

BEAM DIAGNOSTICS WITH IR LIGHT EMITTED BY POSITRON AT DAΦNE

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Abstract

Real-time beam diagnostics is a key issue of accelerator operations and is certainly one of the most demanding aspects of modern storage rings and 4th generation radiation sources such as FEL's. Compact and vacuum compatible mid-IR fast uncooled photo-detectors have been tested at DAΦNE to monitor single e^- bunches with a FWHM of 150-300 ps separated by 2.7 ns. These detectors appear suitable to set up a compact and low cost bunch-by-bunch longitudinal diagnostic device useful to improve the DAΦNE diagnostic. To this purpose a bending magnet synchrotron radiation (SR) front end on the e^+ ring has been set-up with a HV chamber, a gold-coated plane mirror and an IR window. The system will allow collection of the SR light for tests of IR detectors and diagnostic of e^+ bunches using a compact optical system installed in air after the IR window. Here we will present the DAΦNE source characteristics, the optical setup and the detector acquisition system that may allow to monitor, identify and characterize bunch instabilities and/or increase the DAΦNE current in the e^+ ring.

INTRODUCTION

Beam diagnostics is a fundamental aspect of any collider dedicated to high-energy physics experiments but also of storage rings optimized as synchrotron light sources. Indeed, particle accelerators emit synchrotron radiation in a wide energy range that spans from IR to X-ray energies with a time structure that depends by the temporal characteristic of the stored beam. Actually, the analysis of the radiation characteristics, e.g., intensity, spatial distribution, spectral emission, polarization, etc., can be used to observe the beam instability and to measure the characteristic of the light source, i.e., the spatial and temporal distribution of the accumulated particles. As consequence, in storage rings the synchrotron radiation can be really used for beam diagnostics and the principal advantage of photon diagnostic is that it is a direct and non-destructive probe. Typical diagnostic based on synchrotron radiation is based on expensive imaging techniques that allow measurements of the beam transverse dimensions as well as the longitudinal structure such as the bunch length of stored particles. The bunch length is an important parameter of accelerators that is directly correlated with beam dynamics. However, due to the short pulse length fast detectors are required to perform diagnostics with synchrotron light.

Diagnostics at third generation synchrotron radiation sources needs devices with response times from the sub-ns to the ps range. Future FEL sources will require faster detectors with a response time in the fs domain.

An almost standard beam diagnostic device is a streak camera. With such a device images of the temporal structure of particle beams can be obtained with a time of ~ 1 ps or below. The principal drawback of streak cameras is the cost. Moreover streak cameras are delicate and complex devices to manage. Fast, compact and cheaper photon devices such as photodiodes, much easier to manage with respect to a streak camera may represent an effective and reliable alternative for photon beam diagnostics. Indeed, the principal requirements of future beam diagnostic devices are: temporal resolution at least in the sub-ns regime to guarantee the installation in all accelerators, compactness and robustness. Moreover, they could be also easy to manage, possibly vacuum compatible and of low cost.

The accessibility of room temperature infrared devices based on HgCdTe alloy semiconductors already now allow obtaining sub-ns response times [1]. These detectors optimized for the mid-IR range can be used for fast detection of the brilliant synchrotron radiation IR sources and afterwards for beam diagnostics. Recently at DAΦNE, the e^+e^- collider of the LNF laboratory of the Istituto Nazionale di Fisica Nucleare (INFN) measurements of the pulsed synchrotron light emission have been performed with uncooled IR photo-conductive detectors achieving a resolution time of about few hundred of picoseconds [2,3]. Experiments have been performed at SINBAD (Synchrotron Infrared Beamline At DAΦNE), the IR beamline operational at Frascati since 2001 [4]. To improve DAΦNE diagnostics a new experiment, 3+L (*Time Resolved Positron Light Emission*), funded by the Vth INFN Committee, started the installation at the front end of one of the bending magnet of the DAΦNE positron ring. The experiment will allow monitoring the positron bunch lengths at DAΦNE with the principal aim to study and characterize the instabilities of the positron beam and in order to possibly increase the positron current and the collider luminosity.

In the next a short description of the 3+L experiment, of the optical simulations and of the actual status of the experiment will be given. We will present also preliminary measurements of electron bunches collected at the SINBAD beamline and performed with photo-voltaic IR detectors working at room temperature. These

photo-voltaic detectors are based on HgCdTe multilayer heterostructures grown by MOCVD on (211) and (111) GaAs substrates. Their response time is of the order of 100 ps or lower if cooled at 205 K [5,6]. A preliminary characterization of these photo-voltaic devices has been performed and the analysis is in progress. Additional tests on these photodiodes will be performed on the electron beam in order to understand how to improve the resolution time with respect to the response time characteristic of photo-conductive devices. After the characterization on the SINBAD beamline devices will be used for the beam diagnostics in the 3+L experimental set up. Finally we will show how to perform transverse diagnostics with new fast IR array detectors working at room temperature.

