# ELECTRON BEAM CONDITIONING WITH IR/UV LASER ON THE CATHODE

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### *Abstract*

Shining a photocathode at the same time with an UV laser able to extract electrons and an IR laser properly tuned could influence the way the electron beam is generated. Such a process is under investigation at SPARC, through direct measurements, as much as through computer codes assessment studies. Furthermore, electron beam creation with a third order nonlinear photoemission coming from a IR laser, instead of the standard UV irradiation has been evaluated in the case of very short pulse regime.

## INTRODUCTION

The idea of manipulating a low energy e-beam with a laser radiation has been proposed in the past [1]. The goal of such a scheme could be the creation of a proper velocity modulation within the electron beam, which can then translate in a density modulation. Eventually, such a behaviour could be further enhanced within a magnetic compression chicane scheme, where the modulation could be compressed on a much lower wavelenght scale. Obviously, the feasibility of such a scheme could give a big improvement in a FEL process, where the electron modulation would enhance superradiant emission, if the undulator is properly tuned on the right microbunching wavelength.

Further evidence that such a modulation would occur, and, moreover, be preserved and emerge out of the initial beam evolution inside the photoinjector could be addressed to the experimental observations taking place elsewhere at SLAC. Several issues are to be overcome, exploring such a scenario with a computer code. In fact, conversely to the usual working conditions, in a laser modulation regime, the electron beam evolution should be sampled out on time scales typical of the optical oscillation (i.e. a few fs), and, moreover, with a farly bug number of particles, a solution that requests for a big amount of computing resources. A preliminary setup to probe such a scheme at SPARC has been tested, and further measurements will be made.

Another way in which IR beam could be proficiently used is the direct electron generation by third order nonlinear photoemission, when a short pulse length is requested [2]. The preliminary study on on UV/IR interaction gave the opportunity to look at the beam of the nonlinear process itself generated by the use of only IR.

### *Laser Setup*

The scheme outlined was implemented by means of two laser beams, both impinging on the photocathode. More in detail, we decided to use UV light (at 266 nm wavelength) to create the electron beam by linear photoemission, then we used the IR fundamental Ti:Sa beam (at 800 nm) to give the generated electron beam a modulation. For such a reason, the UV beam was sent to the cathode on a standard normal incidence, while IR beam was sent on grazing incidence (72 degrees). Such a setup, with p-polarization on the IR beam, was chosen to enhance the electric field longitudinal component contribution on the outcoming electrons.

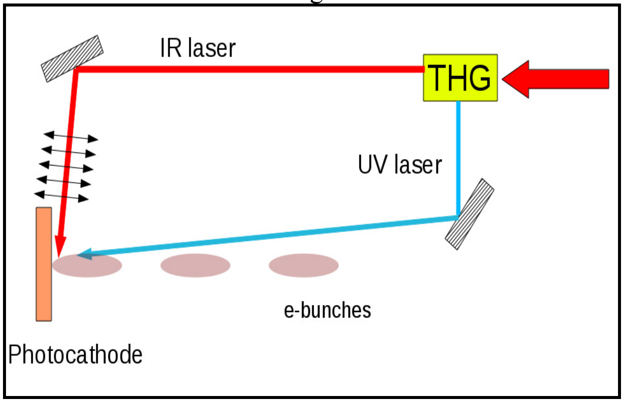

Figure 1: Conceptual layout of the laser scheme used for synchronous use of IR/UV beams.

Furthermore, the use of two laser beams coming from the same laser source was automatically ensuring a very tight synchronization, as necessary to guarantee a repeatable and stable interaction.

The reason for choosing the fundamental frequency was that it could employ a larger amount of radiation (up to few mJ), emerging out of the third harmonic generation process, not affecting the UV beam energy necessary for the generation of the proper amount of charge out of the cathode (a large amount of IR will always come out of the upconversion). Moreover, we believe that the high reflectvitity of the copper photocathode within the IR region (we found in literature between 85% up to 95% for [3]) would keep the emitter itself safer, though the amount of IR radiation was high enough in order to cause damage. Of course, such a statement holds whenever the power level makes nonlinear absorption (i.e. multiphoton emission) negligible.

