BEAM DIAGNOSTICS AT DAΦNE WITH FAST IR DETECTORS

Alessio Bocci, INFN/LNF, Frascati, Italy

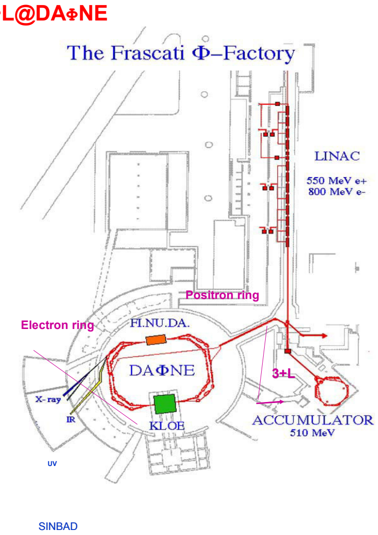
School on Beam Diagnostics for Particle Accelerators
Royal Holloway University of London
30.3. - 3.4. 2009

Abstract

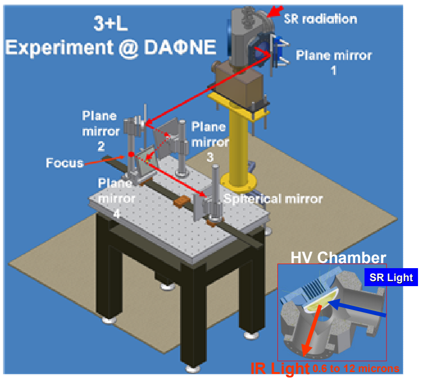
Real-time beam diagnostics is a key issue of accelerator operations and is certainly one of the most demanding aspects of modern storage rings and 4th generation radiation sources such as FEL's. Compact and vacuum compatible mid-IR fast photo-detectors are under tested at DAΦNE to monitor e^- and e^+ bunches with a FWHM of 150-300 ps separated by 2.7 ns [1,2]. These detectors appear suitable to set up a compact and low cost bunch-by-bunch longitudinal diagnostics device at DAΦNE. To improve performances of the e^+ ring of the DAΦNE collider, a beam diagnostics experiment: the 3+L (Time Resolved Positron Light Emission) has been funded by the Vth Committee of the Istituto Nazionale di Fisica Nucleare [3,4]. Instrumentations have been assembled and tested in 2008 and is now in operation in the DAΦNE hall collecting the IR synchrotron radiation emission from one of the bending magnet of the e^+ ring. Here are presented the DAΦNE source characteristics, the simulations performed with the SRW software, the optical setup, the photo-detectors and preliminary measurements of the e^+ beam. Measurements performed at Hefei Light Source (HLS) compared with data collected by a fast visible photodiode are also presented.

3+L@DAΦNE

DAΦNE is the Frascati e^+/e^- collider with a center of mass energy of 1.02 GeV, high currents (>2 A) and up to 120 bunches. Different bunch patterns can be stored with a minimum bunch distance of 2.7 ns and a maximum achieved single-bunch current of ~20 mA. Bunches have a quasi-Gaussian shape with a length in the range of 100 - 300 ps FWHM. Since 2001 an IR beamline is operational at Frascati: SINBAD (Synchrotron Infrared Beamline At DAΦNE). The 3+L instrumentation is installed after the IP2, one of the two interaction regions of DAΦNE and collects the IR light extracted by a bending magnet with a critical energy of 273 eV.



Time Resolved Positron Light Emission 3+L

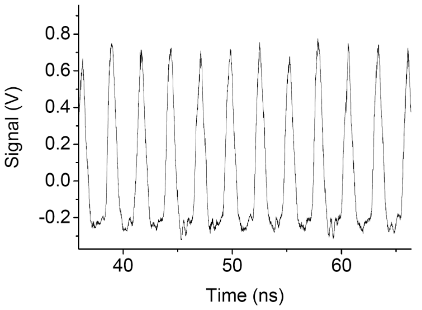


The 3+L experiment consists in a compact front-end with an HV chamber that hosts a gold-coated plane mirror. The mirror collects and deflects the synchrotron radiation through a ZnSe window that transmits radiation in the range 0.6 to 12 microns (800-17000 cm^{-1}). A compact optical system composed by 5 mirrors working in air have been 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 schematic optical layout of the 3+L exit port and of the optical system is showed above.