3+L EXPERIMENT: POSITRON BEAM DIAGNOSTICS

To improve storage ring diagnostics and to perform bunch by bunch beam diagnostics on the positron ring, a compact experimental installation has been recently set up inside the DAΦNE hall in the framework of the 3+L experiment. DAΦNE is the Frascati e^+/e^- collider, with a center of mass energy of 1.02 GeV, designed to operate at high current (~ 2 A), up to 120 bunches [7] and with different bunch patterns. The minimum bunch gap is 2.7 ns with a maximum achieved single-bunch current of ~ 20 mA. Bunches have a quasi-Gaussian shape with a FWHM length ranging from 100 to 300 ps and will be monitored with fast IR photo-conductive and photo-voltaic detectors whose preliminary tests have been recently performed at SINBAD. In Fig. 1 a characteristic measurement of the IR emission of the first bunch of the electron structure is showed.

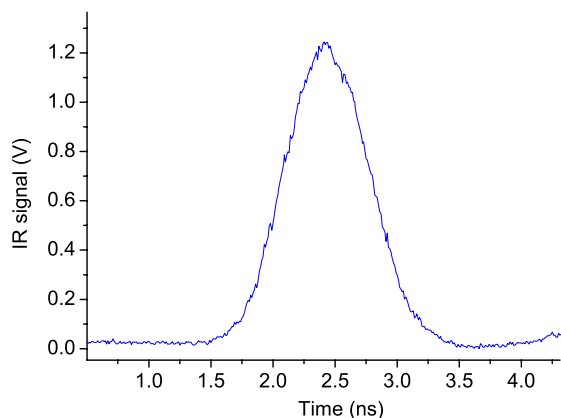


Figure 1 : The first bunch of the electron structure measured with a fast photovoltaic IR detector.

The rise time and the fall time of the IR signal showed in Fig. 1 are about of 550 ps and 630 ps, respectively with a FWHM of about 750 ps. The current of the measured

bunch was about of 14 mA. The signal of the IR photodiode has been amplified by a voltage amplifier with a bandwidth of 2.5 GHz and a gain of ~ 40 db and stored with a 6 GHz Tektronix TDS 820 scope. Measurements were performed at room temperature although using a three stage Peltier cooler such detectors cooled at lower temperature (~ 205 K) may achieve a response time of the order of 100 ps or lower. Further characterization of these detectors will be then performed at lower temperature before they will be used for the diagnostics of the positron beam.

The layout of the 3+L exit port installed in the DAΦNE hall is outlined in Fig. 2. The IR light will be extracted by a bending magnet having a critical energy of 273 eV positioned after one of the two interaction regions of DAΦNE. Actually, this exit-port is the only available in the positron ring. The experiment, in the final installation phase, consists in a simple front-end with an HV chamber that hosts a gold-coated plane mirror. This mirror collects and deflects the IR radiation through a ZnSe window. The IR window allows transmission of radiation in the range 0.6 to 12 μm ($800\text{-}17000\text{ cm}^{-1}$). Finally, as illustrated in Fig. 2, a simple optical layout composed by 5 mirrors in air, set after the window, will allow focusing radiation on a small spot.

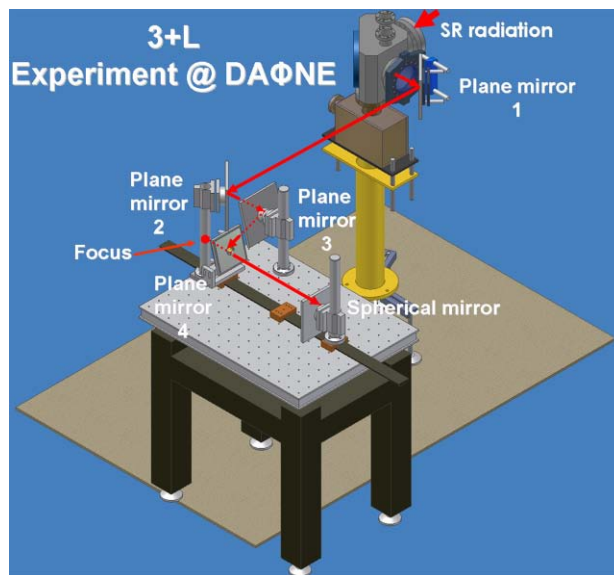


Figure 2 : The optical layout of the 3+L experiment. The path of the light is outlined by red lines. The 4th (plane) mirror has a center hole because the radiation is focalized by the 5th (spherical) mirror behind this mirror.

