity of 5×10^{34} cm^{-2}s^{-1} with integrated luminosities of 250 fb^{-1}/year.

In particular, the LHC Injectors Upgrade (LIU) project aims at increasing the beam brightness from the injectors, limited now by several factors of which the most severe are related to space charge tune shift at the injection into the low-energy synchrotrons in the chain, the PS Booster (PSB) and the Proton Synchrotron (PS) [1]. Increasing their injection energies is thus required to reduce tune shift permitting higher beam brightness; to reach the LIU goals, injection energy from the linac into the PSB has hence to go up from 50 to 160 MeV and from the PSB into the PS from 1.4 to 2 GeV. For the PSB injection, an energy upgrade of the present 50 MeV Linac2 was ruled out because of the lack of space and of its obsolete technology; instead, the construction of the new 160 MeV Linac4 (the 4th hadron linac built at CERN) was approved by the CERN Council in 2007. The new linac will bring other advantages related to injecting into the PSB H^- instead of protons, to a modern construction technology exempt from the reliability concerns of Linac2, and to the possibility of increased beam intensity for non-LHC users [2]. Linac4 is being built in a location parallel to the present Linac2 (Fig. 1); a new surface building houses the RF and all other infrastructure and equipment.

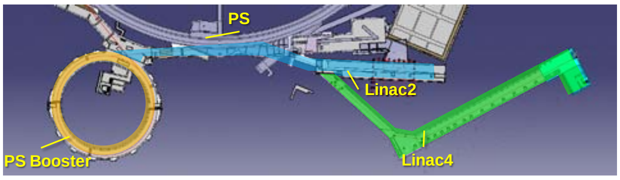

Figure 1: Linac4 and the other low-energy accelerators.

The new linac is dimensioned to double the maximum intensity from the PSB with the same transverse emittances, providing up to 10^{14} protons per pulse; this charge will be supplied by 400 µs long pulses at 40 mA current. The pulse repetition frequency is limited to a maximum of about 1 Hz by the PSB magnetic cycle. In case Linac4 would be used in a future high-intensity facility for neutrino physics, the accelerating structures have been designed for a maximum duty cycle of 10%; nevertheless, infrastructure and power supplies are dimensioned only for the duty cycle corresponding to PSB injection. Chopping of about 35% of the beam at 3 MeV is foreseen to allow low-loss injection in the PSB, bringing the required current out of the ion source to 80 mA. A schematic layout of Linac4 is presented in Fig. 2: the 3 MeV Front end (source, LEBT, RFQ and chopper line) is followed by three normal-conducting accelerating structures all at 352 MHz, for a total length of 76 m. Adopting three different accelerating sections allows maximising the RF efficiency reducing at the same time the construction costs; using the same RF frequency as in the old LEP machine allowed to recover an important stock of klystrons, circulators and waveguides. A 70-m long transfer line connects to the existing Linac2 line.

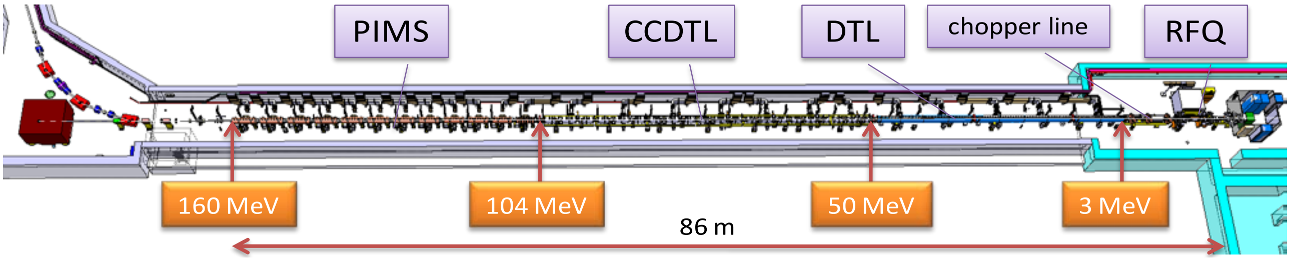

Figure 2: Linac4 layout.

THE 3 MEV FRONT END

The section up to 3 MeV is being installed and commissioned in a dedicated test stand, and will be transferred in 2013 to its location in the Linac4 tunnel. After an initial unsuccessful operation of the original RF volume source at 45 kV extraction voltage due to the high power of the co-extracted electron beam, tests have continued with protons and in parallel the design and construction of two new H^- sources has started [3]. The first source, based again on volume production but with improved beam extraction and electron dumping and a pulsed extraction voltage, is presently being tested and will feed the RFQ on the test stand. The second source foresees the addition of Caesium to enhance H^- current via surface production; it will be completed and installed in 2014 for the linac commissioning. A magnetron source is also being investigated for a possible future upgrade.

The 3-m long RFQ of the brazed-copper 4-vane type has been entirely built in the CERN Workshop [4]. A sequence of machining steps and thermal treatments allowed keeping vane position errors after brazing within the 30 μm tolerance, resulting in field errors within ±1% after adjustment of the slug tuners. Figure 3 shows the RFQ recently installed in the test stand. Vacuum and cooling tests have been completed; RF conditioning followed by beam tests will take place in the next months.

