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Measurement of electron bunch vs laser stability including the spatial stabilization

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Abstract

Elyse photoinjector is seeded with a fs laser synchronized with the 3 GHz accelerator RF frequency. Elyse has been commissioned for a 1 ps time jitter. This jitter has been experimentally confirmed by single-shot electro-optic measurements (DS3 report 3.5). Considering the 15 m long free space laser propagation between the output amplifier and the photocathode, spatial fluctuations of the laser may contribute this jitter. We investigate the correlation between the spatial laser fluctuations and arrival time jitter of the electron bunch by using single-shot electro-optic sampling.

The measurements show that shot to shot spatial fluctuations have no significant contribution to the 1 ps time-jitter of ELYSE. The implemented laser pointing stabilization system only improve the long term stability.

Introduction

The jitter between the laser seeding the photoinjector and the electron bunch results of the combination of different jitter sources such as : synchronization with the 3 GHz accelerator RF, klystron phase stability, spatial laser stability and accelerator transport line stability.

To run a laser trigger accelerator in a regime in which the time jitter between the laser pulse and the electrons bunch is sub-ps jitter it is important to isolate and improve separately each of the above-mentioned jitter contribution. We are reporting on the laser spatial fluctuation contribution to the 1 ps measured jitter of ELYSE. In this report we will described the influence of the laser position (on the photocathode) and its stability, in energy and in position, on the bunch length measurement and the jitter.

The experimental setup is described in figure 1. The electro-optic diagnostic used is detailed in report DS1 [1] and its application to the characterization of ELYSE in report DS3 [2]. In order to investigate the effect of the laser position on the photocathode, two different approaches were used. In the first part we have investigated the influence of the laser position on the photocathode, and in the second part the influence of the laser fluctuations. The laser spot on the photocathode was horizontally moved in two positions and the corresponding electro-optical signal were recorded, for the first part. Second, the simultaneous measurements of the laser position, the laser energy and the electro-optic signal were recorded. Those measurement were done for a low charge of 1 nC in order to remain in the linear regime of emission.

Laser spot positioning

For the first measurement, the laser spot image was taken on the virtual cathode with a CCD camera. This virtual cathode is a simple screen showing the laser spot when a 45° angle mirror is put on the 266 nm laser trajectory (see figure n°1). The laser spot size (FWHM=2.5 mm) is the same as the spot size on the real cathode since the distances mirror-real cathode, and mirror-virtual cathode, are the same.

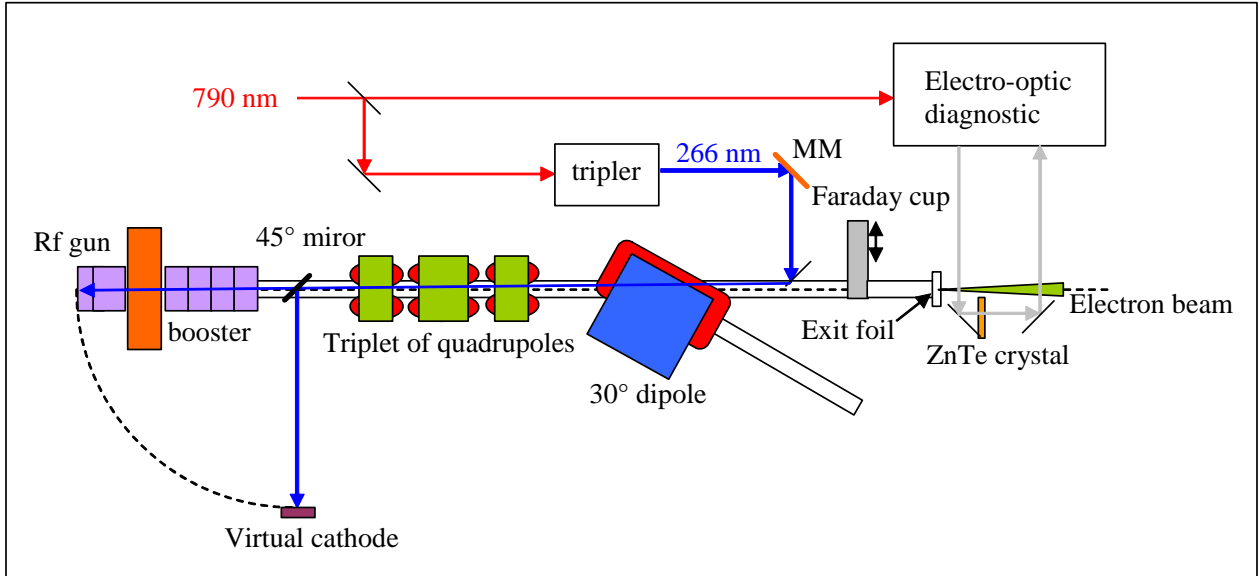


Figure 1. Virtual cathode position within the electro-optic diagnostic of bunch duration at ELYSE. MM is a 45° angle Moveable Mirror with which laser position can be changed.

