IR PHOTON ARRAY DETECTOR FOR BUNCH BY BUNCH TRANSVERSE BEAM DIAGNOSTICS

A. Bocci, M. Cestelli Guidi, A. Clozza, A. Drago, A. Grilli, A. Marcelli, A. Raco, R. Sorchetti,
INFN – Laboratori Nazionali di Frascati, Via Enrico Fermi 40, I-00044 Frascati RM, Italy
L. Gambicorti,
Istituto Nazionale di Ottica Applicata – CNR, Largo Fermi 6, 50125 Firenze, Italy
A. De Sio, E. Pace,
Università degli Studi di Firenze, Largo Fermi 2 , 50125 Firenze, Italy
J. Piotrowski,
VIGO System SA, 3 Swietlikow Str. 01-389 Warsaw, Poland

Abstract

Beam diagnostics based on synchrotron radiation (SR) may use real time imaging methods that monitor the beam transverse dimensions. In particular the bunch-by-bunch transverse beam diagnostics is a powerful method that allows investigations of transient phenomena in which bunch motion and instabilities are correlated to the position in the bunch train. Such diagnostic methods need photon array detectors with response time from ns to ps range and dedicated fast electronics. At DAΦNE, the e^+/e^- collider of the Frascati National Laboratory (LNF) of the National Institute of Nuclear Physics (INFN), tests with an IR array prototype made of 32x2 pixels and its electronics are in progress. The size of the pixels is ~50x50 μm^2 and their response time ~1 ns. In this contribution we describe an experimental set-up to obtain IR imaging of the SR source and a turn-by-turn and a bunch-by-bunch transverse diagnostics of the stored bunches with a sub-ns time resolution. Preliminary measurements obtained using the IR emission of the SINBAD beamline will be presented. Tests of the array detector with its 64 channels electronics are in progress at the ***T**ime **R**esolved **e+** **L**ight* (*3+L*) experiment, a dedicated diagnostics of the DAΦNE positron ring which monitors the longitudinal and transverse dimensions of the positron beam.

INTRODUCTION

Beam diagnostics tools based on synchrotron radiation (SR) are fundamental features of any collider dedicated to high-energy physics experiments and to storage rings optimized as synchrotron radiation sources. Moreover the SR, used for beam diagnostics, gives, as main advantage, a direct and non-destructive system of probing. Typical diagnostics by SR are usually based on expensive imaging techniques that allow measurements of the beam transverse dimensions as well as the longitudinal structure and the bunch length of stored particles (e.g., using a streak camera device). In particular, the real time measurements of the transverse beam dimensions and emittances are growing in interest for next generation of lepton colliders, synchrotron radiation sources and FELs.

In order to measure the beam emittance, the real time analysis of the beam transverse profile is a fundamental requirement of any particle accelerator.

Besides, bunch-by-bunch beam diagnostics is a powerful method for experiments of accelerator physics, such as studies of transient phenomena in which motion and instabilities of bunches depend on the position in the bunch train [1].

Turn by turn and bunch by bunch diagnostics can be implemented using very fast IR, visible, UV or X array detectors (from the sub-ns to the ps range) with dedicated electronics in order to collect and store a large amount of data. Recently at DAΦNE, the Frascati e+/e- collider, measurements of the time structure of synchrotron radiation emitted by the bunches have been performed using uncooled IR photon detectors, achieving a time resolution of a few hundred picoseconds [2]. Future foreseen applications of this technology are based on faster photo-voltaic devices with <100 ps response time and IR uncooled array detectors, to achieve bunch by bunch imaging of the photon source and to investigate transverse instabilities on the DAΦNE rings. In particular, the ***T**ime **R**esolved **e+** **L**ight* (*3+L*) experiment, dedicated to beam diagnostics, has been installed in the DAΦNE hall to collect the SR extracted by a bending magnet of the positron ring [3]. The SR is focalized by a set of mirrors in air in front of a fast IR photo-detectors in order to measure longitudinal lengths and transverse sizes of the bunches and to investigate bunch instabilities [4].

This novel device and its electronics have been assembled to test the first transverse diagnostics of the e^+ beam at DAΦNE at IR wavelengths. The device consisting of a fast array detector with 2x32 pixels exhibits a response time of ~1 ns. Preliminary data from single elements of the array and of the electronics have been acquired in order to characterize the assembled device. After completion of the device and its dedicated electronics we could monitor the beam both in the bunch-by-bunch and turn-by-turn transverse modes, two fundamental tools to improve accelerator performances, e.g., at DAΦNE to increase the positron current and the luminosity, and to monitor transverse beam instabilities.

In the following we describe the experimental set-up and present preliminary tests performed with several pixels of the array illuminated by the IR SR emission at the SINBAD beamline of DAΦNE.

