BEAM DIAGNOSTICS OF THE POSITRON BEAM AT DAΦNE BY 3+L EXPERIMENT

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Abstract

At the Laboratori Nazionali di Frascati of the INFN to monitor real time bunch behavior of the positron ring of the DAΦNE collider a novel diagnostics experiment has been set-up on a bending magnet exit port of the positron ring. The front-end of the experiment consists of a UHV chamber where a gold-coated plane mirror deflects the radiation through a ZnSe window. After the window, a compact optical layout in air focuses the radiation on compact mid-IR fast uncooled HgCdTe photodiodes used to measure the bunch-by-bunch emission. Alignment of the mirrors and a first characterization of the radiation emitted have been performed. Here we present the longitudinal measurements of the bunch behavior in the time domain performed with fast IR detectors. This novel diagnostics is ready to allow real time monitoring of the bunch-by-bunch positron emission. The system has been designed to improve the DAΦNE diagnostics with the main aim to identify and characterize longitudinal bunch instabilities. Possible upgrades to improve detection capabilities in the transverse plane are considered.

INTRODUCTION

To improve the diagnostics of the e^+ ring of the DAΦNE collider, a novel beam diagnostics experiment: the 3+L (**T**ime **R**esolved **e**$^+$ **L**ight) has been proposed and funded by the Vth Committee of the Istituto Nazionale di Fisica Nucleare [1,2]. The main goal of the proposal is to perform bunch-by-bunch and turn-by-turn longitudinal and transverse beam diagnostics of the e^+ beam at DAΦNE in order to investigate bunch instabilities and to improve collider performances. The experiment assembled and tested in 2008 is now in operation in the DAΦNE hall and thanks to a compact optical system collects the IR synchrotron radiation emission from one of the bending magnet of the e^+ ring focusing the radiation on compact fast IR detectors performing a real-time bunch diagnostics. Here we present data of the e^+ bunch emission obtained with fast IR devices collected during standard DAΦNE runs.

EXPERIMENTAL SET-UP

The 3+ L optical systems collects the IR light extracted by a bending magnet with a critical energy of 273 eV placed after one of the two interaction regions (IP2) of the collider. It consists of a compact front-end with an HV chamber that hosts a gold-coated plane mirror. The mirror collects and deflects the synchrotron radiation through a ZnSe window that transmits radiation in the range 0.6 to 12 μm (800-17000 cm^{-1}). The following compact optical system is composed by 5 mirrors working in air that are installed and aligned after the ZnSe window in the DAΦNE hall. The optical system allows focusing radiation on a small spot of about 0.1 mm^2. A photo of the 3+L optical systems mounted on the positron ring is showed in Fig.1.

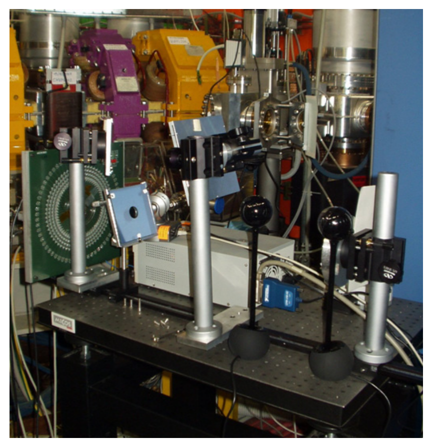

Figure 1: The optical system of the 3+L experiment aligned inside the DAΦNE hall.

Except the first two, the other mirrors are mounted on the optical table showed in Fig. 1. All mirrors are plane mirrors except the last one that is spherical. To maintain the layout as compact as possible, the 4th plane mirror has a centre hole to allow radiation focused by the 5th spherical mirror to have its focus behind the 4th mirror. Detectors placed behind the 4th mirror are mounted on a xyz micrometer stage to align them to the small light spot.

IR detectors are based on HgCdTe multilayer hetero-structures grown by MOCVD technology on oriented GaAs (211) and (111) substrates. These photo-detectors are optimized to work in the mid-IR at 10.6 μm. Actually the best response time of these detectors are of the order of 100 ps or lower when cooled at 205 K with a 3-stage Peltier cooler [3].

A PC installed in the DAΦNE hall allows the remote control and the acquisition of the experiment. In particular a PCI-COM bridge RS-232 board controls the motors and the xyz stage. Two web-cams and a camera monitor the detector position and positioning of mirrors. A fast scope (model Tektronics TDS 820) with 6 GHz of bandwidth is available and connected to the PC by a USB-GPIB interface for data collection. A power supply connected to the PC by a GPIB I/O controller is used to supply amplifiers and detectors. Dedicated software packages have been developed under the LabVIEW platform for data acquisition, to control the power supply of detectors and amplifiers, and to move the xyz stage.