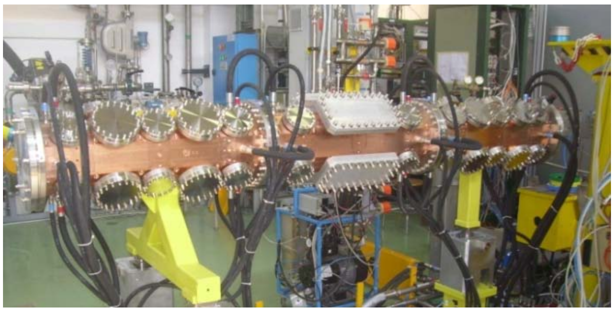

Figure 3: The Linac4 RFQ in the 3 MeV test stand.

The 3.6 m long chopper line connecting the RFQ to the DTL is completed and ready for beam tests. It contains a fast chopper made of two 40-cm long meander-line electrostatic deflectors, together with rebunching cavities, quadrupoles, diagnostics and the chopper dump.

ACCELERATING SECTION

The 50 MeV Drift Tube Linac (DTL) is divided in three tanks, with focusing provided by 113 Permanent Magnet Quadrupoles (PMQ) placed in vacuum inside the drift tubes and end walls. The innovative design which allows precise positioning of the drift tubes inside the tank, without the need for flexible connections, has been tested on a 1.2 m long prototype conditioned up to full RF power; construction of the three tanks is progressing at CERN with contributions from ESS-Bilbao (Spain). Figure 4 shows the assembly of the first DTL tank.

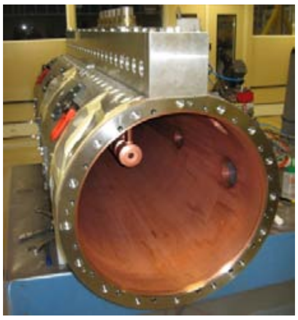

Figure 4: Assembly of DTL Tank1.

The 102 MeV Cell-Coupled DTL (CCDTL) is composed of 7 modules; a module contains 3 tanks with two drift tubes each, connected by coupling cells. Focusing is external to the drift tube structure, provided by a combination of PMQs (between tanks) and electromagnetic quadrupoles (between modules). After the successful high-power test of a prototype, the modules are being built by a collaboration of Russian laboratories (VNIITF Snezinsk and BINP Novosibirsk); delivery of the completed modules (Fig. 5) to CERN just started.

Figure 5: CCDTL module 2 during tests at Novosibirsk.

The PIMS (Pi-Mode Structure) section is composed of 12 EB-welded 7-cell copper cavities operating in pi-mode. The first cavity has been built at CERN and tested to full RF power; construction of the others has started at NCBJ Swierk (Poland), with part of the assembly being done at CERN and at FZ Jülich (Germany).

CONSTRUCTION PROGRESS

Installation of the machine infrastructure has been progressing since delivery of the Linac4 building and tunnel by the civil engineering company at end 2010; this includes electrical network, safety and communication equipment, cooling and ventilation, installation of racks and laying of all the cables. All equipment has been preliminarily integrated into an extensive 3-D computer model which allowed an early solution of interference problems. The infrastructure installation will be completed in September 2012, to leave place to the installation of machine components.

The complex RF network (Fig. 6) has been installed in the hall and tunnel as well as in the 15 shafts connecting the two levels. Its peculiarity comes from the fact that Linac4 will initially use a combination of thirteen 1.3-MW-klystrons from the old LEP feeding one cavity each and six new 2.8-MW-klystrons feeding two cavities (or two couplers) each. In a following phase, as the stock of LEP klystrons runs out, pairs of LEP klystrons will be replaced by new klystrons equipped with a power splitter, leaving the waveguide network unchanged and progressively extending the number of RF stations feeding two cavities. Prototypes of the newly developed 2.8-MW klystrons have been successfully tested at the factory, while testing and refurbishing of the LEP klystrons is progressing.

Figure 6: RF Network installed in the Linac4 Hall.

The 110 kV long-pulse klystron modulators developed at CERN are now being produced in the frame of a collaboration with the LAL Laboratory (France). A digital Low-Level RF derived from the LHC system and equipped with feed-forward capability is being completed to be used in Linac4. Construction of diagnostics equipment is progressing and most of the devices will be tested in the 3 MeV test stand.

Figure 7 shows the tunnel ready for the installation of the linac components.

Figure 7: Linac4 tunnel (August 2012).

COMMISSIONING PLANS

After completion of the infrastructure installation, the Linac4 tunnel will be used for ion source testing until the transfer of the 3 MeV line (RFQ and chopper line) foreseen for mid-2013. Additional time in 2013 for beam commissioning of the low-energy part has been recently foreseen to reduce use of critical resources (mainly survey and vacuum) during the long LHC shut-down that will take place in 2013/14. From 2014 it is foreseen to restart commissioning at the normal pace, in progressive steps of energy and sending for every step the beam into a dedicated temporary measurement bench. The different commissioning steps are DTL tank1 (January 2014), full DTL (spring 2014), CCDTL (end 2014), PIMS (mid-2015, on the final measurement section). The beam commissioning will be followed by an extensive series of beam measurement to prepare for the injection in the PSB and by a long reliability run in 2016, to assess and improve Linac4 reliability in preparation for the moment when it will become a critical element in the LHC injection chain. The connection of Linac4 to the PSB requires a long shut-down because of the upgrade to H^- of the PSB injection region and will be coupled with the increase in extraction energy to 2 GeV; it will take place at the next long LHC shut-down, indicatively in 2017/18.

Temporary operation with 50 MeV protons of Linac4 is being considered as a back-up solution in case of problems with Linac2 in the period between the two long shut-downs.

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