# CONSTRUCTION OF THE PROBE BEAM PHOTO-INJECTOR OF CTF3

J. Brossard#, M. Desmons, B. Mercier, C. Prevost, R. Roux,
Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université Paris-Sud 11, Centre Scientifique d'Orsay, B.P. 34, 91898, Orsay cedex, France.

*Abstract*

This paper describes the HF (High-Frequency) and dynamic beam modelling performed onto the 3 GHz / 2,5 cells photo-injector of the future CTF3 (CLIC Test Facility 3) probe beam linac. The latter provides the beam to demonstrate the feasibility of the 30 GHz accelerating sections in the framework of the CLIC project. The Probe Beam Photo-Injector (PBPI) is inspired from the Drive Beam Photo-Injector (DBPI) already designed by LAL and actually tested in our laboratory. However, the design of PBPI has been simplified with respect to the previous because the charge per bunch is 4 times lower and the number of bunches several orders of magnitude smaller. The internal geometry and the coupling system of the PBPI have been designed with 2D (SUPERFISH*) and 3D (HFSS†) codes. Based on the modified design, PARMELA and POISSON simulations showed that the technical specifications are fulfilled. The vacuum issue has been also carefully investigated, and NEG (Non Evaporated Getter) technology has been adopted in order to reach the $10^{-10}$ mbar pressure inside the structure. This work is done in deep collaboration with CEA/Saclay, which is responsible of the CTF3 Probe Beam Linac design and construction [1].

## GENERAL REQUIREMENTS

The PBPI has been designed to fulfil the following requirements [2]:

| | | |
|---|---|---|
| RF frequency | 2.99855 | GHz |
| Beam energy | 5 - 6 | MeV |
| Charge per bunch | 0.5 | nC |
| Bunch length (FWHM) | <10 | ps |
| Energy spread | <2 | % |
| Normalized emittance | <20 | π.mm.mrad |
| Number of bunches | Variable 1-32 | $s^{-1}$ |
| Bunch spacing | 333.3 | ps |
| Vaccum pressure | $<2.10^{-10}$ | mbar |

The electromagnetic design of the photo-injector has been performed in 2 stages. The first part was related to the HF performances of the photo-injector "without particles" (HF modelling). The second part was performed in order to deduce - and optimize - the real behaviour of electron bunches inside this structure (Beam dynamic modelling). In parallel with theses studies, a mechanical and a vacuum analysis was performed.

## HF MODELLING

The HF modelling has been achieved in two stages. The first step was a 2D analysis which optimizes the internal shape of the photo-injector (assuming a pure axis-symmetrical system). The main advantage of such a study is that it requires a very short time computation (less than 10 mn for one run). The second step is a 3D analysis, which allows one to make a design taking into account the effect of the coupling holes. This kind of modelling is much more time consuming (between 0.5 and 1 hour, depending on the used software and the available machine resources).

### *2D-HF modelling*

The PBPI geometry is based on a 2,5 cells which must be tuned for the $TM_{010-\pi}$ mode. We carried out a study of several shapes of the gun. In practice, the internal geometry of the photo-injector always needed to be slightly modified (for example: the radius of each cell as to be adjusted in order to obtain an equilibrated on-axis accelerating electrical field). Thus, the designed photo-injector has a frequency resonance higher than the requirement. For the DBPI design [2], it was decided – mainly for surface electrical field optimisation - to adopted iris with elliptical shape [3]. In the PBPI case, requirements are less stringent and we choose circular profile, with contiguous tangential straight line segments.

A 2D-HF SUPERFISH analysis has been performed in order to define the size (length and radius) of each cell. The best case (cf. Figure 1) gives a quality factor of 14 500, an impedance shunt of 50 MΩ/m, a resonant frequency of 3003.5 MHz, and a relative maximum accelerating electrical field of 100%, 95.7% and 98.5% along the axis (respectively for cell n°1, 2 and 3).