EXPERIMENTAL SET-UP

DAΦNE is an e^+/e^- collider, with center of mass energy at 1.02 GeV, designed to operate at high current levels (>2 A) and up to 120 bunches [5]. DAΦNE can work with different bunch patterns: the present typical operation mode is with 105 consecutive electron buckets out of the available 120, with a gap of 15 bunches to avoid ion trapping in the electron beam. In this bunch configuration, the minimum bunch distance is 2.7 ns and bunches are characterized by a Gaussian shape with a bunch length of σ~56 ps.

At DAΦNE an IR photon beam extracted from a bending magnet located in the external arc section of the electron ring is already available for experiments [6]: the infrared SR beamline SINBAD (Synchrotron Infrared Beamline At DAΦNE) is operational since 2001. This beamline is dedicated to Infrared spectroscopy and microscopy and collects radiation at wavelengths from about 10 to 10000 cm^{-1} (1-100 μm). The prototype of the imaging device with its electronics board has been assembled for preliminary tests using the IR light of the SINBAD beamline. A picture of few pixels of the device and of the assembled array is shown in Fig.1.

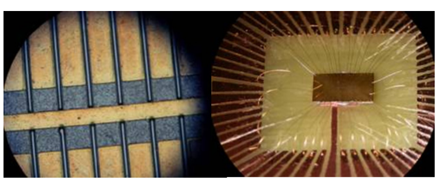

Figure 1: Magnified view of the IR array showing a few pixels of the photoconductive IR detector (left). Interface board and detector showing the connection between pixels and interface board made of gold bonding wires (right).

In this preliminary measurement an interface board has been built and the pixels of the array have been connected by gold bonding wires to the board and finally to the input of an analog electronics board. The dedicated electronics is composed of 64 channels with a bandwidth ≥1 GHz for channel built to amplify signals from the array with a gain of ~40-50 dB (depending on the power supply voltage). In order to characterize each pixel of the array, a four channels oscilloscope has been used to collect and analyze the signals. In the next future we plan to use a fast digital electronics in order to acquire and store the signals and the data of all 64 channels. In these preliminary measurements only four pixels of the array have been connected to the electronics board. These pixels belong to two different lines of the array. A layout of the array detector indicating the tested elements is shown in Fig 2.

The array has been placed at the focus spot of the optical system after the last toroidal mirror of the SINBAD beamline. The SINBAD optical system de-magnifies the source image by a factor 2.3 and its size is estimated about 2.0x1.5 mm at mid-IR wavelengths. The array has been placed in the vertical position in front to the IR spot. Because of the pixel size of the array (i.e. 50x50 μm^2) and because only 4 pixels were connected to the electronics, only a small part of the spot can now be monitored by the IR array for now. The signals of the four pixels have been collected at the same time by a scope with four input channels, a bandwidth of 600 MHz and 2.5 Gsample/s.

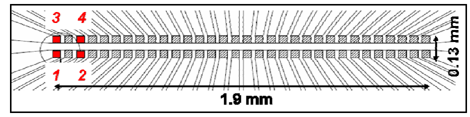

Figure 2: A layout of the IR array detector with its dimensions. Red pixels are those used for the tests.

EXPERIMENTAL DATA

Measurements obtained from a single pixel of the array are shown in Fig. 3. The individual IR emission of the 105 bunches of the beam and the gap can be resolved.

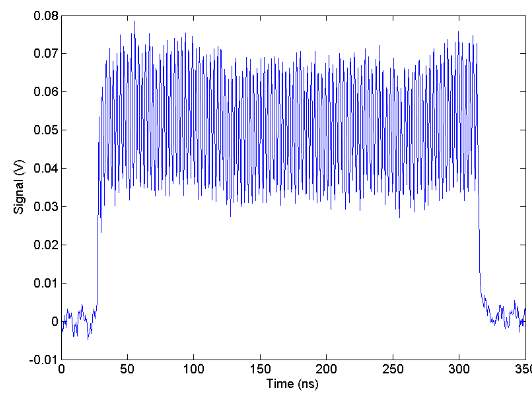

Figure 3: IR signals of the 105 electron bunches collected by one pixel of the IR array detector.

In order to reduce the noise level and to obtain a good S/N ratio the acquisition has been performed by averaging 200 sweeps of waveforms. In this measurement a maximum S/N~36 has been achieved with a beam current of ~1550 mA.

Fig. 3 shows also that the bandwidth of the system is large enough to separate the signals at a distance of ~2.7 ns between bunches even if the response to each bunch is not fast enough to reach the offset level at the beginning of the first bunch. Nevertheless, performing an exponential fit of the signal of the last bunch, a preliminary estimate of the response time of each pixel has been obtained.

The IR signal from the last bunch and its fit are compared in Fig. 4 (blue and red lines, respectively) yielding a response time of the pixel of ~1 ns. Comparing these data with those of other pixels, the response time varies between ~1 and ~1.3 ns. However, we need to underline that, in this configuration, the measurements are limited also by the bandwidth of the scope (600 MHz) limiting the resolution of the measurements.

