# BUNCH-BY-BUNCH LONGITUDINAL DIAGNOSTICS AT DAΦNE BY IR LIGHT

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*Abstract*

Compact uncooled HgCdTe semiconductor detectors optimized in the mid-IR range have been used to record time resolved single bunch synchrotron radiation (SR) emissions from the DAΦNE electron ring [1]. These IR devices allow a low cost bunch-by-bunch longitudinal diagnostics. Indeed, these detectors make possible to record a train of a few ns long bunches per turn. To the purpose of diagnostic a comparison with the light signals coming from the positron ring appears stimulating but at DAΦNE only two SR beamlines are operational on the electron ring. The lack of apertures in the shielding wall offers no easy alternatives for the emission from the $e^+$ ring. To solve the problem, a compact SR port has been designed and is going to be implemented at DAΦNE where a HV chamber and remotely controlled mirrors will focus the positron light on IR detectors.

The source characteristics have been simulated and the optical setup with the complete acquisition system will be described. After the installation and tests, a real time comparison between data collected with the two beams will be possible improving accelerator diagnostics and as a major tool to increase the stored currents in the $e^+$ ring and possibly the collider luminosity.

## INTRODUCTION

Particle accelerator diagnostics in the IR region has never been considered because visible light devices are much more popular easy to use and characterized by a large bandwidth (e.g. Si photodiodes, InGaAs Shottky photodiodes [2, 3] and also streak cameras). Moreover, many X-ray based synchrotron light monitors exist and they are preferred because of their spatial resolution, a characteristic extremely important to measure low and very low emittance beams and to obtain high resolution times (e.g., a few ps times) [4]. This is easier in particular for high energy accelerators while DAΦNE is a low energy collider working at 0.51 GeV and loosing 9.7 keV per turn for radiation damping.

The devices that we will describe in the next, acquire signals in the mid-IR, are vacuum compatible and work at room temperature without cooling. They represent the result of an important synergy that shares expertises from three quite different researches areas: astronomy, industrial semiconductor research and particle accelerator diagnostics.

## DESCRIPTION OF THE APPARATUS

The technology of IR detectors in the near and mid IR range based on photovoltaic devices, e.g., those fabricated on HgCdTe semiconductors and cooled at liquid nitrogen temperatures, is essentially limited to response times of a few ns. However, new uncooled mid-IR devices exhibit sub-ns response time and may be used with success for the detection of intense IR sources such as SR storage rings.

Figure 1 – Photo of the IR photoconductive device.

Uncooled and compact photoconductive (see Figure 1), photovoltaic or photoelectromagnetic IR devices, all working at ambient temperature, realized with HgCdTe semiconductors (see Figure 2) and optimized in the mid-IR range with sub-ns response times, are available for fast detection of the intense and brilliant IR SR emissions [5].

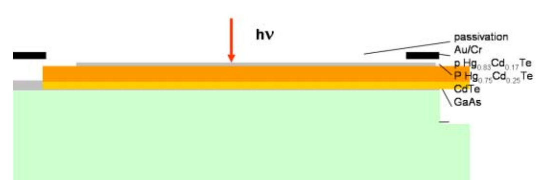


Figure 2 – Schematic cross section of an uncooled IR $Hg_{1-x}Cd_xTe$ photodetector.

## MEASUREMENTS ON THE ELECTRON BEAM

Since 2001 SINBAD (Synchrotron Infrared Beamline At DAΦNE) an IR SR beamline is operational at DAΦNE [6]. The IR beam is extracted by a bending magnet located in the external arc section of the electron ring. Time resolved measurements of the synchrotron light emitted by the $e^-$ bunches have been already carried out at SINBAD to monitor the longitudinal bunch length of the accumulated bunches [7,8]. Measurements with different single-element uncooled detectors have been performed detecting the pulsed structure of the IR light emission. The emission of the 106 bunches was measured by using uncooled photoconductive and photovoltaic detectors. The detectors have been placed at the focus of the last mirror at the entrance of the interferometer of the SINBAD beamline monitoring the pulsed structure of the DAΦNE emission (see Figure 3).