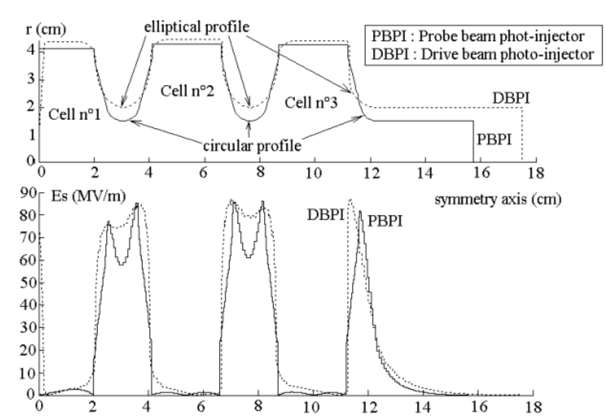


Figure 1 : upper part : 2D profile of PBPI and the DBPI. Lower part: surface electrical field amplitude (for an on-axis maximum field of 80 MV/m).

# brossard@lal.in2p3.fr
* http://laacg1.lanl.gov/laacg/services/download_sf.phtml
† http://www.ansoft.com/products/hf/hfss/

An important issue in the HF design of a photo-injector is the maximum electrical field amplitude on the internal surface. A too high electrical field surface enhances the probability of a breakdown that would greatly affect the performance of the photo-injector. In our selected option, this field value is 87.5 MV/m (for maximum accelerating electrical field amplitude of 80 MV/m on the axis).

### *3D-HF modelling*

The 3D-HF modelling has been performed using HFSS software (version 8). The main goal of this study is the design of the gun with holes which allows the RF power to be delivered inside the photo-injector cavity. The dimensions of the holes must be adjusted to avoid any reflexion back to the power generator. As we have done for the CTF3 drive beam photo-injector [2], we decided to connect two couplers symmetrically with respect to the vertical plane (cf. Figure 2) in order to keep the accelerating electrical field symmetry at an acceptable level.

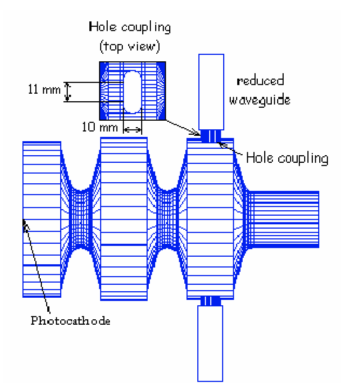


Figure 2 : Sketch of the PBPI with power coupling devices.

The introduction of the hole coupling system perturbs the electrical field mode inside the cavity (frequency and distribution inside the cells). A fine study has been performed to define the shape of the two (identical) coupling holes. We chose a racetrack shape, with a length of 21 mm and a width of 10 mm, centred at the middle of the third cell (cf. Figure 2). For the 3D model, the frequency is 3001.36 MHz, and compared with the 2D HF design, the radius of the cells has been modified by few 0.1 mm.

## BEAM DYNAMIC

Beam dynamic simulations have been performed using a modified version of PARMELA [4] which allows one to take into account the photo-injectors. Simulations are based on the electrical field obtained with RF calculations done with SUPERFISH. The nominal peak accelerating field should be around 80 MV/m. Performances of the gun have been studied in two cases, in its natural behaviour and with two solenoids used to compensate the emittance growth induced by the space charge forces.

### *Natural behaviour*

For fixed laser parameters, one must find the operating point which optimizes the performances of the gun. So, for conservative rms widths of the laser, 4 ps of pulse duration and 1 mm transversally, we made a scan as a function of the RF phase. There is a phase, 36 °, for which the energy spread and the emittance are minimum. For this value of the RF phase, the scan as a function of the gradient showed that the minimum emittance is reached at 120 MV/m. But it seems not reasonable to operate the gun with such high gradient because of the enhancement of breakdown occurrences probability. Results are resumed in table 1 for a gradient of 80 MV/m.