The mirrors are mounted on an optical table. They are plane mirrors except one spherical mirror used to focus the IR beam. To maintain the layout compact, the 4th plane mirror has a centre hole to allow radiation focused by the last spherical mirror to have its focus behind the 4th one. Detectors are mounted on an xyz micrometer stage in order to align the devices to the light spot.

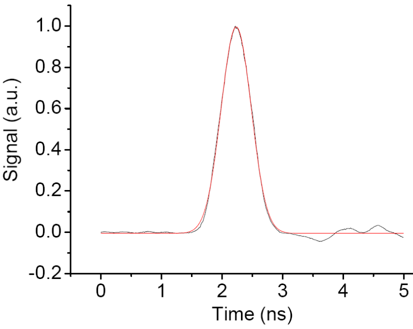
Experimental data with e^+ bunches

IR emission of 10 bunches separated by 2.7 ns detected by an IR uncooled photovoltaic detector at DAΦNE



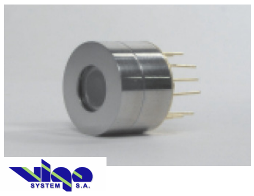
A first preliminary characterization of the e^+ beam with IR detectors has been performed. The signal of few e^+ bunches acquired when a beam current of 650 mA was circulating in the e^+ ring is showed in the figure above. The time resolution of the set-up allows the separation of the emission of single bunches of the e+ beam and addresses the possibility of a real time longitudinal bunch-bunch diagnostics.

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



The above plot shows that the bunch profile is Gaussian with a length of ~240 ps. The rise time and the fall time of the detector is ~400 ps. Comparison of data obtained with IR detectors with those obtained with the streak camera at visible wavelengths [7] and at the same bunch current shows that evaluations performed at IR wavelengths are from 3 to 4 times higher. Improved performances are expected in 2009 with an optimized electronics and detectors.

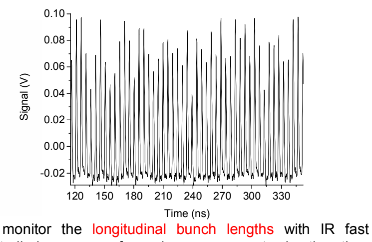
IR Photodetectors



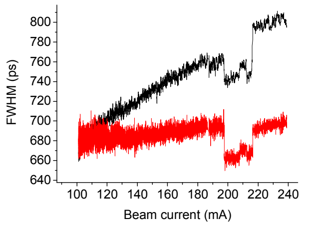
The availability of uncooled infrared devices optimized in the mid-IR range (10.6 μm), based on HgCdTe alloy semiconductors allows obtaining sub-ns response times. These detectors can be used for fast detection of the intense synchrotron radiation IR sources and then for beam diagnostics. IR detectors are based on HgCdTe multilayer heterostructures grown by MOCVD technology on oriented GaAs(211) and (111) substrates. These photo-detectors have a response time of ~100 ps or lower when cooled at 205 K with a 3-stage of Peltier cooler [6].

Measurements performed at Hefei Light Source (China)

Within the framework of the Scientific and Technological Co-operation Agreement between the Italian Republic and the People's Republic of China supported by Italian Ministry of Foreign Affairs, in order to compare the data collected at DAΦNE using the same diagnostics technique, we performed experiments at the IR port of the Hefei Light Source (HLS), the dedicated synchrotron radiation facility of the Hefei National Synchrotron Radiation Laboratory (NSRL). Measurements of the bunch lengths of the electron beam at different beam currents have been performed and compared with data of the diagnostics beamline operational at HLS. The instrumentation allowed measurements of the longitudinal lengths of the electron beam with a fast visible photodiode that were compared with the IR data.