The mirrors of the optical system are mounted on an optical table as showed by the photo in Fig. 3. The optical layout is based on four plane mirrors that collect the emitted radiation towards a spherical mirror that will focus $10 \times 10\text{ mrad}^2$ of the radiation on the detector position (see Fig. 2). Ray tracing simulations have been carried out to design and optimize the optical system.

Different fast IR detectors could be aligned on the focus spot of the optical system through a motorized and remotely controlled xyz stages. A remotely controlled scope connected to a PC by a GPIB I/O controller will be used to collect data with a dedicated software package developed for acquisition under the Labview platform.

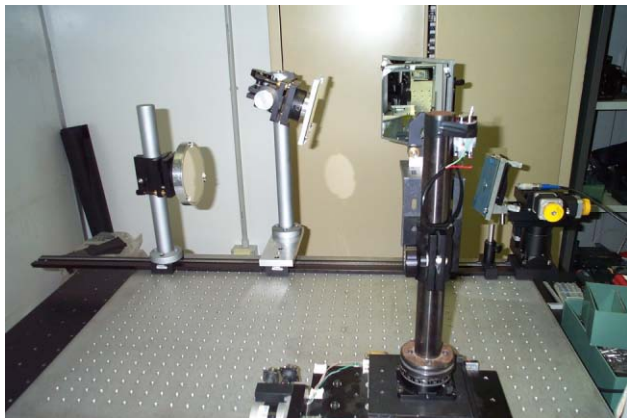


Figure 3: Photo of three plane mirrors and of the spherical mirror (on the left) of the 3+L optical system under alignment on an optical table.

To design and optimize the optical system and to compare the measured intensity of the IR source we performed wavefront propagation simulations at the wavelength of $10\ \mu\text{m}$ with the SRW software package [8]. To calculate the flux of the source at the focus of the optical system different simulations have been performed. To characterize the power of the source we have also performed preliminary measurements at the exit of the window with a calibrated NIST power meter. Data have been collected with the Melles Griot 13 PEM 001/J power meter and different filters in the range $5\text{--}20\ \mu\text{m}$. The source power measured after the first mirror of the 3+L optical system is $\sim 0.08\ \text{mW}$. A careful comparison between measurements, simulations and calculations is in progress although from the first evaluations we estimated that in the energy range $0.6\text{--}10\ \mu\text{m}$, more than 50 % of the energy of the source at the exit port is focused in a $400 \times 400\ \mu\text{m}^2$ spot at the end of the optical system. When the optical system will be aligned a direct measurement of the power concentrated in the focus spot will allow an effective evaluation of the transmission of the optical system.

CONCLUSIONS

To improve beam diagnostics of the DAΦNE accelerator complex, in addition to test of fast IR detectors, the set up of the 3+L experiment is in progress at the exit port of one of the bending magnet of the positron ring. Using this optical layout, IR photo-conductive and photo-voltaic will characterize the bunch by bunch emission of the beam. These devices made by

MCT semiconductors working at room temperature or cooled down to 205 K are: fast, robust, vacuum compatible, easy to manage and in particular are available at much lower cost if compared with existing diagnostic systems. Measurements performed at DAΦNE at the SINBAD beamline, with uncooled photo-conductive detectors, looking at the time structure of the electron bunches showed a sub-ns response time. Preliminary measurements with faster IR photodiodes ($\sim 100\ \text{ps}$ response time) are also in progress.

The 3+L experiment has been also designed to monitor the bunch profiles of the stored positrons and to identify and characterize beam instabilities. Data could be used to increase the current on the e^+ ring and the collider luminosity. Indeed, positron bunch instabilities already observed at DAΦNE and associated to the occurrence of e^- cloud effect inside the pipe [9,10], actually limit the maximum available positron current to $\sim 1.3\ \text{A}$.

Detailed and simultaneous measurements and comparison of bunch lengths in both electron and positron rings by fast photon detectors could be very helpful to investigate and characterize instabilities phenomena and possibly to understand the role of e^- cloud effects and how they limit the maximum stored current in the DAΦNE positron ring.

Future foreseen applications of the uncooled IR technology are small array detectors to perform bunch by bunch imaging of the source and to investigate simultaneously transverse bunches instabilities on the DAΦNE rings. First prototypes made by 32×2 pixels each $50 \times 50\ \mu\text{m}^2$ are under test at the SINBAD beamline.

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