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MEASUREMENT OF LOW-CHARGED ELECTRON BEAM WITH A SCINTILLATOR SCREEN

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Abstract

Measuring electron beam charge lower than 1pC in an accelerator is very challenging since the traditional diagnostics, like Faraday Cup and ICT (Integrated Current Transformer), are limited in resolution to a few pC because of electronic noise. A way to simply measure lower charge would be then to use the linear relation, existing before saturation regime, between the incident charge on a scintillating screen and the total light intensity emitted in response by this screen.

Measurements have been performed on PHIL accelerator at LAL, with charge lower than 200pC, with a LANEX screen located close to a Faraday Cup or an ICT. It shows a very good linear response of the screen down to the Faraday Cup and ICT resolution limits (≈3pC for the Faraday Cup and ≈10pC for the ICT) and therefore allows calibrating the screen for lower charge measurement with an estimated precision of 1% on the linear fit. A noise analysis enables estimating the ultimate screen resolution limit, which is actually dictated by the thermal noise of the CCD imaging the screen, around 10fC. Results of low charge measurements on PHIL will be shown and compared to those coming from a diamond detector installed on PHIL, in order to validate the measurement principle and cross-check both measurements.

Such powerful and simple measurement may thereafter be used as a single-shot charge diagnostic for electron beam generated and accelerated by laser-plasma interaction and will be used in the context of the Dactomus project [1].

EXPERIMENTAL LAYOUT

The PHIL Accelerator

The PHIL accelerator is a 3GHz RF photo-injector test bench located at LAL (Orsay) [2]. A layout of PHIL, with the main elements composing it, is shown in Figure 1. It essentially comprises 3 beam charge diagnostics (ICT n°1, ICT n°2 and Faraday Cup n°2) and 4 beam imaging diagnostics (YAG1, YAG2, YAG3 and YAG4). It is possible to perform our measurements with 3 sets of beam charge + beam imaging diagnostics on PHIL : ICT n°1 + YAG1 ; ICT n°2 + YAG3 ; Faraday Cup n°2 + YAG4. However, it is not possible with any of these 3 sets to compare our measurements with those coming from the diamond detector, since it can't be currently placed in the beamline. We have therefore to perform the measurements in the open air, just after the Aluminum window of 18μm thickness located 5.35m after the photocathode, with a movable Faraday Cup (Faraday Cup n°1) or the ICT n°2 and a movable LANEX screen. We performed the measurements thanks to a translator, moving perpendicularly with respect to the exit window in the horizontal plane, allowing us to put successively the Faraday Cup n°1, the LANEX screen and the diamond detector in front of the exit window so in the electron beam trajectory. The Figure 3 shows a schematic of the experimental layout.

The CVD Diamond Detector

The diamond detector used at PHIL is a single-crystalline detector produced by CIVIDEC [3] thanks to the Chemical Vapor Deposition (CVD) technique, which allows obtaining high-purity diamond leading to an improvement in the charge collection efficiency. Two important features of the diamond detector are its quite high thermal conductivity, allowing fast evacuation of the heat caused by radiation thus preventing damages, and its high radiation hardness.

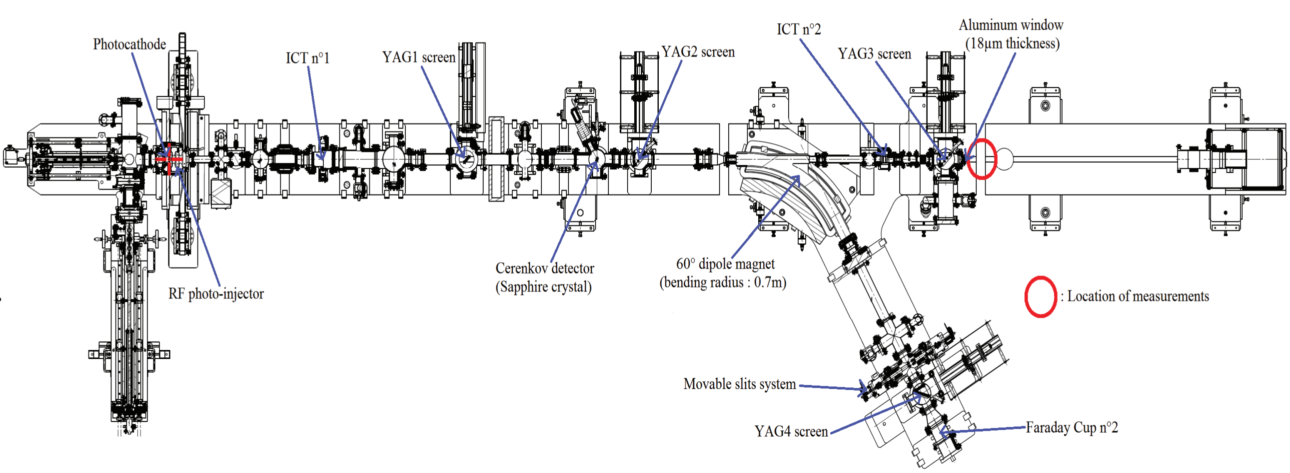

Figure 1 : Layout of PHIL accelerator at LAL.