EXPERIMENTAL DATA

In order to optimize the optical system of the experiment and to characterize the photon source at IR wavelengths both ray tracing simulations with the ZEMAX software and a wave optics simulation with the SRW package [4] have been performed. As an example, in Fig. 2 is showed the source image at 10 µm at the focus of the optical system as obtained by SRW.

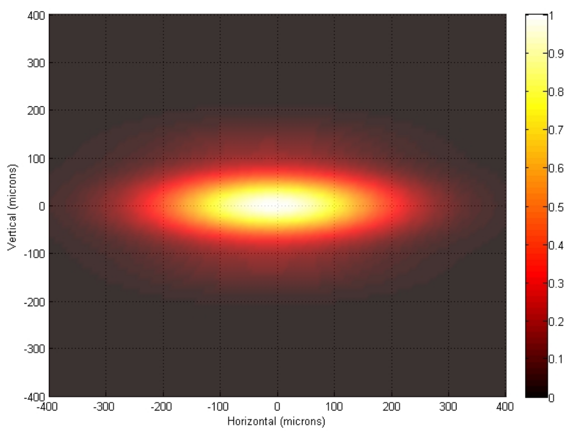

Figure 2: Simulated distribution of the IR photon beam at 10 µm as obtained by the SRW software.

A first characterization of the optical system has been first performed at visible wavelengths with a commercial CCD camera monitoring the spot size along the optical path around the focus in order to compare measurements with ray tracing simulations. The estimated FWHM of the visible spot is 750x150 μm^2 (HxV) a value slightly larger than data from the wave optics simulations and expected also at shorter wavelengths. However, we have to underline that the estimation is affected by the saturation of the central pixels of the CCD due the intense photon flux in the visible and the presence of optical aberrations due to the spherical mirror. At the wavelength of 10 µm the FWHM of the source at the focus point, showed in Fig. 2, is 340x110 μm^2.

The power of the source at the focus of the optical system allows obtaining with the fast IR detectors dedicated to the beam diagnostics a good S/N ratio. A determination of the source power at IR wavelengths has been performed using a calibrated NIST power meter. Data have been collected with a Melles Griot 13 PEM 001/J power meter and filters in the range 5-20 µm. In the range 5-20 µm, the estimated power at the focus of the optical system is ~2.2 mW with an accumulated current of 500 mA. Calculations of the bending magnet power with respect to the slit in the same wavelength range (5-20 µm) and with the same beam current returned ~3.2 mW, a value comparable with the experimental data obtained with the power meter at the focus of the optical system.

During DAΦNE operations different fast IR photon detectors were tested at the focus of the optical system. In particular, measurements were carried out using an uncooled IR photodiode. A first characterization of the e^+ beam has been performed with these detectors. In Fig. 3 we show the signal of few e^+ bunches acquired with a beam current of 650 mA. As showed in the figure, the time resolution of the apparatus allows the separation of the emission between two consecutive bunches of the e^+ beam and addresses the possibility of a real time longitudinal bunch-by-bunch diagnostics.

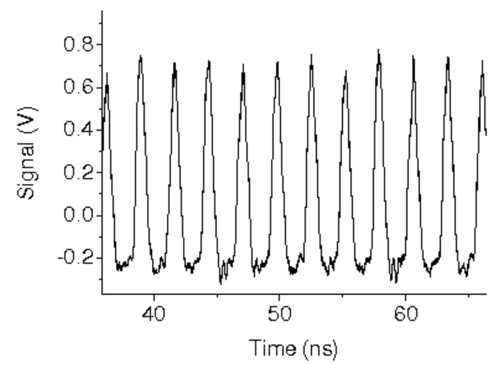

Figure 3: The pattern of the e^+ bunches. The response time of 3+L experimental set-up resolve a separation between consecutive bunches up to 2.7 ns.

The shape of a single e^+ bunch acquired with the 3+L experimental set-ups and an uncooled IR photodiode is showed in Fig. 4.

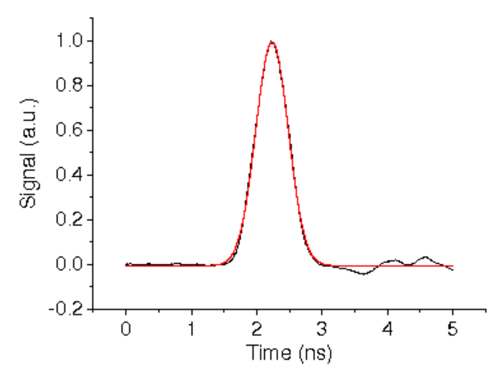

Figure 4: The shape of a typical e^+ bunch (black curve) and its Gaussian fit (red curve) at IR wavelengths.