The two laser beams were different in pulse length, because of a different manipulation downstream the harmonic generation stage. The fundamental is first sent to the harmonic generator, close to its transform limit (150 fs), in order to ensure the proper conversion efficiency and amplitude stability, then, the remaining IR was sent to the cathode through a transfer line preserving the pointing stability and pulse length, in order to get a high field on the cathode. The UV beam, instead, was sent through a stretcher, lenghtening the pulse up to 6.8 ps and then sent to the cathode, in order to allow time compression of the electron beam downstream the photoinjector, by the velocity bunching technique [4]. An optical delay line aimed for the fine tuning of the two beams arrival time to be adjusted looking at the electron beam was set. Just a coarse synchronization was made offline through a fast photodiode, in order to ensure the IR and UV getting on the cathode within the same radiofrequency bucket (well below the limits). The grazing incidence of the IR was also causing an issue of different time arrival of the laser between one side and another of the cathode (and ellipticity as well). On a first step we decided to compensate the time arrival of the IR beam through the use of a diffraction grating and an imaging optic, in order to have a synchronous time arrival on cathode by all the IR front. Such a scheme, though, brought to a significant loss of energy, and, hence we decided to operate without compensation scheme, just minimizing the time arrival difference by means of a cylindrical lens, focusing close to the cathode surface up to 100 µm, for a remaining delay between the two sides of the beam within 1 ps (still high).

### *Synchronization*

Fine synchronization between IR laser arrival on cathode, and UV generated electron beam hase been made through a RF deflector installed at SPARC and located downstream the accelerating sections of the linac (at 150 MeV energy) and a beam arrival monitor (BAM). In both cases, IR time arrival has been evaluated thanks to the nonlinear emitted electrons. In figure 2 it is shown the sequence of steps made to refine the time arrival.

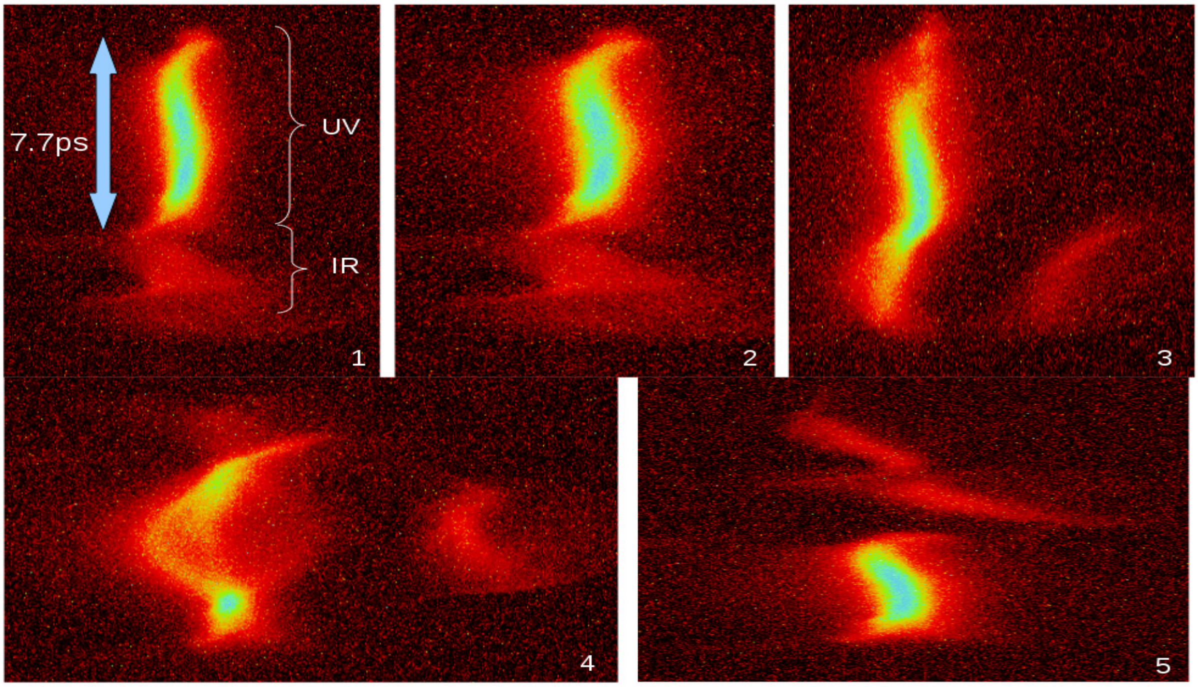

Figure 2: Five different stages of fine delay adjustment using RF deflector and nonlinear generated electrons by IR laser.

Such a procedure was made working with a relatively high charge of the non linear electrons (160 pC), in order to have a signal high enough to be probed on the scintillating screen downstream the deflector or in the BAM. The synchronization was evident also because the insertion of the IR, was barely perturbating the UV generated beam, also displacing it (figure 2). Such effect was probably caused by the space charge associated with such an intense IR electron beam, and disappeared decreasing the intensity and the charge of the secondary electron beam.