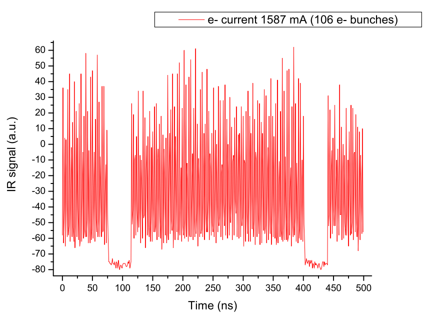


Figure 3: The DAΦNE electron bunches structure as detected by a fast IR uncooled device.

The IR emission of single bunches were measured by using a single element uncooled photoconductive detector. The device is a high-speed device operating at RT and optimized at 10.6 µm, typically a HgCdTe heterostructure fabricated on GaAs substrate that is buffered with CdTe or CdZnTe [9] (Figure 2). This device is front-side illuminated and as a consequence the absorption of radiation at any wavelength occurs only in the narrow energy gap absorbing layer.

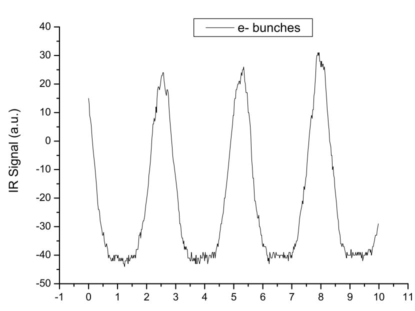


Figure 4: IR signal of three adjacent electron bunches.

The detector was biased by a current of about 20 mA through a bias tee. The output was amplified by a voltage amplifier (gain ~ 40 dB, bandwidth of 2.5 GHz) and acquired by a scope with a bandwidth of 6 GHz. The average rise time and fall time of the signal emitted by a single-electron bunch are about 560 ps and 600 ps respectively (Figure 4).

Measurements in multibunch and single bunch configuration have been carried out at DAΦNE with a photoconductive IR detector (see Figure 1). In multibunch mode, the electron synchrotron frequency has been measured as well the longitudinal feedback correct behaviour showed in Figure 5.

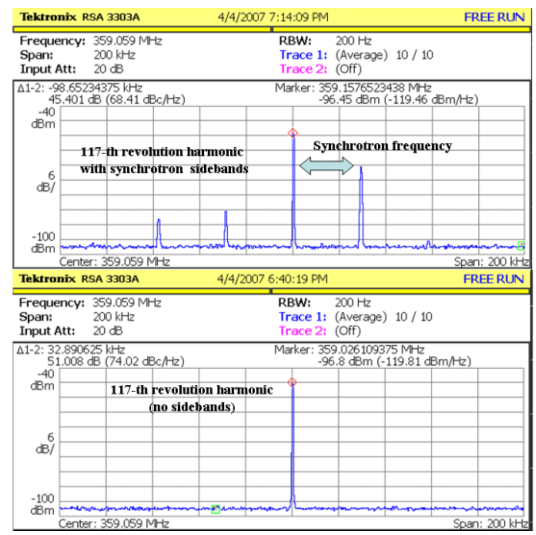


Figure 5: Upper panel: 106 bunches with 734 mA $e^-$ beam current and longitudinal feedback **off**. Lower panel: 106 bunches with 1227 mA $e^-$ beam current with longitudinal feedback **on**.

In a single bunch mode different currents have been stored, from ~3 mA to ~18 mA. For each electron current value, a signal has been measured with a single element uncooled photoconductive detector (Figure 6).

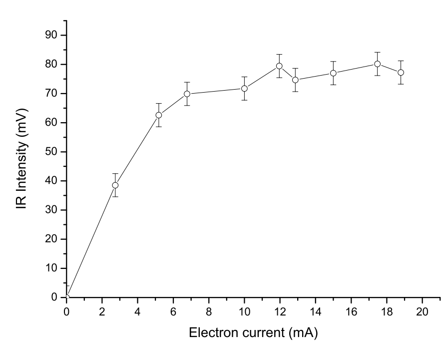


Figure 6: IR signal vs. the electron current.