Moving the laser spot position is changing the initial positions of electron emission on the photocathode. A simulation with ASTRA [3] was made with ELYSE parameters and the laser position was moved in the horizontal direction. The calculation is reproducing what is observed experimentally : if the laser spot is moved horizontally on the cathode plane, the electron beam spot in the ZnTe plane has a coupled (horizontal and vertical) movement (see figure n° 2).

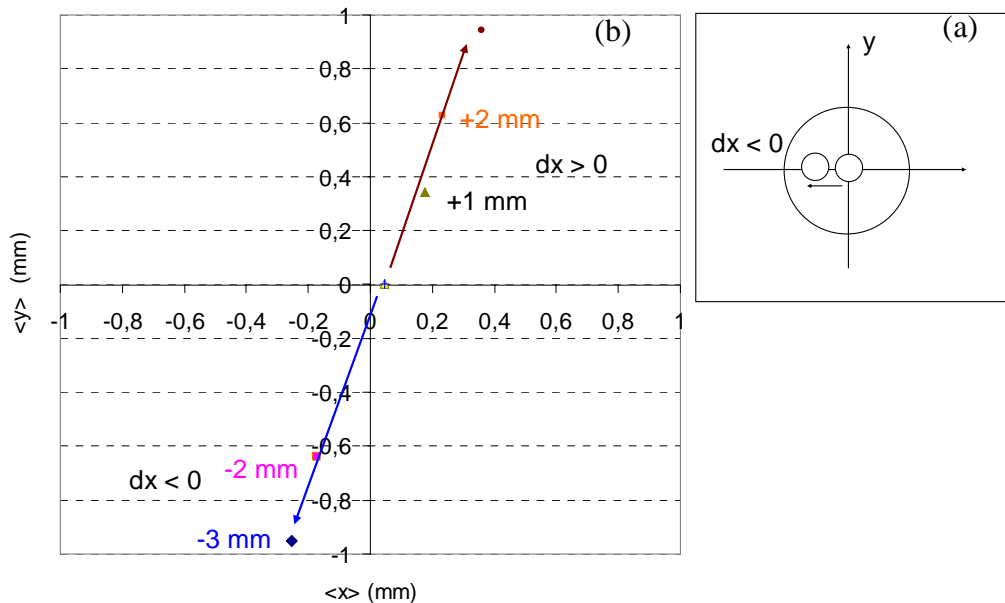


Figure 2. (a) is showing the laser spot displacement on the photocathode in the horizontal direction with $dx < 0$ (emitted electrons are coming towards the reader), and (b) is showing the electron beam centroid in x & y direction given by an ASTRA simulation of the beam transport from the cathode up to the exit window of the accelerator.

We clearly see in figure 2 that a horizontal displacement on the photocathode (fig. 2a) is leading to a coupled x & y displacement of the electron beam (fig. 2b). This is due to the presence of the solenoid between the RF gun and the booster. From the figure n° 2, one would expect the electro-optical signal to rise since the electron beam is getting closer to the ZnTe cristal.

Two electro-optical signals were recorded (20 shots) with two different laser spot positions (figure 3) : -2.5 mm and 0 mm (laser centered on the photocathode). The bunch charge was 1 nC, the electron beam energy 7.8 MeV, and the distance between the electron bunch and the probe laser was 5.2 mm.

