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Time Resolved Spectrometry on the CLIC Test Facility 3

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Abstract

The high charge (>6ìC) electron beam produced in the CLIC Test Facility 3 (CTF3) is accelerated in fully beam loaded cavities. To be able to measure the resulting strong transient effects, the time evolution of the beam energy and its energy spread must be determined with at least 50MHz bandwidth. Three spectrometer lines are installed along the linac in order to control and tune the beam. The electrons are deflected by dipole magnets onto Optical Transition Radiation (OTR) screens which are observed by CCD cameras. The measured horizontal beam size is then directly related to the energy spread. In order to provide time-resolved energy spectra, a fraction of the OTR photons is sent onto a multi-channel photomultiplier. The overall setup is described, special focus is given to the design of the OTR screen with its synchrotron radiation shielding. The performance of the time-resolved measurements are discussed in detail. Finally, the limitations of the system, mainly due to radiation problems are discussed.

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Abstract

The high charge (>6μC) electron beam produced in the CLIC Test Facility 3 (CTF3) is accelerated in fully beam loaded cavities. To be able to measure the resulting strong transient effects, the time evolution of the beam energy and its energy spread must be determined with at least 50MHz bandwidth. Three spectrometer lines are installed along the linac in order to control and tune the beam. The electrons are deflected by dipole magnets onto Optical Transition Radiation (OTR) screens which are observed by CCD cameras. The measured horizontal beam size is then directly related to the energy spread. In order to provide time-resolved energy spectra, a fraction of the OTR photons is sent onto a multi-channel photomultiplier. The overall setup is described, special focus is given to the design of the OTR screen with its synchrotron radiation shielding. The performance of the time-resolved measurements are discussed in detail. Finally, the limitations of the system, mainly due to radiation problems are discussed.

INTRODUCTION

In the CTF3 linac the beam energy spread must be tuned precisely. The use of fully loaded accelerating structures [1] generates transient effects which result in a strong beam loading. In this context and if no correction is applied, the very first electrons experience a much higher accelerating field than the steady state part of the beam. Moreover, any fluctuations of klystron phase and amplitude must be controlled and adjusted so that the variations on beam energy and energy spread remain small during the whole pulse duration (1.5μs).

Spectrometer lines were developed with the aim of measuring beam energy spread with 50MHz bandwidth. Three lines are now routinely used along the linac. Different types of detectors were tested in the past [2] and we present here the use of an OTR screen coupled to a multi-anode photomultiplier (MAPMT).

Using a dipole magnet, the electrons are deviated by 23° to a dedicated beam line, as shown in Fig. 1. The beam position and its size are measured using an OTR screen imaged by a CCD camera. Time resolved measurements are obtained using a MAPMT. At the end of the line the electrons are then absorbed by Iron blocks.

Because of radiation issues the devices (camera, MAPMT) must be installed on the ground surrounded by an appropriate lead shielding. An optical line composed of a set of lenses is then used to optimize the collection of the OTR photons. An optical beam splitter divides the light intensity in two parts, guiding 70% of the photons onto the MAPMT and the remaining 30% onto the camera. An optical density filter wheel equipped with neutral density filters provides the required attenuation to avoid saturation of the CCD camera.