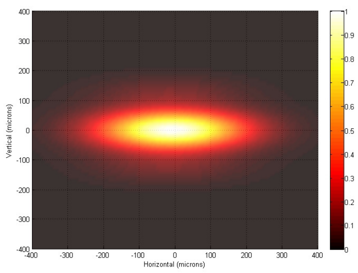


To monitor the longitudinal bunch lengths with IR fast photodiodes we performed measurements in the time domain. At HLS the RF is 204.016 MHz and the revolution frequency is 4.534 MHz. The full-fill pattern of the machine is 45 bunches with a total beam current ranging from 100 to 300 mA and a bunch separation of 4.9 ns. A measurement *of the IR signal of the 45 e^- bunches stored in the HLS ring is reported above.*



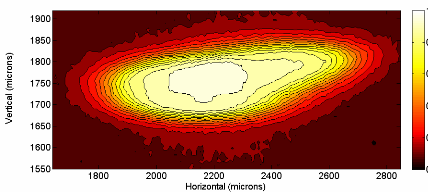
During normal runs at HLS, we collected the signal of the same bunch with both the IR and the visible photodiode after the bunch re-filling monitoring the length vs. beam current. The FWHM of the bunch as function of the beam current during one run is showed above. Red curve refers to data of the IR photodiode while black one refers to the visible detector.

SRW simulations



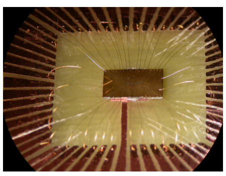
To optimize the optical system and to compare the measured intensity of the IR source, we performed simulations at the wavelength of 10 μm with the SRW software package [5]. From simulations at 10 μm we obtained a spot with a FWHM of 340 x 110 μm^2 at the focus of the optical system (see above).

CCD camera

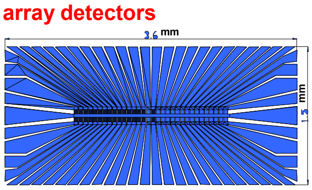


In order to compare the simulations of the beam spot with the measurements, a first characterization of the optical system has been performed with a commercial CCD camera. The CCD was used to monitor the spot size of the beam along the optical path. In the figure above is showed the contour plot of the smallest focal spot measured with the CCD. The estimated FWHM of the visible spot is ~750x150 μm^2 (HxV).

IR fast array detectors



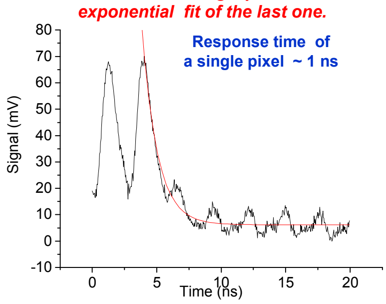
The interface board and the array detector. The pixels are connected to the interface board by gold bonding wires.



A layout schematic of the IR array photo-detector.

A prototype of an imaging device has been also assembled and first tests are planned. The device is a fast photon array detector composed by 2x32 pixels working at mid-IR wavelengths. Each element has 50x50 μm^2 area and a measured time response of about 1 ns. A fast dedicated electronics composed by 64 channels has been built. The array may allow real time imaging of the DAΦNE IR synchrotron source and a turn-by-turn and a bunch-by-bunch diagnostics of the transverse dimensions of the e^+ beam.

IR signal of the last two bunches collected with a single pixel and the exponential fit of the last one.



References

1. A. Bocci et al., NIMa, 580, 1 (2007) 190-193.
2. A. Bocci et al., *Bunch-by-bunch longitudinal diagnostics at DAΦNE by IR light*, DIPAC'07, Venice, May 2007, WEPB29, http://felino.elettra.trieste.it/papers/WEPB29.pdf.
3. A. Bocci et al., "Beam diagnostics at DAΦNE with fast uncooled IR detectors", Proc. BIW'08, http://www.als.lbl.gov/biw08/papers-nal/WECOTC03.pdf (2008).
4. A. Bocci et al., "Beam Diagnostics with IR Light Emitted by positron at DANE", Proc. EPAC'08, 1056 (2008).
5. O. Chubar and P. Elleaume, Proc. EPAC'98, 1177 (2008).
6. J. Piotrowski and A. Piotrowski, Proc. SPIE B5957, 117 (2005).
7. A. Ghigo et al., Proc. EPAC'02, 1494 (2002).

Acknowledgments

I would to thanks the people that work and collaborate within the 3+L experiment:
A. Clozza, A. Drago, A. Grilli, A. Marcelli, M. Piccinini, A. Raco, R. Sorchetti, INFN/LNF, Frascati, Italy
L. Gambicorti, INOA, Firenze, Italy
A. De Sio, E. Pace, Università degli Studi di Firenze, Firenze, Italy
J. Piotrowski, Vigo System Sa, Warsaw, Poland