From these experimental data we may obtain bunch parameters, information regarding detector characteristics and an evaluation on the performance of the electronics.

Data show that the bunch profile is Gaussian with a length of σ~240 ps with a bunch current of ~5 mA. The estimated rise time and fall time of the detector is ~400 ps. Comparison of data obtained with IR detectors at the same bunch current with data collected with the streak camera at visible wavelengths (σ~66 ps) [5] shows that the σ at IR wavelengths is from 3 to 4 times larger. As a consequence, at present the experimental set-up is still slower with respect to the streak camera but improvements are expected in the next future using optimized electronics and more performing detectors.

IR ARRAY DETECTOR FOR FAST IMAGING

A prototype of an imaging device with a new electronics board has been assembled and is now ready for tests. To characterize performances of this device we planned in the next months also tests on the e^- ring using the IR beamline SINBAD. The device is a photon array detector composed by 2x32 pixels working at mid-IR wavelengths. Each element has 50x50 μm^2 area and a time response of about 1 ns. A photo of few pixels of the device and of the assembled array is showed in Fig. 5.

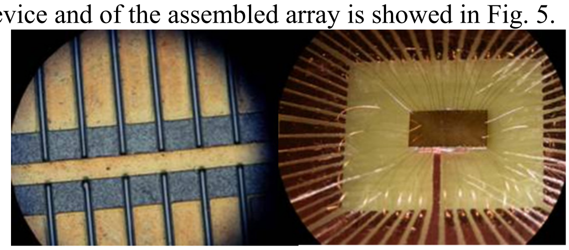

Figure 5: A magnified view showing few pixels of the photoconductive IR array detector (left). The interface board and the array detector showing the connection among pixels and the interface board made by gold bonding wires (right).

A first interface board has been built and pixels of the array have been connected by gold bonding wires to the board and finally to the input of an analogue electronics board (see Fig. 5). A fast dedicated electronics composed by 64 channels with a bandwidth of about 1 GHz for channel has been built to amplify signals of the array with a gain of ~60 dB. For this first preliminary set-up at the output of each channel of the electronics we use *SMA* connectors. In order to characterize each pixel of the array a fast scope will be used to collect and analyze signals. In the next future we plan to use a fast digital electronics in order to acquire and store the signals of all 64 channels. The array may be able performing real time imaging of the DAΦNE IRSR source and a turn-by-turn and a bunch-by-bunch diagnostics of the transverse dimensions of the e^+ beam. With such new diagnostics device would be possible the investigation of beam instabilities possibly trying to correlate them with bunch positions along the train. This real-time diagnostics could improve DAΦNE performances and possibly increase the e^+ current and the collider luminosity.

CONCLUSIONS

A novel experiment dedicated to the longitudinal beam diagnostics of the e^+ beam of the DAΦNE collider has been installed at DAΦNE. The experiment is based on compact fast photon IR detectors that allow detecting the synchrotron radiation extracted by a bending magnet of the e^+ ring. In principle, the experiment could allow the bunch-by-bunch longitudinal diagnostics of the e^+ beam improving the available diagnostics of the DAΦNE machine. Preliminary and limited measurements have been performed with our fast uncooled IR photodiodes. At present, the rise and fall time of the experimental setup is ~400 ps allowing the measurement of the single e^+ bunch length of σ~240 ps with a bunch current of ~5 mA. Although this value is 3-4 times larger than the bunch length measured with a streak camera at visible wavelengths, the results achieved show that diagnostics at IR wavelengths is possible in the sub-ns time domain using IR uncooled photodiodes. Better results could be obtained using faster (cooled) IR photodiodes and with a dedicated fast electronics, i.e., improving the actual time resolution achieved in the 3+L experiment. However, these IR detectors may be successfully used in other accelerators with longer FWHM bunch lengths [6]. A new device and a dedicated electronics has been also built and assembled in order to attempt the first transverse diagnostics of the e^+ beam of DAΦNE at IR wavelengths. The device is based on a fast array detector made by 2x32 pixels with a pixel response time of ~1 ns. First tests of the single elements of the array and of the electronics are in progress in order to characterize the assembled device. This latter device and its dedicated electronics could allow both the bunch-by-bunch and the turn-by-turn transverse beam diagnostics at DAΦNE, useful techniques to monitor transverse beam instabilities in order to improve accelerator performances, e.g., a higher e^+ current and a higher collider luminosity.

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