Table 1 : Beam parameters in rms value for a beam charge of 0.5 nC at the output of the gun; laser parameters: $\sigma_t = 4$ ps, $\sigma_r = 1$ mm

| | | |
|---|---|---|
| E | 5.35 | MeV |
| $\varepsilon_{x,y}$ | 6.6 | π.mm.mrad |
| $\sigma_{x,y}$ | 1.85 | mm |
| $\sigma_z$ | 3.33 | ps |
| $\sigma_\gamma / \gamma$ | 0.3 | % |

The duration of the laser pulse is rather difficult to change while the transverse size of the spot on the photo-cathode is easily varied with lens. So it is interesting to look at the variations of the beam parameters as a function of the laser transverse width. Simulations show that it is possible to reduce the laser transverse width down to 0.3 mm without electron beam losses. The emittance is reduced to 4.6 π.mm.mrad at the cost of an increase of 40 % of the bunch length and a factor 2 of the energy spread. Nevertheless to have a good transmission of the beam through the 30 GHz accelerating sections it could be more important to reduce the emittance rather than to preserve the bunch length and the energy spread. A last issue to consider is the evolution of the beam in the drift space between the output of the gun and the entrance of the first accelerating section.

### *Compensation of the space charge forces*

Even with the low charge which must be accelerated in the probe beam linac, the space charge force induces a growth of the emittance linear with the distance.

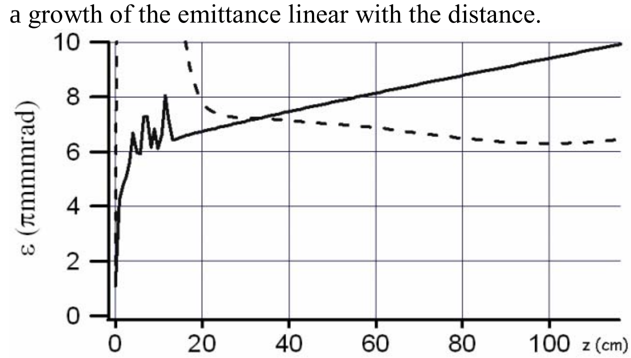


Figure 3 : rms normalised emittance as a function of the distance; PARMELA simulation with the same parameters used in Table 1, without coils (plain line) and with coils (dashed line).

As illustrated in Figure 3, the emittance is increased by 50 % when the electron beam arrives at z = 100 cm which stands roughly the entrance of the accelerating section. One well-known technique, proposed by E. Carlsten [5], is the use of a magnetic lens to compensate this emittance growth. In addition, it is known that closer to the photo-cathode the solenoid is, better is the compensation. So, a bucking coil and a focusing coil have been designed with POISSON. Both are placed between the photo-cathode plane and the RF waveguides as shown in Figure 4. The profile of the magnetic field is shown in Figure 5.

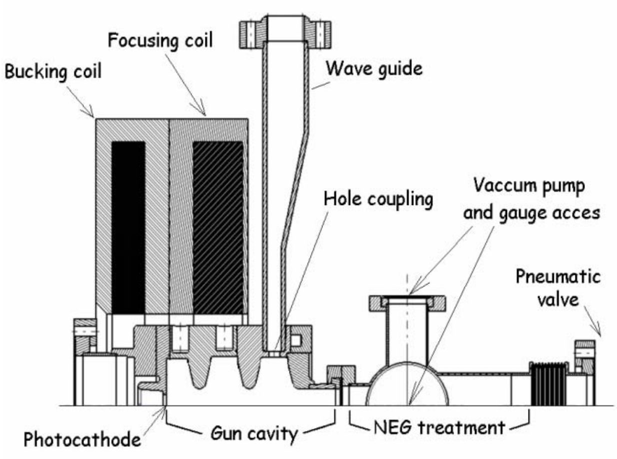


Figure 4 : Sketch of the photo-injector.

