

## PHIL: A TEST BEAMLINE AT LAL\*

R. Roux, S. Cavalier, M. Bernard, G. Bienvenu, M. Joré, B. Leblond, B. Mercier, B. Mouton,  
C. Prevost, A. Variola

LAL, bâtiment 200, Université Paris-Sud, 91898 Orsay, France.

### Abstract

In the framework of a European contract\*, LAL is in charge of the construction of one photo-injector for the drive beam linac of the CLIC Test Facility 3 [1] at CERN. This contract together with national funds allowed LAL to build a home test accelerator, PHIL, with the same photo-injector as for CTF3. The goal is to undergo experiments on the design and technology of advanced RF guns, to develop diagnostics and feedback techniques, a part of the beam time will be also shared with users of the electron beam. So far, the construction of this accelerator at LAL was very much delayed because of the legal obligation to upgrade the radiation shielding in agreement with the actual radiation safety thresholds. The required civil engineering is now finished and the installation of the components is under way. We will first present a design of the accelerator and few dynamic simulation results. Finally we will give an up to date status of the accelerator construction.

### BEAMLINE

The size of the accelerator PHIL is compact with respect to others large facilities which deal with particle physics or synchrotron radiation. The accelerator is basically dedicated to test photo-injectors or accelerating sections which are designed and built in the laboratory. Few laboratories are equipped with such installations; in Europe one can quote the CERN [2] and PITZ [3]. In addition to accelerator experiments, PHIL will be opened to users needing a low energy electron beam to calibrate detectors for example.

A drawing of the beamline is shown in figure 1.

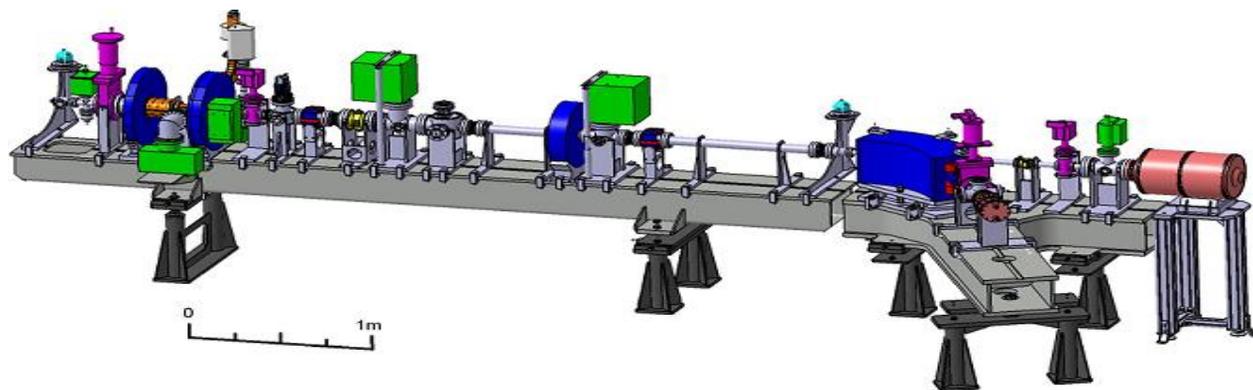


Figure 1: drawing of the PHIL beamline, blue boxes are magnetic elements, orange is the RF gun, green boxes stand for vacuum pumps, charge is measured with Faraday cup after the dipole in the both ways of the beamline.

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The technical specifications are summarized in table 1. The RF frequency is 2.998 GHz and the repetition rate is limited to 10 Hz.

Table 1: Specifications of PHIL

	Phase 0	Phase 1
Energy (MeV)	6	10
Charge (nC)	0.1	3
rms bunch length (ps)	4	4
rms energy spread (%)	0.3	< 2 %
Normalized rms emittance ( $\pi$ mmrad)	$\approx 1$	< 20

The construction of the machine will be carried out in 2 phases. In the phase 0, there will be only a photo-injector with a copper photo-cathode, vacuum chambers with pumps and all the magnetic elements will be installed: 2 coils on the RF gun, 2 steerers to correct the orbit, one coil in the middle of the beamline and a dipole used as a spectrometer to measure the energy of the beam. There will be also 2 collimators before and after the dipole to analyse the energy distribution. The transverse positions of the electron beam are measured with 2 Wall Current Monitors (thanks to its 4 electrodes), one just after the RF gun and the other after the dipole in the straight line. The charge is measured with Faraday cups at both ends of the beamline.

In phase 1, we will install a booster to bring the beam energy up to 10 MeV. A photo-cathode preparation vacuum chamber to prepare to provide in situ cesium and telluride coatings will be connected to the gun.

Photo-cathodes will be inserted in the gun with a translation arm under vacuum. The diagnostics will be implemented: screens to measure the transverse beam distribution; Cerenkov screen to measure the bunch length with a streak camera and a device to measure the emittance consisting in 2 masks with horizontal and vertical slits followed by a screen.