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The range of measurement for this kind of detector goes from theoretically 1 electron to 10^9 electrons thanks to the use of various electronic amplifiers and attenuators.

Figure 2 shows the detector, consisting of the diamond sensor itself which is a 4.5*4.5mm^2 chip with 0.5mm thickness placed in a 2mm thickness aluminium box, with extra RF shielding, as a protection. The 4*4mm^2 collecting electrode is made of gold and the bias voltage can be adjusted between -400V and +400V. The charge yield for this detector is of 2.88fC/MIP (Minimum Ionizing Particle) in case of full charge collection efficiency.

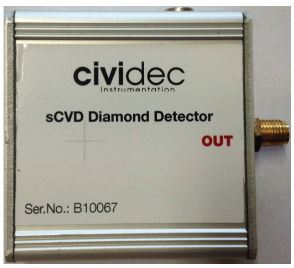

Figure 2 : The diamond detector used at PHIL [3].

The CCD Camera

The CCD camera used for imaging the LANEX screen is a Matrix-Vision BlueCougar-S123 [4]. The most important feature for our experiment is the gain of the camera, which can be adjusted between 0 and 18. As an example, there is a factor close to 8.5 in signal intensity between the gain 0 and the gain 18, but it is noteworthy that the increase in signal intensity is non-linear with the gain.

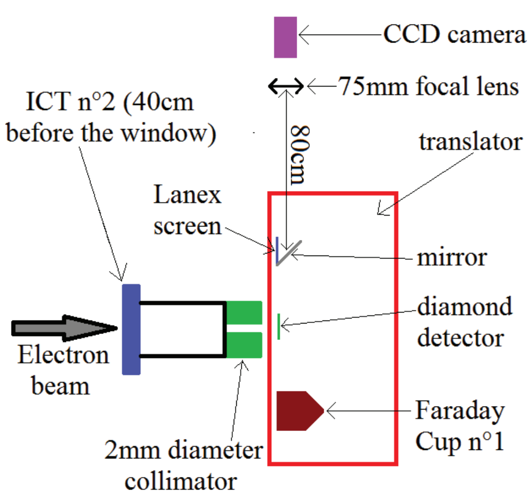

Figure 3 : Schematic of the experimental layout.

MEASUREMENTS

Calibration of the LANEX screen

We performed the calibration of the LANEX screen for 2 different configurations, the first one without collimator on the Aluminum window and reading the charge on ICT n°2 (see Figure 4) and the second one with a 2mm diameter aluminium collimator mounted on the window reading the charge on Faraday Cup n°1 (see Figure 5). The beam charge has been varied by changing, via optical densities, the energy of the laser pulse used to generate the beam. Since we are not in the space-charge saturation regime for photoemission in the RF gun, the beam charge varies linearly with the laser pulse energy.

The configuration with a collimator allows measuring lower beam charge, since the signal is more focused on the CCD and can therefore be more easily separated from the noise. However, this configuration cannot be used to measure beam charge higher than 5pC since the signal on CCD saturates even with gain 0. It implies that only 3 points have been taken in this configuration before reaching the Faraday Cup resolution limit (see Figure 5). The signal is more diluted on the CCD in the configuration without collimator and allows to measure beam charge up to 200pC. It allows a far better check of the linearity of the LANEX response to the beam (see Figure 4). To measure higher charge a less sensitive screen, like a 100µm thickness YAG screen, can be used.

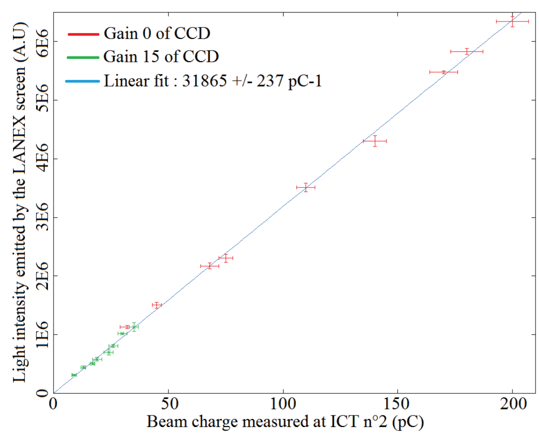

Figure 4 : Calibration of LANEX screen without collimator. Gain 15 points are rescaled on gain 0 scale.

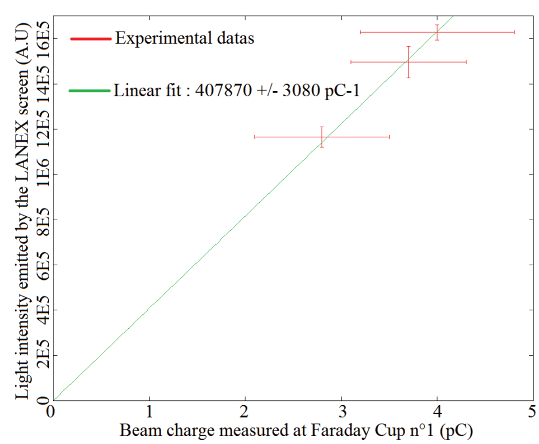

Figure 5 : Calibration of LANEX screen with collimator.