The intensity of the bunch signal has been plotted vs. the electron currents in Figure 6. The detector is suitable for this experiments because also from this preliminary data is evident that the output signal collected by the experimental apparatus, e.g., detector and amplifier, was saturated when the electron current of a single bunch was about 8 mA (Figure 6).

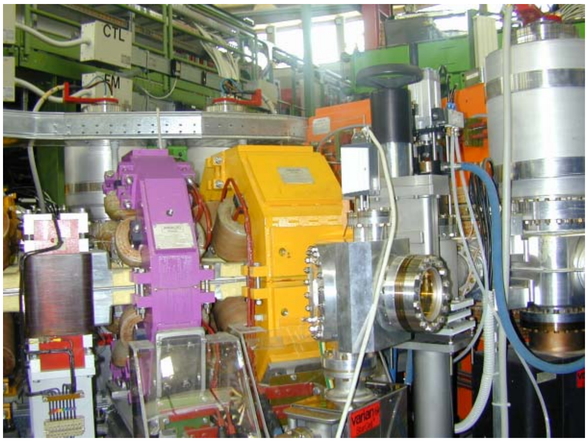


Figure 7: Photo of the exit port recently installed at one of the bending magnet of the DAΦNE positron ring.

## SIGNAL ACQUISITION FOR THE POSITRON BEAM

To the purpose in the future to measure bunch by bunch both the electron and positron signals with dedicated photoconductive or photovoltaic uncooled IR detectors, a new experiment, 3+L (*Time Resolved Positron Light Emission*), funded by the Istituto Nazionale di Fisica Nucleare, is going to be installed at the exit of a bending magnet at DAΦNE. A photo of the compact Al made HV chamber containing a gold coated mirror and the ZnSe IR window recently installed on one of the bending magnet of the positron ring is visible in Figure 7. After the window the IR beam will be focussed towards the detector by a set of mirrors working in air and remotely controlled.

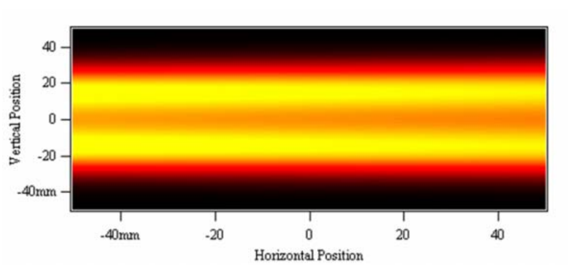


Figure 8: Simulation of the intensity distribution of the DAΦNE bending magnet IR emission at the wavelength of 10 μm.

To design the optical system we performed simulations of the IR source at the wavelength of 10μm (Figure 8). The vertical and horizontal intensity distribution of the IR synchrotron radiation source simulated at 20 cm from the ZnSe window with the SRW software package [10] is showed in Figure 9.

## CONCLUSIONS

Beam diagnostics is really a key aspect of the future advancement of accelerator and represents one of the major issues of the next generation storage rings and FEL's. As a consequence, this really simple and fast diagnostics tool has already demonstrated powerful capabilities to perform bunch-by-bunch longitudinal measurements. New IR devices are available and they promise to increase the detection performances to the sub-ns time domain [11]. As a consequence an accurate real time comparison of the longitudinal characteristics of $e^-$ and $e^+$ beams at DAΦNE where the typical bunch lengths are hundreds of ps appears then possible. When the 3+L installations will be tested a comparison between data collected from the two SR exit ports will be possible improving accelerator diagnostics in order to increase both the stored current in the $e^+$ ring and the collider luminosity.

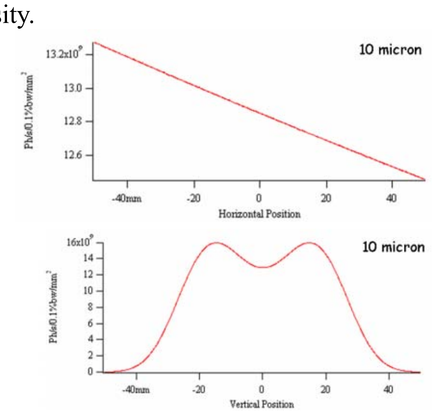


Figure 9: Vertical and horizontal intensity distributions of the IR source simulated at 20 cm from the window.

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