At the beginning of the project, four years ago, the goal was to build the full accelerator as described in phase 1. But a radiation safety study pointed out the obligation to strengthen the shielding. For example we had to reinforce the ceiling with 1.4 m thickness of concrete over the accelerator. The civil engineering required for the upgrade of the shielding induced supplementary and unforeseen expenses and we decided to split this installation plan in 2 phases. Details of the beamline are described in the following chapter.

## COMPONENTS

### Laser

A ND:YLF picosecond mode locked laser, produced by the HighQ company, is used in our experimental system. It delivers one single pulse at 5 Hz repetition rate. But it is possible to increase it up to 100 Hz. It is used on the fourth harmonic, at 262 nm wavelength, generated through LBO crystal for the second harmonic and BBO crystal for the fourth harmonic. The pulse energy at the exit of the laser box is 90  $\mu$ J in UV light. The pulse length duration is 8 ps (FWHM) measured with an ARP single sweep streak camera. One typical measurement is shown in figure 2. The laser pulse to pulse stability is near 1% during roughly 8 hours.

The optical path length between the laser hutch and the photocathode of the gun is about 17 m. It includes several lenses and mirrors. The laser light is injected into the gun at nearly normal incidence to the photocathode plane. Different spot sizes can be obtained by changing the last lens position.

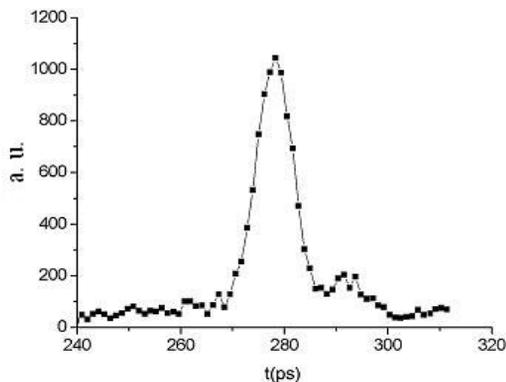


Figure 2: temporal measurement of the laser pulse with a streak camera, resolution of the device is 1.5 ps.

### RF source

The low level RF, pilot and amplifier of few hundred watts and the modulator are a LAL fabrication. The latter produces a high voltage pulse of 20 kV with delay lines

switched by a thyatron. The maximum pulse length is 10  $\mu$ s and the repetition rate is limited by the high voltage supply to 10 Hz. A transformer brings the voltage up to 170 kV which is applied on the cathode of the klystron. The maximum RF peak power is 20 MW and is transported by 3 GHz waveguides under SF6 (with the possibility to be under vacuum) to the RF gun.

### RF gun

The fabrication of the RF gun as the construction of PHIL is funded by the European contract CARE. The gun model called PHIN [4] was machined in two issues, one for the CERN and the other one for PHIL. The photo-injector has 2.6 cells at 3 GHz of resonant frequency. The shunt impedance is 6 M $\Omega$  and the quality factor 14500. Irises were machined with an elliptical shape which reduces the surface electrical field according to the RF simulations. In addition waveguides are symmetrically connected to the last cavity of the gun with respect to the mechanical axis in order to reduce emittance degradation induced by a non isotropic electrical field. A picture of the brazed gun is shown in figure 3. Unfortunately due to the extreme difficulty of the brazing process only one gun was successfully brazed and sent to CERN. So before the delivery of a third issue (foreseen in summer 2009), we will use a photo-injector stored in our laboratory. This one is a copy of the photo-injector built by LAL for the ALPHAX accelerator in the University of Strathclyde in UK [5]. The design of this gun is similar to the PHIN one except that the coupling between the gun and waveguides is done by a co-axial “doorknob” antenna in the cut-off tube after the cells of the gun.

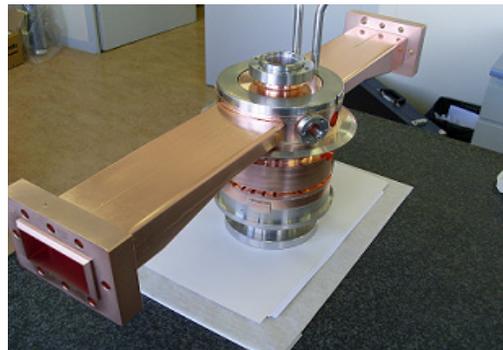


Figure 3: PHIN photo-injector.

### Magnetic elements

There are 2 coils around the gun, a focusing one after the waveguides coupled to the gun and a bucking coil to cancel the magnetic field in the photo-cathode plane. The maximum magnetic field it can produce is 0.33 T. We preferred to install again a solenoid in the middle of the beamline to transport the beam because it is less expensive than a triplet. In addition, at these low energies, a solenoid fulfills the function as well as a triplet. The maximum magnetic field available is 0.5 T and should be sufficient even when the accelerator will be upgraded to 10 MeV. The dipole for the beam energy measurement is retrieved from the old injector of TTF. The deviation

angle is  $60^\circ$  and the curvature radius is 0.7 m. Systematic measurements were done in CERN to exactly map the magnetic field.