### *Next Steps*

The horizontal displacement was probably due to the different time arrival of IR laser on the two opposite sides of the cathode. In anycase, this perturbation was confirming the presence of the two lasers arrival within the same RF bucket, and then the beams were compared in time injecting one at the time up to a superposition under a hundred of fs on the RF deflector. Now that synchronization has been ensured, there will be need of probing an eventual modulation of the electron beam. In such a direction, we will foresee within the next run some specific diagnostic (i.e. transition radiation, or the FEL radiation itself) for detecting an eventual modulation superimposed on the electron beam. We plan also to apply the front correction for the IR time arrival.

## IR GENERATED BEAM

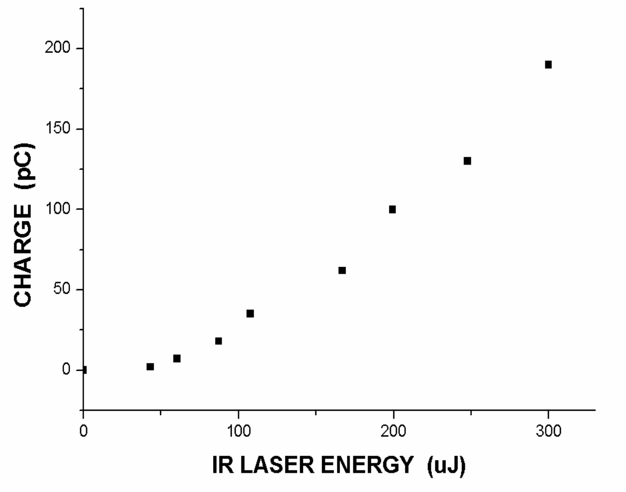

Figure 3: Emitted electron charge at 50MV/m extracting field vs. IR laser energy at 800 nm wavelength.

During employment of IR and UV laser we had the opportunity to evaluate also the use of an alternative use of the solely IR to generate very short electron pulses. As expected from the theory of photoemission, third order efficiency increases going to higher fluences, hence working with a short enough pulse. So, there could be a range of working points where IR is more convenient, considering also that conventional lasers emit in the IR interval, and that in this way, it could be possible to bypass the harmonic generation process, wich is usually not very efficient (a few percent in the third harmonic for Ti:Sa). Moreover, we decided also to inject the IR on normal incidence, to evaluate the feasibility of such a scheme, and see that the characteristics of the beam were the same as the UV generated one, with no need of front arrival compensation. We used in this case 0.5 mm spot diameter on cathode, and a laser pulse length of 250 fs FWHM at 50MV/m RF field (figure 2). The curve behaviour is clearly nonlinear, i.e. the QE increases with the energy. It can be seen that the efficiency at the higher energy probed is 1.55E-6. Taking in consideration a standard efficiency of copper of 1E-5 at 266 nm, and an upconversion efficiency of 10% from fundamental to third harmonic of Ti:Sa, we clearly see that we reach a point in which the two overall chain (laser plus cathode) equal each other. This means that going beyond that power level would make IR overall efficiency higher, and then more convenient. Going to the electron beam, we can see that we could recall the same performances seen on the UV generated beam, trasporting the electrons up to high energy, and characterizing its trasverse and longitudinal phase space.

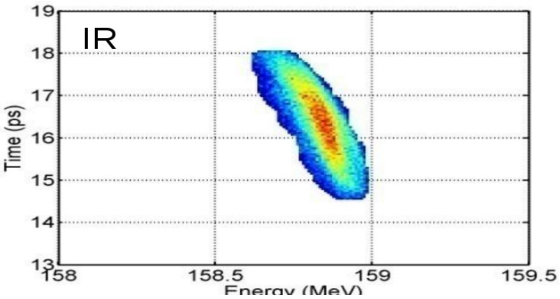

Figure 4: Longitudinal phase space of the IR generated electron beam.

We just mention as the main difference between the two processes, a higher charge fluctuation in the IR case (15% againist 5%). This is due to the nonlinear process in act, which increases energy jitter (to the third power), whereas a saturation within the harmonic generation process is able to dump such a detrimental effect on the stability [5].

## REFERENCES

[1] Tsumoru Shintake, Focal point laser-field as optical seeder, proc. of FEL conference 2006 pp. 242-247.

[2] P.Musumeci, et al. Multiphoton photoemission from a copper cathode illuminated by ultrashort laser pulses in a RF photoinjector , Phys. Rev. Lett. 104, February 22, 2010.

[3] http://www.luxpop.com/.

[4] M.Ferrario et al. Experimental demonstration of emittance compensation with velocity bunching, Phys. Rev. Lett. 104, 054801 (2010), February 5, 2010.

[5] W. Koechner, Solid state laser engineering, 6 ed., Springer 2006.