Figures 4 and 5 show a very good linearity of the LANEX response for beam charges between 3pC and 200pC. The fits can therefore be used to perform lower

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beam charge measurements via the measure, with the CCD camera, of the light intensity emitted by the LANEX screen. It is noteworthy that the uncertainty on the charge measured by this method mainly comes from the fluctuations of the CCD signal, since the uncertainties on the fits are very low (<1%).

Comparison with the CVD diamond detector

By using the calibration of Figure 5, we performed comparative beam charge measurements between the diamond detector and the LANEX screen. Namely, we progressively lower the beam charge in the range 0.8pC-15fC and each time measure the charge with the LANEX screen and the diamond detector. Figure 6 shows the result of these measurements.

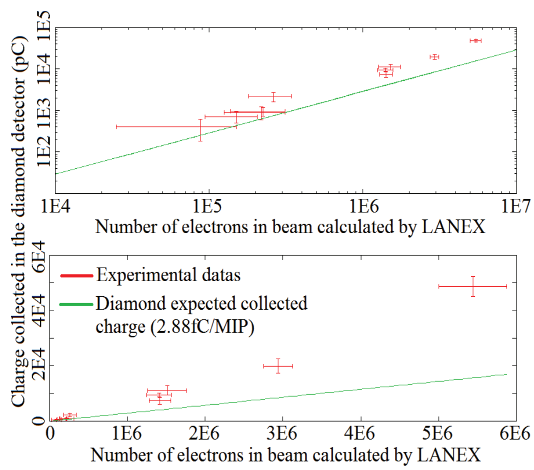

Figure 6 : Comparison of beam charge measured by LANEX screen and CVD diamond detector. Top plot : logarithmic scale ; Bottom plot : linear scale. Since the PHIL electrons (3MeV) are very close to the MIP energy, the diamond charge yield of 2.88fC/MIP has been used to calculate the beam charge via the diamond detector.

Figure 6 consists in two parts. The part at low charge (around 10^5 electrons per bunch) is linear and shows a very good agreement between the measure via the LANEX screen and the diamond detector with a diamond charge yield of 2.88fC/MIP. At higher charge the behaviour seems also to be linear but with a higher charge yield of the diamond detector, which has to be increased around 8.2fC/MIP to match the LANEX values. The source of deviation is still under investigation. The first way of investigation is to have a better understanding of the diamond detector response in an accelerator environment.

Nevertheless, in this paper, we are interested to investigate what is the lowest beam charge measurable with a LANEX screen. This comparison shows that the lower beam charge measured via the LANEX screen, and confirmed by the diamond detector, is of 15 +/- 10 fC. The ultimate resolution limit of charge measurement with LANEX screen seems therefore to be around 10fC in our experimental configuration. This limit can however be lowered by shielding the CCD camera against X-rays and by cooling it in order to reduce the thermal noise.

There is though one very important limitation to the use of LANEX screen for measuring low beam charge in accelerator. In fact the LANEX cannot be placed at all in ultra-high vacuum (<10^{-6}mbar) because of a too important outgassing rate, especially in a photo-injector based accelerator as PHIL is. It thus prevents to use it in a large majority of electron accelerator. However, a sufficiently thick (>500µm thickness) YAG screen can be used in vacuum and produce a light intensity equivalent to that of LANEX and therefore measure beam charge lower than 100fC.

CONCLUSION

The LANEX screen has a perfectly linear luminous response to the beam charge from 3pC up to 200pC and probably beyond. It can be used to measure beam charge as low as 15fC with an ultimate resolution limit around 10fC, which is mainly due to the noise on the CCD camera signal. The measure taken with the CVD diamond detector confirms this value.

The values obtained were unable to be confirmed by the measure with the CVD diamond detector for an incident charge higher than $3*10^5$ electrons. Under vacuum measurements are intended with a new detector to find the origin of the discrepancy between the diamond detector and the screen at high charge. Different types of scintillating screen have also to be tested, in order to see if the discrepancy can be explained by a peculiar behaviour of the LANEX screen for low incident charge.

A YAG screen will be soon implemented in the DACTOMUS project to be used as single-shot charge diagnostic for electron beam generated and accelerated by laser-plasma interaction.

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REFERENCES

[1] A. Chance & al., "Transport line for a multi-staged laser-plasma acceleration : DACTOMUS", Nucl. Instr. Meth., A740, March 2014, p. 158-164
[2] M. Alves & al., "PHIL photoinjector test line", Journal of Instrumentation, Vol. 8, January 2013
[3] Cividec website : http://www.cividec.at/index.php?module=public.product_splash
[4] Matrix Vision website : http://www.matrix-vision.com/camera-GigE-Vision-mvbluecougar-s.html