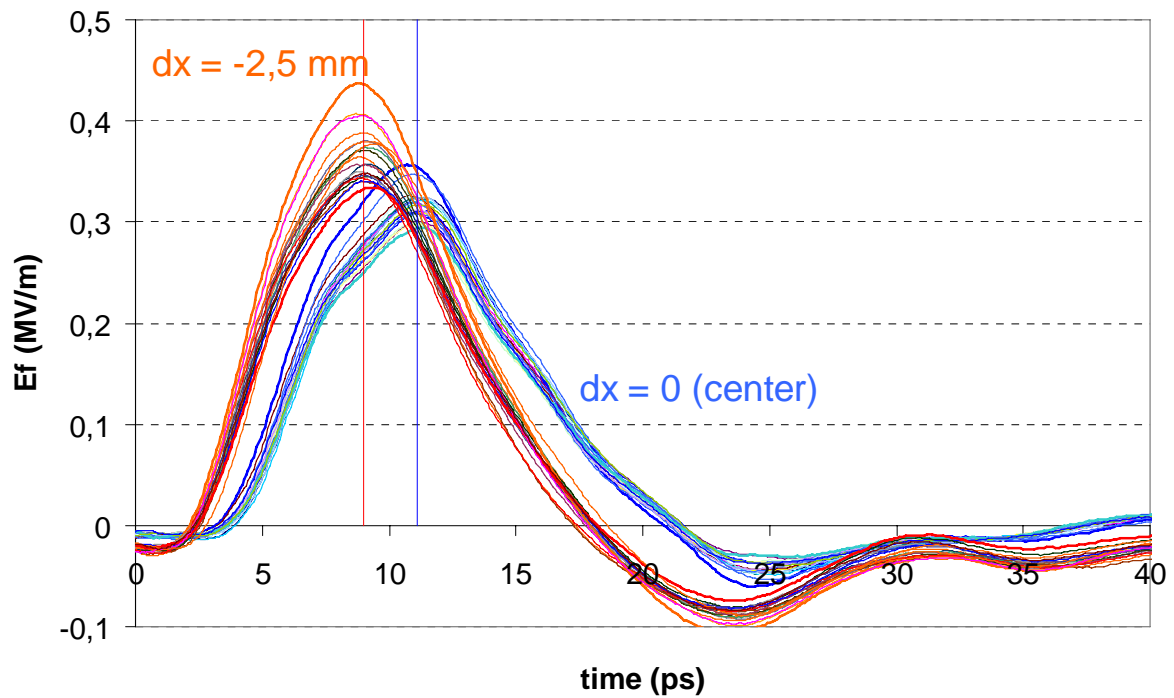


Figure3. Electric field of the electron bunch corresponding to two different laser positions on the photocathode ($dx=0$ mm, laser centered on the cathode) and $dx = -2.5$ mm, laser off center in the horizontal plane. Each measurement consists of 20 shots. The vertical blue and red line is pointing out the arrival time (AR) of the electric field maximum.

Table 1. Relevent numbers for the two measurements $dx = 0$ mm and $dx = -2.5$ mm : $\langle Ef \rangle$ is the average of the maximum electric field, rms Ef is the rms value of the electric field maximum fluctuations, AR is the arrival time (AR) of the electric field maximum, the rms jitter and the bunch length (FWHM).

dx (mm)	$\langle Ef \rangle$ (MV/m)	rms Ef	AR (ps)	rms jitter (ps)	FWHM (ps)
0	0.32	0.015	11.10	0.24	9.16
-2.5	0.37	0.027	9.00	0.19	8.42
Difference	0.05	0.011	-2.10	-0.05	-0.75

The fact that the electron beam is getting closer to the ZnTe cristal as the laser spot is moved by -2.5 mm is explaining that the electric field maximum is a bit higher (by +50 kV/m). The fluctuations of the electric field maximum are almost double in the $dx=-2.5$ mm situation. In this situation the electrons have a different starting point and the trajectories are changed compared to the laser centered situation.

The arrival time is showing a noticeable difference : the electrons emitted with $dx = -2.5$ mm are arriving 2 ps before compared to the other situation. For a 8 MeV electron beam a 2 ps difference in time is corresponding to a 0.6 mm difference in distance. A simulation with ASTRA should be helpfull here if a fine effects as this one can be computed.

The jitter value is the same for both measurements, and the bunch length is showing a non significant difference.

Laser fluctuation

A small fraction of the laser was derived on a screen before the accelerator entrance and the image of the laser spot was recorded (see figure 4). The laser position on the photocathode is derived from this image. The laser energy fluctuation were recorded with a photodiode before the tripler. The electro-optical signal, the laser spot position, and the value of the photodiode were recorded with a timing given by the accelerator.