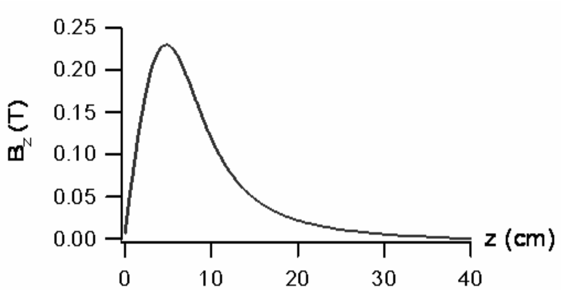


Figure 5 : longitudinal magnetic field simulated with POISSON.

A scan of the beam emittance as a function of the magnetic field amplitude has been performed with PARMELA. The best compensation of the emittance growth, as illustrated in figure 3, is obtained for a magnetic field of 0.23 T. So the emittance at the entrance of the accelerating section can be kept at 6 π.mm.mrad. Further reduction of the emittance could be achieved if the transverse and temporal profiles of the laser pulse are flat top [6]. This shape leads to a decrease of the peak electronic density and the space charge force which derives from it. In our modified PARMELA, square profiles for the laser are not available. A way to overcome this problem is to use a Gaussian with a large sigma which is truncated at a smaller value. Simulations show it is possible to get a reduction by almost a factor 2 of the normalized emittance, $\varepsilon = 3.5$ π.mm.mrad.

## VACUUM CALCULATIONS

To keep the longest possible lifetime of the photo-cathodes, Ultra High Vacuum (UHV) is required inside the gun, especially in the first half cell. The pumping takes place in a vacuum chamber just at the output of the gun. A 40 l/s ionic pump and 2 gauges are foreseen. Then it is connected to a bellows and closed by a pneumatic valve (see Figure 4). So, with an out-gassing rate of $5.10^{-13}$ mbar.l.s$^{-1}$.cm$^{-2}$, simulations, using Monte-Carlo results, gives a residual pressure of $10^{-10}$ mbar in the gun when the valve is closed. When it is opened and assuming a reasonable $2.10^{-9}$ mbar at the entrance of the accelerating section, simulations foresees a residual pressure of $5.10^{-10}$ mbar near the photo-cathode. In order to improve the quality of vacuum, it was decided to use NEG (Non Evaporative Getter) coating on the vacuum chamber walls. In these conditions, the pressure is $3.10^{-11}$ mbar and $2.10^{-10}$ mbar when the valve is closed or opened, respectively.

## CONCLUSION

The design of the CTF3 probe beam photo-injector has been presented and all the requirements (RF, vacuum, beam properties) are - according to the simulations, fulfilled. The machining is under way and the RF test at LAL will be performed by the end of the year. After RF tuning, the gun will be brazed at LAL, and the overall photo-injector (including RF gun, vacuum chamber, coils …) should be assembled in the beginning of 2007 and delivered to CERN.

## REFERENCES

[1] A. Mosnier & al., “The Probe Beam Linac in CTF3”, EPAC 2006 proceedings.
[2] R. Roux, “Conception of photo-injector for the CTF3 experiment”, Proceeding of “The Physics and Applications of High Brightness Electron Beams”, Erice, Sicily, October 9-14, 2005 (under press).
[3] J. Luiten & al., proc. of the 9th Eur. Part. Acc. Conf. EPAC 2004, Lucerne, Switzerland, p.725, 2004.
[4] PARMELA from Los Alamos modified at LAL by B. Mouton
[5] B. E. Carlsten, “New photoelectric injector design for the Los Alamos National Laboratory XUV FEL accelerator”, Nucl. Instr. Meth. in Phys. Research A 285 (1989), 313.
[6] F. Zhou et al, “Emittance growth due to the laser non-uniformity in a photo-injector”, proc. of the 8th Eur. Part. Acc. Conf. EPAC2002, Paris, p. 275, 2002.