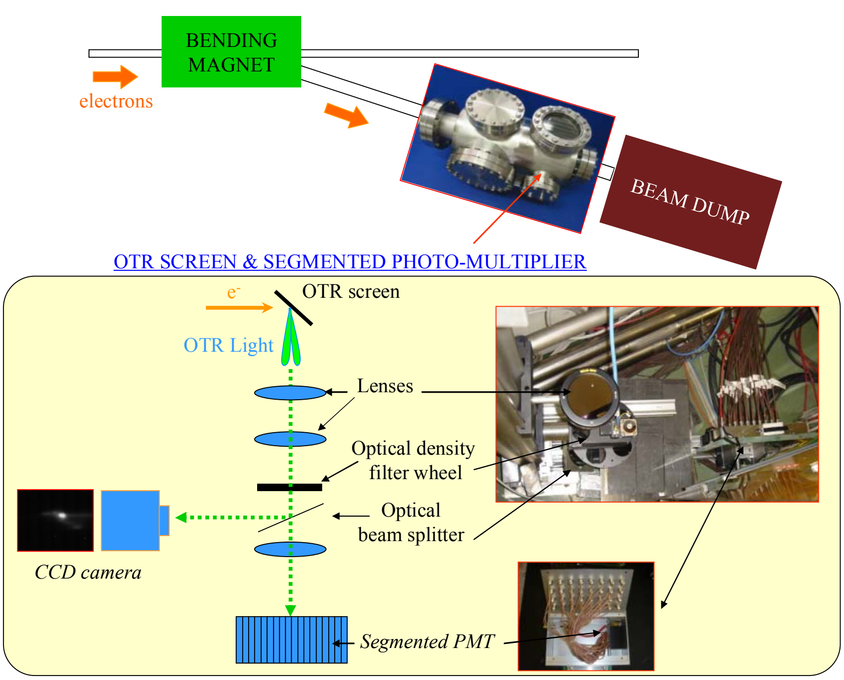

Figure 1: Layout of a spectrometer line

OTR SCREEN AND SYNCHROTRON LIGHT SHIELDING

When the electrons are bent in the spectrometer line, they emit synchrotron radiation (SR), which is reflected by the OTR screen and may degrade the performances of the monitors. Since the photons are not generated at the same longitudinal position, the SR light increases the measurement background and distorts the beam shape. SR spectrums have been calculated using the program XOP [3] for our beam parameters and the results are presented in Figure 2.

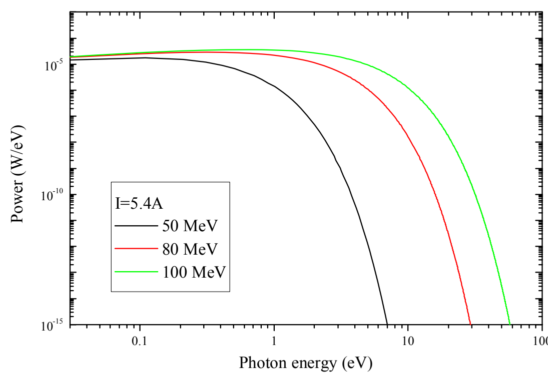

Figure 2: Synchrotron light spectrum in the spectrometer line. Calculations assume that a 5.4A current beam is bent by 23° and that the distance between the centre of the magnet and the screen is 1m.

In order to get the number of visible photons produced by SR in the dipole, the spectra are integrated between 2 and 3eV and compared to OTR yield calculations (see Table 1). The number of OTR photons emitted by an electron in the wavelength interval [λ_a, λ_b] is given by [4]:

$$N_{OTR} = \frac{2\alpha}{\pi}\left(\ln(2\gamma) - \tfrac{1}{2}\right)\cdot \ln\left(\frac{\lambda_b}{\lambda_a}\right)$$

with α the fine structure constant and β the electron velocity.

Energy (MeV)	SR [400,600nm]	OTR [400,600nm]
50	$1.5\ 10^{-9}$	$7.7\ 10^{-3}$
80	$5.0\ 10^{-4}$	$8.6\ 10^{-3}$
100	$4.0\ 10^{-3}$	$9.0\ 10^{-3}$

Table 1: Number of emitted photons / electron

For electron energies higher than 80MeV, the amount of SR produced in the bending magnet is comparable to the intensity of the OTR light. In order to efficiently stop the SR photons a 50μm carbon foil was implemented a few cm in front of the OTR screen as shown in Figure 3.

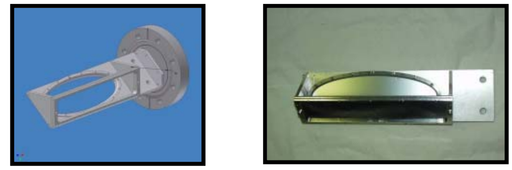

Figure 3: OTR screen tilted at 45° with respect to the beam trajectory equipped with a synchrotron radiation shielding.

MULTI-ANODE PHOTOMULTIPLIER

The horizontal beam size, measured at the screen position returns directly the beam energy spread. Time resolved energy spectra are obtained using a 32 channel multi-anode photomultiplier from Hamamatsu (model H7260). The signals are then digitized on 100MSa/s ADC's. The MAPMT has a 0.6ns rise time and the crosstalk between adjacent channels is lower than 3%. Due to the manufacturing process, the anode uniformity may fluctuate by 20% so that all channels need to be calibrated first using a pulsed laser. The signals are then corrected after digitization. The output voltage of the MAPMT cannot exceed some mV per channel. Thus to use the full dynamic range of the ADC (12bits, +/-2V), a 32 channel amplifier has been developed to increase the signal amplitude by 40dB with a 200MHz bandwidth. As an example signals corresponding to different channels are displayed in Figure 4.