## BEAM DYNAMICS

The beam dynamic is performed with the code PARMELA\*. In the code, we used the electrical field extracted from the results of the 2D RF simulations done with SUPERFISH. The magnetic field of the coils designed with POISSON is also carefully reproduced in the PARMELA input file with COIL cards. The simulations have been done for the PHIN gun at 0.1 nC; laser spot size (rms) on photo-cathode is 1.4 mm, the RF peak electrical field is 85 MV/m. Results of the simulations are shown in figure 4.

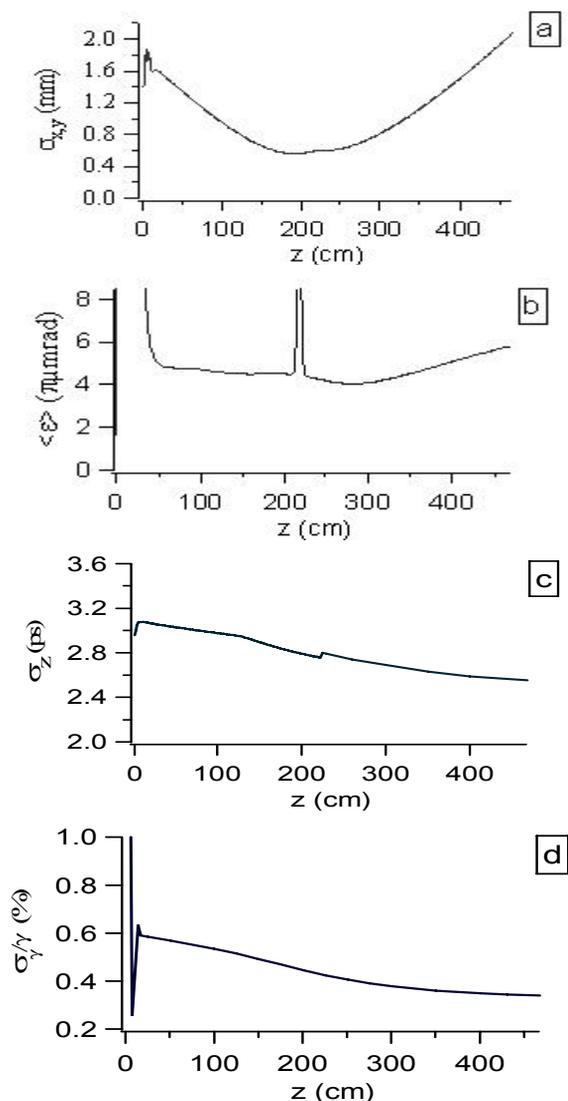


Figure 4: a, transverse size; b, normalized emittance; c, bunch length; d, energy spread as a function of the distance in PHIL. All values are rms. 5000 macro-particles have been used in the simulations.

At this low charge, there is no problem to transport the beam along the accelerator without losses. At the end of the accelerator, the normalized emittance is about  $4 \mu\text{mrad}$ , the bunch length is lower than 3 ps, the beam energy is 6 MeV and the energy spread 0.34 %. Simulations performed at higher charge, above 2 nC, show that it is mandatory to install a booster to bring the beam energy up to 10 MeV otherwise we get losses during the transport and degradation of the beam performances because of the space charge forces.

## STATUS

Civil engineering has been achieved at the end of 2007. Since January 2008 we proceed at the installation of the beamline: ALPHAX RF gun, all magnetic elements have been put on the girder. All the infrastructure, water cooling system, cabling has been completed. The control room is available and the software to drive the accelerator is nearly finished. The main tasks still to perform are the installation of the vacuum chambers on the girder, the completion of RF network and of the laser transport which are already begun and the tests of the modulator. We estimate that the accelerator should be ready to operate in the beginning of July 2008 but before to start the authorization of the radiation safety authorities is required.

## CONCLUSION

The construction of the home accelerator PHIL is almost finished and a first electron beam at 0.1 nC, 6 MeV is expected by the end of 2008. For this achievement we are very grateful to the technical staff of LAL who made big efforts to catch up the delay in the planning.

## REFERENCES

- [1] H. H. Braun *et al*, CERN yellow report, CERN-99-06 (1999).
- [2] R. Bossart, H. Braun, M. Dehler, J.-C. Godot, Nucl. Inst. and Methods, Vol A **375**, ABS7-ABS8, 1996.
- [3] M. Krasilnikov *et al*, Nucl. Inst. and Methods, Vol A **528** (2004), 360-365.
- [4] R. Losito *et al*, "The PHIN photo-injector for the CTF3 drive beam", EPAC'06, Edimburgh, June 2006, WEPLS059, p. 2517 (2006); <http://www.JACoW.org>.
- [5] T. Garvey *et al*, "Construction of the ALPHA-X photo-injector cavity", EPAC'06, Edimburgh, June 2006, TUPCH113, p. 1277 (2006); <http://www.JACoW.org>.

\* PARMELA from Los Alamos National Laboratory, modified by B. Mouton at LAL.