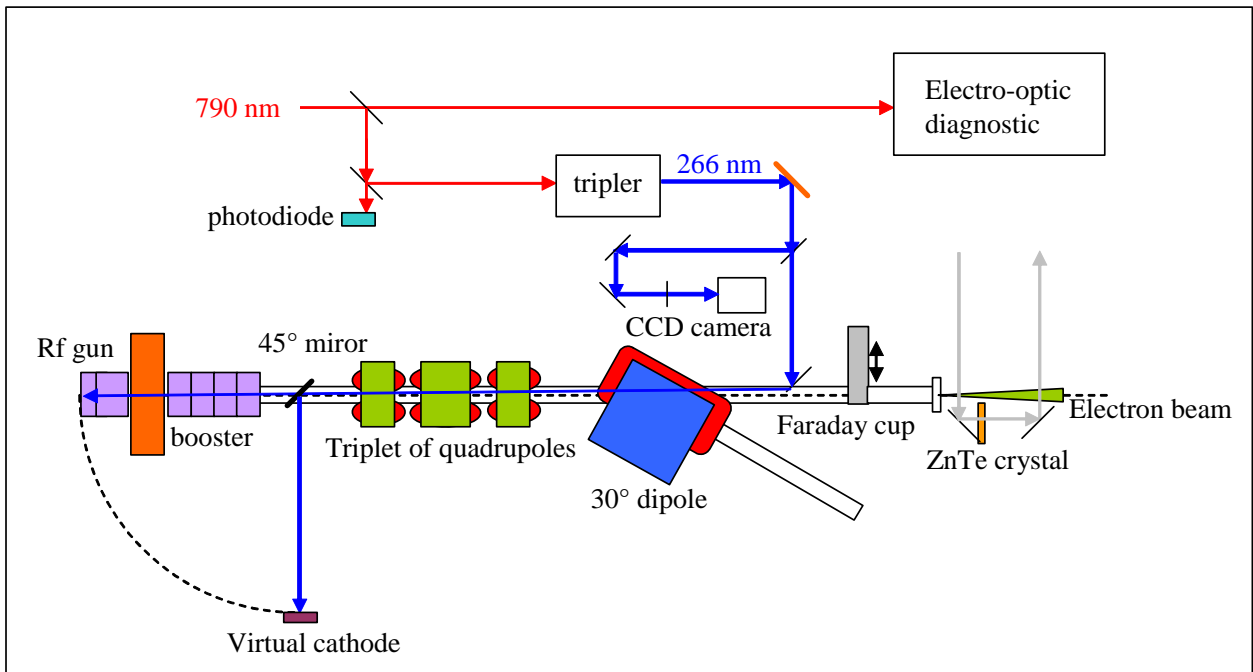


Figure 4. Setup used for the measurements of the laser fluctuations in position (CCD camera) and in energy (photodiode) at ELYSE.

The figure 6a is showing the arrival time of the electric field maximum versus the laser position (for 100 shots). There is no correlation between the electron bunch arrival time and the laser horizontal position which means that the jitter is not dependant on the laser position.

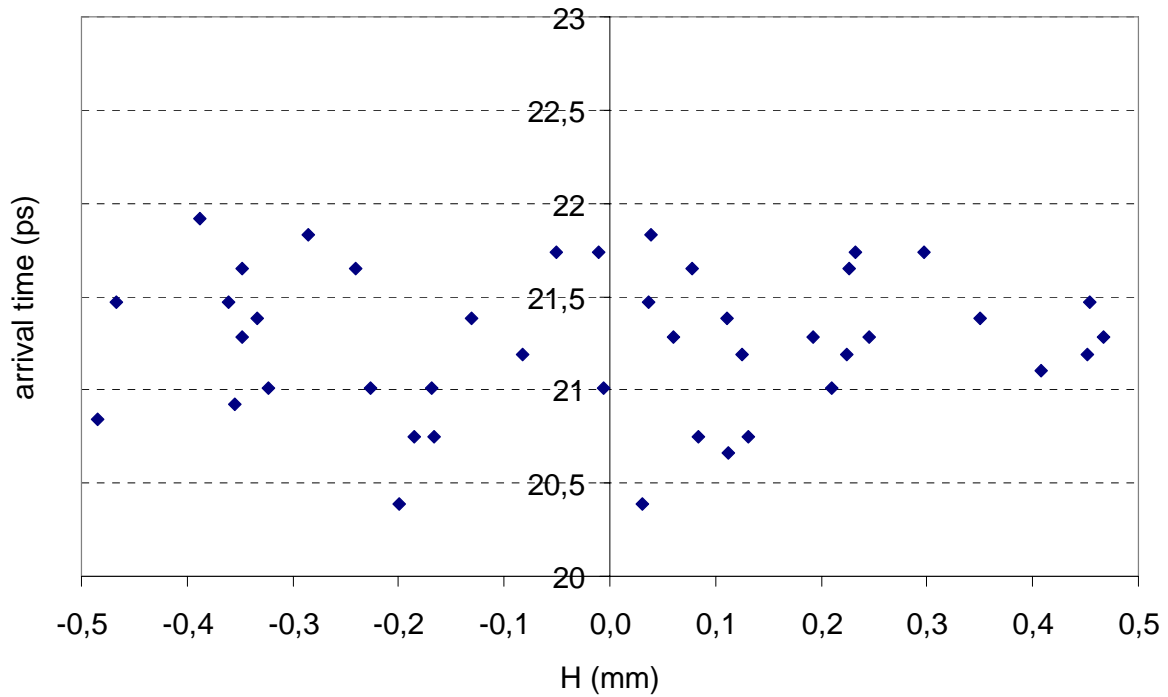


Figure 6a. Arrival time of the maximum electric field in ps versus the horizontal laser position H in mm.