As an example, two data sets obtained acquiring at the same time the signal of four pixels of the detector are compared in Fig. 5 and in Fig. 6, with an electron beam current of ~2000 mA and 1700 mA, respectively. The upper panel of Fig. 5 and Fig. 6 shows the signals of pixels 1 and 2 (black and red lines, respectively), the lower the signals of the pixels 3 and 4.

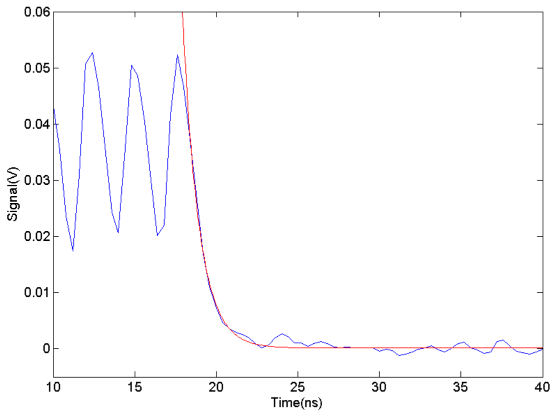

Figure 4: Signal from the last bunch of the train (blue line) and the fit (red line) used to calculate the pixel response time.

Plots in Fig.5 and in Fig. 6 refer to the first and to the last 22 bunches of the train, respectively. Actually, the four pixels measured two different portions of the IR spot and pixels 1 and 2 showed amplitude differences for different bunches, with the signal of pixel 1 always higher than that of pixel 2. The same results have been obtained with pixels 3 and 4, with the signal of pixel 3, at the same level of pixel 1, always higher than pixel 4. We explain this behaviour with a different illumination of the upper pixels (i.e., 1 and 3) collecting the brighter part of the spot. Differences between the relative amplitudes among bunches as measured by different pixels are also observed in both Fig. 5 and in Fig.6 but dedicated measurements are necessary in order to confirm this data.

Work is still in progress to measure the bunch-by-bunch transverse size of the source collecting data from all pixels of the array.

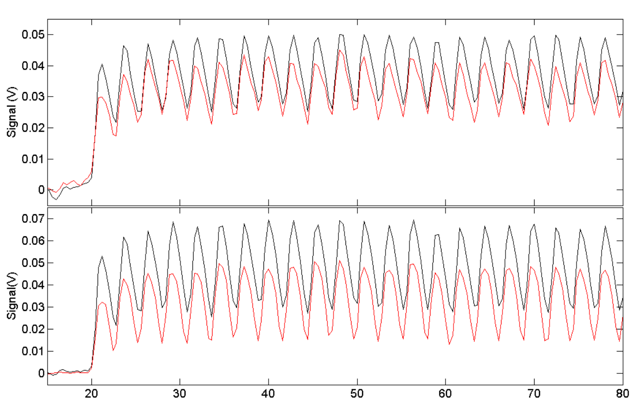

Figure 5: Data from four pixels of the array detector showing the first 22 bunches of the e- beam (I~2000 mA).

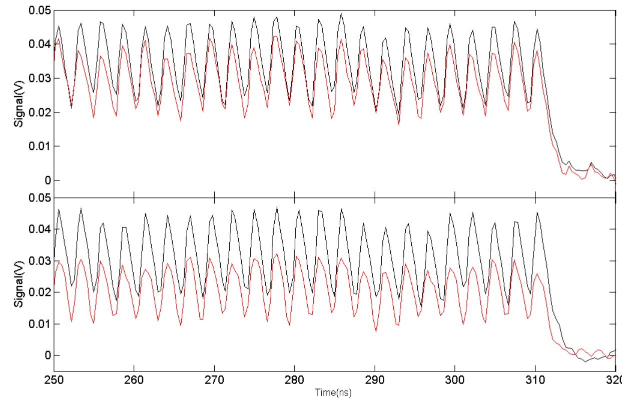

Figure 6: Data from four pixels of the array detector showing the last 22 bunches of the e- beam (I~1700 mA).

CONCLUSIONS

A first preliminary measurement of few pixels of a fast IR array detector have been performed. Four pixels of an IR array of 64 pixels were connected to four channels of an analog electronic board to test the device placed at the focus of the SINBAD IR beamline at DAΦNE. The measured response time of the pixels is about ~1 ns, sufficient to separate the emission of two consecutive bunches at DAΦNE (~2.7 ns). The signals from the pixels exhibit amplitude differences with respect to each other which can be correlated to the intensity of the source. Work is still in progress to connect all pixels of the array to store a fast transverse IR image of the circulating bunches. We plan also to characterize the linearity of the array elements, to acquire signals with a faster scope to improve the evaluation of the time resolution with a faster digital electronics. The array with the electronics board will be finally installed at the *3+L* experiment, with the goal to monitor the bunch-by-bunch longitudinal and transverse size of the positron beam at DAΦNE. This experiment will represent an important step to improve accelerator performances, e.g., positron beam dynamics and hopefully maximum collider luminosity.

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