Development of Longitudinal Beam Profile Diagnostics within DITANET

A Marie Curie Initial Training Network on Novel Diagnostic Techniques for Particle Accelerators

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Abstract

The exact determination of the time structure of ever shorter bunches in accelerators and light sources such as for example the X-FEL, the ILC or CLIC is of high importance for the successful operation of these next-generation machines. It is also a key to the optimization of existing scientific infrastructures. The exact measurement of the time structure poses a number of challenges to the beam diagnostics system: The monitors should be non-destructive, easy to maintain and provide time resolutions down to the femtosecond regime. Several DITANET partners are active in this field.
Here, some examples of the network's research activities in this area with a focus on the LHC longitudinal density monitor, beam profile monitoring using electro-optics techniques and the exploitation of diffraction radiation for non-invasive diagnostics are given.

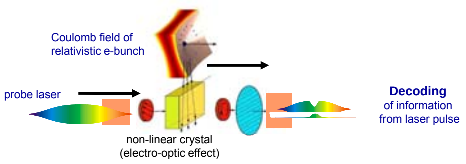
Electron Accelerators

EO Techniques for Femtosecond Diagnostics

R. Pan, CERN, S. Jamison, ASTeC and W.A. Gillespie, U Dundee

Electro-optic (EO) and related techniques have shown themselves to be extremely promising for the measurement of electron beam longitudinal profiles where the ultra-short electron bunches have structure in the range from picoseconds down to tens of femtoseconds.

Three techniques of EO longitudinal diagnostics have been demonstrated in accelerator experiments, spectral decoding, temporal decoding and spectral upconversion. Of these, SD and TD have been most extensively developed and demonstrated.
In all techniques, the encoding of the bunch profile is via the Coulomb field at a radially offset distance, which introduces a time resolution limit through the relativistic angular spread of the Coulomb field. This limit can be ignored for multi-GeV and TeV electron beams.



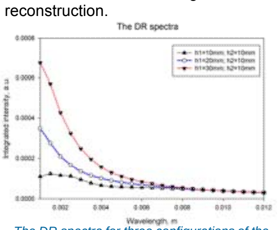
Principle of operation of EO detection.

In spectral upconversion, the encoding is realized in terms of optical sideband generation via sum and difference frequency mixing of the optical and terahertz fields in the crystal. The aim here is to directly measure the Fourier spectrum of the electron bunch, accepting the loss of phase and explicit time information compared with temporal decoding, but gaining as a result the potential for determining information on even shorter structures within the bunch, potentially below 10 fs.
Current extensions of this work include investigations of multiple crystal arrangements, and new materials with enhanced optical bandwidth including thin metal-dielectric films and "metamaterials". These techniques will now be used at the CTF3 test facility at CERN, as part of a project to measure the bunch profile of the CLIC Main Beam. The requirement is to measure the detailed longitudinal profile of the 44 µm (150 fs) rms bunch with a resolution of 20 µm (20 fs) rms, at high charge density.

Coherent Diffraction Radiation Monitor

K. Lekomtsev, Royal Holloway University of London

The recent installation of a second target at one of the beam profile monitors at CTF3 required in depth studies of a two-target configuration. This includes investigations into the generation of coherent diffraction radiation (CDR) from such two targets. The main goal of this work is to obtain a single electron spectrum which can then be utilized in a bunch profile reconstruction.



The DR spectra for three configurations of the experimental setup.

For all calculations, the classical theory of Diffraction Radiation (DR) was used. Each point of the target surface can then be represented as an elementary source.
Once two radiation components are obtained one can derive the DR distribution from two targets. By integrating the DR spatial distribution over the detector aperture , the single electron spectrum can be obtained, see the figure to the left.

It shows the spectra for three different configurations of the system, when the upstream target is gradually lifted upwards and the DR spectrum converts itself while the influence of the second target becomes negligible. These single electron spectrum calculations will now be utilized for bunch profile reconstruction in the CDR experiment at CTF3.

Hadron Accelerators

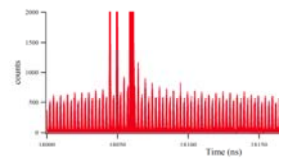
LHC Longitudinal Density Monitor

A. Jeff, CERN

Synchrotron radiation (SR) is an excellent tool for particle beam diagnostics as it is non-disruptive and carries information on both the transverse and longitudinal particle distribution. The Longitudinal Density Monitor (LDM) for the LHC uses single-photon counting to overcome the problem of low light intensity and achieve a high dynamic range.

Within this ESR project the synchrotron light for the LDM is exploited from two different sources: A dipole with a maximum field of 3.9 T emits visible SR at beam energies above 1.5 TeV, but produces only infra-red radiation at LHC injection energy of 0.45 TeV.

To fill this gap a superconducting undulator with two 28-cm periods and a peak field of 5 T was installed upstream of the dipole. The undulator produces visible light from 0.45-1.5 TeV before moving into the ultraviolet above 1.5 TeV. Visible light is thus available across the whole energy range, with a minimum in intensity at the crossover of the two sources around 1.2 TeV .
The detector used for the LDM is the Photon Detection Module (PDM) from Micro Photon Devices. This is a Silicon avalanche photodiode (APD) operated in the Geiger mode. Its detection efficiency is ~35% averaged over the visible range and its resolution is 50 ps FWHM. Measurements were taken with the LDM during both proton and ion runs. In the case of lead ions, the lower relativistic γ means that the SR is almost entirely in the infra-red at injection, and measurements with the LDM were only possible above 900 GeV proton-equivalent energy.



Measured longitudinal profile of heavy ion beam in the LHC with 500 ns bunch spacing. The main bunch arrives at t=18,060 ns and is preceded by two satellites; ghost bunches spaced at 2.5 ns are present around the ring.

A measured beam profile is shown above. Ghost bunches can be distinguished down to a peak of 50 counts, compared to the main bunch with a peak of 1.4 x 10^6 counts, corresponding to a dynamic range of better than 10^4. Small ghost bunches spaced at 2.5 ns (i.e. occupying the LHC RF buckets) spread around the ring with population slowly decreasing far from the full bunches. Larger satellites near to the full bunch have 5 ns spacing and are thought to originate in the LHC injectors where a lower RF frequency is used. This pattern of satellites, with the largest occurring 10 and 15 ns before the main bunch, was reproduced in most ion fills.

Topical Workshop

As part of its training events, DITANET organized a Topical Workshop on Longitudinal Beam Diagnostics for Accelerators and Light Sources. During two days, 30 scientists and engineers discussed the state-of-the-art and open challenges in present and future accelerator projects.

Full details, including all presentations, can be found at the CERN Indico under ConfID: 93401.

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