

FIRST RESULTS FROM COMMISSIONING OF THE PHIN PHOTO INJECTOR FOR CTF3

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Abstract

Installation of the new photo-injector for the CTF3 drive beam (PHIN) has been completed on a stand-alone test bench. The photo-injector operates with a 2.5 cell RF gun at 3 GHz, using a Cs₂Te photocathode illuminated by a UV laser beam. The test bench is equipped with transverse beam diagnostic as well as a 90-degree spectrometer. A grid of 100 micrometer wide slits can be inserted for emittance measurements. The laser used to trigger the photo-emission process is a Nd:YLF system consisting of an oscillator and a preamplifier operating at 1.5 GHz and two powerful amplifier stages. The infrared radiation produced is frequency quadrupled in two stages to obtain the UV. A Pockels cell allows adjusting the length of the pulse train between 50 nanoseconds and 50 microseconds. The nominal train length for CTF3 is 1.272 microseconds (1908 bunches). The first electron beam in PHIN was produced in November 2008. In this paper, results concerning the operation of the laser system and measurements performed to characterize the electron beam are presented.

INTRODUCTION

The third CLIC Test Facility (CTF3) will demonstrate the feasibility of the CLIC drive beam generation scheme [1]. In CTF3 the time structure of the beam consists of 1908 bunches with a 1.5 GHz bunch spacing and a charge per bunch of 2.3 nC. This long train is sub divided into eight 140 ns long sub-trains all shifted in phase by 180 deg with respect to each other. After acceleration in the drive beam linac, half of the pulses will be deviated into the Delay Loop by means of a 1.5 GHz rf deflector and, after one turn, will be interleaved with the following non deviated sub trains yielding a train with substructure at 3 GHz. This beam is then sent into a ring called "Combiner Ring" which performs a second frequency multiplication by interleaving four sub trains with a 3 GHz substructure coming from the Delay Loop. The final train will have a substructure at 12 GHz, a current of 28 A and a length of 140 ns.

The photoinjector has been built in collaboration among LAL, RAL and CERN, and funded within the Joint Research Activity "PHIN" of CARE, the EU project for a

Coordinated Accelerator Research in Europe. LAL is responsible for the design and construction of the RF gun, RAL and CERN for the design and construction of the laser and CERN for producing the photo-cathodes, overall coordination and commissioning. Contributions came also from LNF/INFN.

The main photoinjector parameters are:

- Charge of 1.5 GHz electron micro bunch - 2.33 nC;
- Macro bunch length - ~1273 ns;
- current within the macro bunch - 3.5 A;
- Normalized emittance - < 25 π -mm-mrad;
- Cathode quantum efficiency QE - ~3 %;
- UV laser pulses energy - ~370 nJ;
- Charge stability - <0.25 %rms.

PHOTOCATHODE

The Cs₂Te semiconductor has been chosen as photocathode. In fact, after several years of on site studies it has demonstrated to have a reliable life time at the efficiency of 3% with a 262 nm laser beam wavelength to allow the run of the machine for >40h. CERN hosts a photoemission laboratory which has been equipped to produce this type of cathode by the co-evaporation process which yields high cathode performances. The machine is built so that the stoichiometric ratio of the deposited compound (Cs, Te) can be properly monitored during the production as well as the quantum efficiency in order to stop the process when the cathode has reached an optimum performance. The cathode is then installed into the PHIN rf gun trough the cathode loader, see Fig 1, required to maintain a good vacuum level during the installation. Two photo cathodes have been used during commissioning one reached a QE of 3% and the second a QE of 4%.

LASER

A Nd:YLF oscillator* produces pulses at a repetition rate of 1.5 GHz with an average power of ~300 mW, a central wavelength λ ~1047 nm and with a pulse width of τ ~8 ps. These pulses are first amplified by a Nd:YLF "pre-amplifier"[†] to boost the average power up to ~10 W. The pulses delivered by the pre-amplifier have the same