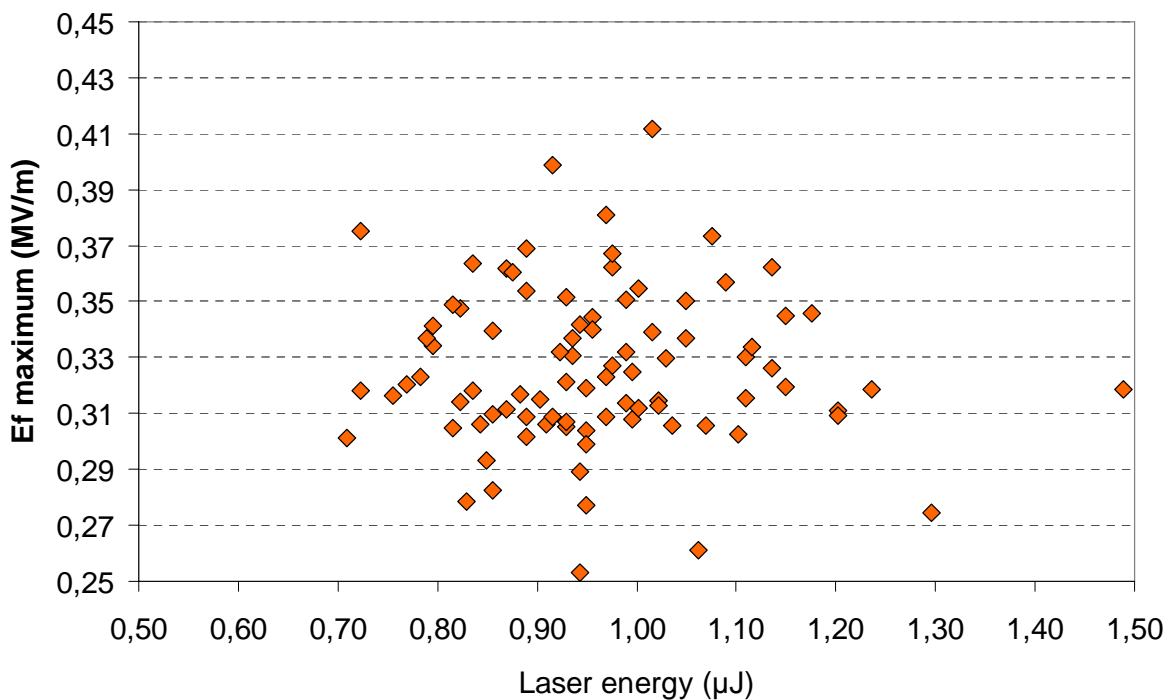


Figure 6b. The maximum electric field versus the laser energy. More than 90% of the laser energy fluctuations is within the range 0.8 to 1.2 μJ . No correlation is observed

Figure 6b is illustrating the maximum electric field dependence with the laser energy. One would expect the maximum electric field to be dependant of the laser energy because the

charge is depending on that last parameter, especially in the low charge regime (out of the photocathode saturation). There is no apparent correlation.

The analysis of all the measurements is not showing any kind of correlation between the laser energy fluctuations, the laser position fluctuations, and the electron bunch characteristics (maximum electric field, arrival time of this maximum, bunch duration given with FWHM).

Conclusion

The influence of the laser position and fluctuations over the electron bunch characteristics has been characterized. We have measured that a displacement of the laser spot by 2.5 mm on the photocathode induces an arrival time shift of about 2 ps. A crude extrapolation suggests that a laser stabilization of 0.1 mm would be required to achieve less than 100 fs time-jitter. Nevertheless any clear correlation between the fluctuations of the laser, in position and in energy, and the electron-laser time-jitter have been observed for ELYSE. The laser stability is not the major contribution to the 1 ps jitter. One could suspect a significant contribution from the accelerating field amplitude fluctuations. The spatial laser pointing stabilization on ELYSE is however useful at ELYSE to improve the long term stability.

References

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