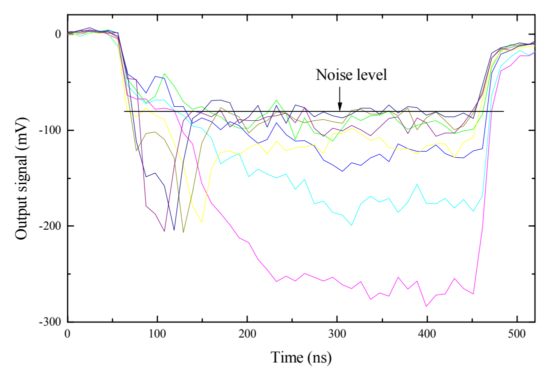

Figure 4: Signals from the MAPMT at a beam energy of 93 MeV

The MAPMT is sensitive to beam losses. Given the proximity of the beam dump blocks a non negligible amount of radiation is present in this area. This is visible in Figure 4, where the noise level is represented by the black line. With an amplitude three times smaller than the OTR signal, background radiation clearly limits the sensitivity of the measurements. The performances of the monitor are also linked to the optical limitations discussed in [5]. Improvements using parabolic or diffusive screens were already proposed and tested.

A MATLAB program reads the ADC's and plots the time resolved energy spectrum as shown in Figure 5(a). The beam energy is calculated and the beam energy spread can be measured in a user-defined time window, represented in Figure 5(a) by the two black lines. A profile is then extracted as shown in Figure 5(b) and the full width half maximum value of the curve gives the energy spread.

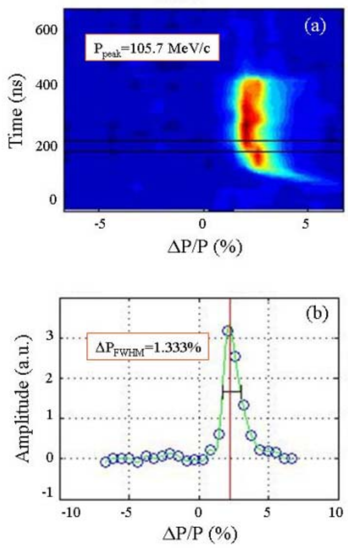

Figure 5: (a) Evolution of the beam energy spread with time at E=105.7 MeV. (b) Energy profile integrated over time

TIME RESOLVED ENERGY MEASUREMENTS

In order to run the machine as efficiently as possible, a beam loading compensation technique is used. The optimum is achieved if all electrons during the pulse duration experience the same accelerating field. If no correction is applied, the first part of the beam has a higher energy than in the steady state, as seen in Figure 6 (a). When the RF pulse is delayed by some 50ns with respect to beam pulse, the transient is compensated as shown in Figure 6(b).

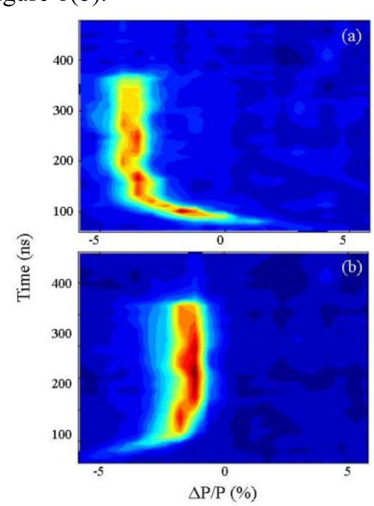

Figure 6: Energy Spectrum without (a) and with (b) beam loading compensation

Because of the tight requirements on the bunch combination scheme [6], the variations of the beam energy along the pulse duration must be monitored and controlled below the 1% level. The measurement presented in Figure 7 shows the energy spectrum on a 1μs long beam pulse. No saturation of the MAPMT is visible. The evolution of the beam energy and energy spread can be directly correlated to the temporal variations of the klystron phase.

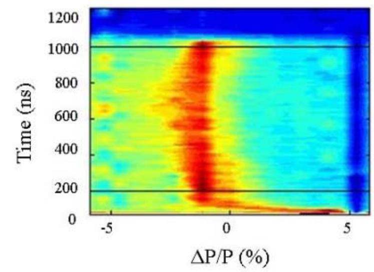

Figure 7: Energy spectrum for a 1μs long pulse. Beam energy is 73 MeV and FWHM energy spread is 1.8%

CONCLUSION AND OUTLOOK

Time resolved energy measurements are done along the CTF3 linac using OTR screens and a multi-anode photomultipliers.

The achieved time resolution is at the moment limited by the sampling rate of the ADC's (50MHz). It was demonstrated that the sensitivity of the monitor is limited by background radiation from beam losses. However, with a signal to background ratio of three to one, it was still possible to measure time resolved energy spectra for the tuning of the accelerator.

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