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characteristics ($\tau \sim 8$ ps FWHM and $\lambda \sim 1047$ nm). In between the oscillator and the preamplifier a dedicated device called “Phase Coding” will be placed. This equipment provides a special time distribution of the pulses necessary to produce electron bunches with a distribution in time as required for the CTF3 Delay Loop. After these first stages, the laser beam is injected sequentially into two powerful Nd:YLF amplifiers [2-3]: the first one is made up of a $L_1 = 8$ cm long Nd:YLF rod with $d_1 = 7$ mm diameter aperture pumped by 5 stacks of diode lasers symmetrically arranged around the rod. The total diode pump peak power is 15 kW and its amplification window is $\tau_1 \sim 400$ μ s. The second amplifier has the same geometry of the first one but a rod length $L_2 = 12$ cm and diameter $d_2 = 10$ mm; the pumping peak power is 17 kW and its amplification window is $\tau_2 \sim 250$ μ s. This amplification starts with a delay of 150 μ s with respect to the starting time of the first amplifier. Both amplifiers are designed to work at a repetition rate in the range 1-50 Hz. After the second amplifier, an electro optical gating system based on a Pockels cell allows to select the pulse train length, according to the requirements of the CTF3 RF gun. Ultimately, the CTF3 drive beam will require a ~ 1.270 μ s long train of pulses at 1.5 GHz, with a repetition rate of up to 50 Hz. Presently, a repetition rate of 5 Hz is being used. The wavelength of gated laser pulses is converted from 1047 nm to 523 nm by a second harmonic process in a KTP crystal \sim with $\sim 28\%$ efficiency; this is converted to 262 nm in a BBO with 22% efficiency. This final wavelength is required by the Cs₂Te cathode. It has been shown [4] that the jitter between the synchronization of the laser with respect to the master clock rf frequency at 1.5 GHz required to trigger the laser with the RF gun is below the 1ps specification.

RF GUN

The design of the RF gun [4] is based on a previous 3 GHz CERN RF gun [5, 6] (so called “type IV”). The gun has been optimized for high average current and outstanding vacuum. In order to cope with the beam loading at the nominal 85 MV/m accelerating field, the gun structure is over coupled to $\beta \sim 2.72$. The angle of the wall of the half cell hosting the cathode has been optimized for emittance growth compensation. The walls of the accelerating cells have holes to increase the pumping via a NEG coated chamber around the gun.

The shape of the cells is elliptical to decrease the surface electric field minimizing the risk of electrical breakdown and dark currents. The RF power is fed to the gun via standard 3 GHz waveguides and coupled to the third cell through two holes symmetric with respect to the beam axis [6]. Two solenoids have been added around the gun in order to perform the emittance compensation process. The focusing coil is placed just after the coupling cell and the bucking coil between the photocathode preparation chamber and the gun (see Fig.1). Results of simulations after optimization of the RF phase, of the magnetic field

and of the laser pulse profiles, show that good performance in terms of emittance is obtained at the expense of a small increase of the energy spread. Due to the high average extracted charge, a very good vacuum level 10^{-11} mbar is required as discussed in [5].

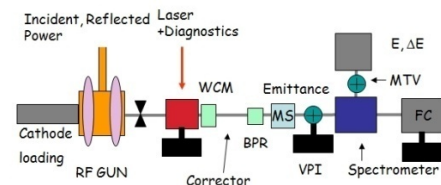


Figure 1: Photo injector layout.

MEASUREMENTS

The photoinjector has been commissioned during two runs for an overall duration of ~ 4 weeks.

During the commissioning, the rf phase has been optimized looking at the charge vs phase scan and using the spectrometer to optimize energy and energy spread.

The nominal energy of 5.5 MeV with a spread of $\sim 0.3\%$ has been reached and measured for a low charge beam. The full train of 1908 bunches has been generated with a typical bunch charge of 1.5 nC. The nominal bunch charge of 2.3 nC has been demonstrated for shorter trains of 500 ns where most of the commissioning was done.

Beam size scans as a function of the solenoid current as well as emittance measurements have been performed. An example of such a beam size scan is shown in Fig 2 for a laser spot dimension of ~ 4 mm knife edge (85%). Same measurements have been performed for a smaller laser spot size (~ 2 mm knife edge) showing that in such conditions a smaller waist of the electron beam could be reached: (~ 2 mm).

Single shot emittance measurements have been performed using a slit mask made of a 2 mm thick tungsten plate.

The slits have a width of 100 μ m and are spaced by 800 μ m (25 slits in total). In Fig 3 an emittance scan versus solenoid current is shown with the expected behavior that comes from PARMELA simulations performed for the same experimental conditions.

It must be pointed out that for each presented measure the error bars come only from a statistical analysis therefore systematic errors have not yet been considered in this first stage of analysis. The statistical analysis has been performed over a set of several measurements (10) acquired for each applied solenoid current.

Finally, the beam loading was studied and optimized by adjusting the timing of the beam versus the rf pulse. Fig 4 shows the successful beam loading compensation: in presence of the beam we obtained a flat top rf pulse resulting in a mono energetic beam. The reflected power is well matched at this point confirming that the input coupler has been adjusted to the right over coupling.

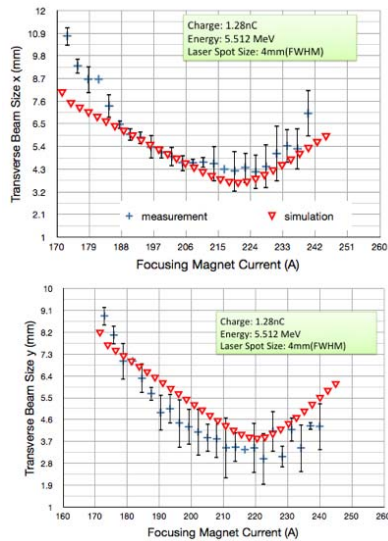


Figure 2: Envelope scan: Beam size measurements (crosses) versus solenoid current ; triangle PARMELA simulation. Beam parameters : 1.28nC charge, ~5.5 MeV energy.

CONCLUSIONS AND FUTURE PERSPECTIVES

From the beam dynamics point of view the photoinjector behaves as expected: the results of the beam characterization can be reproduced with PARMELA simulation within the tolerance range of the measurements. The laser pulse energy onto the cathode was lower than specified: 250 nJ instead of 360 nJ, the intensity stability was ~2% rms. Nevertheless, we have been able to achieve the nominal charge of 2.3 nC when a new Cs₂Te cathode with QE = 4 % has been used at the end of the run (a one year old cathode with 3% QE has been used during most of the run). Modifications of the laser are under development to increase the final UV energy and to improve its intensity stability. The beam layout of second amplifier is going to be modified for better matching between the beam size and the rod allowing to extract the power out the all pumped volume of the rod. [3]. The harmonic conversion stage is going to be modified to achieve higher conversion efficiency. In particular the BBO crystal could be substitute by a K*DP which has a lower value of the non linear coefficient but better acceptance angle. We believe that with such crystal and a suitable beam we could improve the fourth harmonic conversion efficiency. The “Phase Coding” required to provide the 180 deg phase deviation in the laser pulses, thus in the electron distribution, has been studied and tested in a different laser system. The device

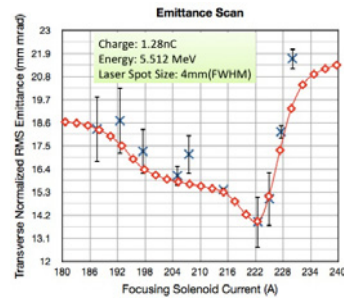


Figure 3: Emittance vs solenoid current. Beam parameters: 1.28nC charge, ~5.5 MeV energy.

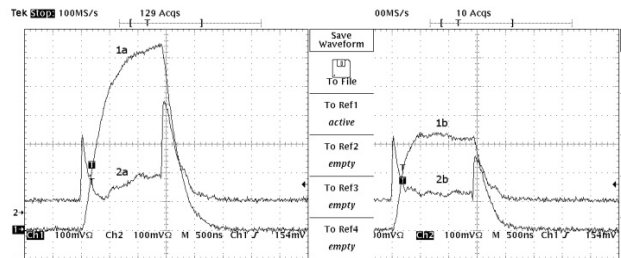


Figure 4: Beam loading. Left: rf power in the gun (1a) and reflected power (2a) when no beam is present. Right: rf power in the gun (1b) and reflected power (2b) when electron beam is present.

could not be installed in the laser chain after the oscillator due to the high losses it introduces. Further studies are in progress to avoid this problem: a fiber amplifier to catch up for the losses could be a good solution to the problem.

To what concerns the cathode, it must be pointed out that most of the run has been performed with a one year old cathode and the QE of 3% is the expected response from it. The new fresh cathode only gave us a QE of 4% even though it was completely a new one. The expected value in the early moment of the cathode life time is close to 8%. The reason for this lack of QE is that we have not enough Cesium for finish properly the photocathode with a high QE.

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