DESIGN STUDY OF A DEDICATED BEAMLINE FOR THz RADIATION GENERATION AT THE SPARC LINAC

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Abstract

A feasibility study for a dedicated beamline for a THz radiation source at SPARC is discussed here. Two phases are foreseen for the THz radiation generation beamline. In the first phase of operation the SPARC electron beam will be transported through a dogleg and then delivered to a THz radiator, allowing a full characterization of the THz radiation.

In the second phase a magnetic compressor with negative R_{56} will be implemented in the dogleg, allowing exotic experiments with THz radiation produced by comb beams. A radiofrequency electron gun followed by a compressor can generate trains of THz sub-picosecond electron pulses by illuminating the photocathode with a comb laser pulse. This structure of the beam can be used to produce coherent radiation. The quality of the coherent spectrum emitted by a comb beam is tightly connected to the electron micro-bunches lengths and to micro-pulses inter-distance.

INTRODUCTION

Electron pulse trains of some hundreds pC charge, sub-picosecond (sub-ps) length and repetition frequency of some terahertz can be useful to drive FEL experiments, plasma accelerators and efficient generation of terahertz (THz) radiation [1].

We present the feasibility study of a THz generation source at the high brightness SPARC [2] photoinjector that could be situated downstream the dogleg, as in the upper and lower layouts of Fig. 1, corresponding to a foreseen phase 1 and 2 of operation, respectively. Both phases consider a two bending magnets dogleg with bend angles of equal magnitude but opposite sign separated by a straight section hosting three quadrupoles. After a straight line with three more quadrupoles and a doublet necessary for matching conditions, in the second phase a magnetic compressor will be implemented, consisting of four bending magnets and five quadrupoles, necessary for reaching highly negative R_{56} values.

THz radiation could be generated as coherent transition radiation (CTR) emitted by the beam crossing a metal foil oriented at 45º incidence.

The first phase of operation in which the electron beam will be transported through the dogleg and sent to the CTR target will allow first experiments dedicated to a full characterization of the radiation, like its spectral content, spatial distribution and intensity. In the following section there is a description of this first layout of the THz beamline.

The beamline layout of phase 2 (shown in lower plot of Fig. 1) foresees the addition of a magnetic compression that will allow comb beam experiments, tightly connected to the THz radiation quality, in term of power and frequency, depending on the electron beam train. Start-to-end simulations from the comb beam generation at cathode to the THz detector station are useful to set the working conditions for the photoinjector, including the laser pulse needed to produce the electron bunch train [3-4]. First full simulations have been performed within the PARMELA [5] and RETAR [6] codes, assuming for simplicity a bending magnet as a THz radiator. Beam dynamics studies for this kind of electron beams are described in [7]. A simulation of the radiation produced by these beams has been done with the RETAR code. The RETAR simulation results are consistent with the simple evaluation from the FFT and form factor of the electron comb beams. In the second section there is a brief description of these simulation results.

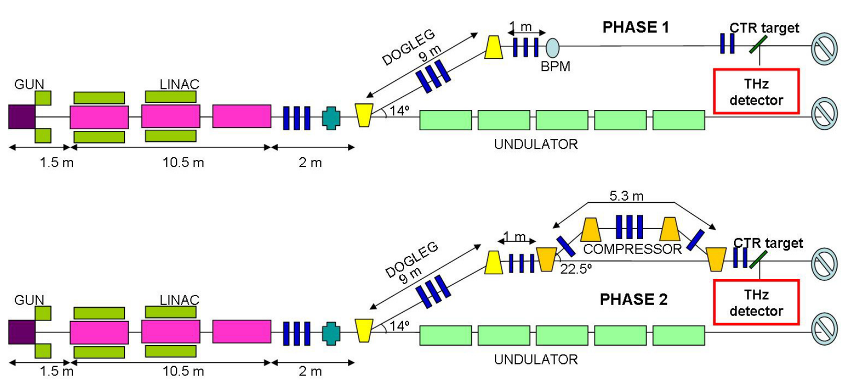

Figure 1: Cartoon of the SPARC photoinjector with a THz radiation station in phase 1 (upper) and 2 (lower). A magnetic compressor is foreseen in the second phase only. Bending and quadrupole magnets are marked by yellow wedges and blue lenses, respectively.

However, a simulation code that allows simulating the transition radiation produced by a metal target at 45º with respect to the direction of beam propagation is in progress, and more realistic simulations for our specific case are underway. Finally, the frequency contribution of the SPARC rf compressed beam is briefly discussed.

PHASE 1 BEAMLINE LAYOUT

During the first phase of operation the goal will be the characterization of the THz radiation under different beam conditions. For example, radiation will be studied for different beam energy, beam rf compression factor and laser pulse shapes. Few mirror optics are needed to fulfill this goal.

During this phase we plan to measure the radiation intensity through two standard THz detectors: a pyroelectric [8], and a Golay cell [9].

Terahertz radiation will be produced through coherent transition radiation (CTR) produced by a 350 μm silicon (SiO_2) wafer over which a 80 nm aluminum layer is sputtered. The emitted radiation is then extracted through a z-cut quartz window whose clear aperture is 60 mm. Its optical transmittance is nearly flat up to 5 THz except for a deep absorption minimum at about 4 THz. The distance between the CTR target and the window is 70 mm corresponding to an angular acceptance of 800 mrad, much larger than the angular divergence of the radiation at the minimum frequency of 100 GHz (3 cm^{-1}) that can be optically measured. Fig. 2 shows the angular distribution of the CTR for different frequencies, calculated through a modified Ginzburg-Frank formula [10], which takes into account the low-frequency cut-off due to the finite size of the target.

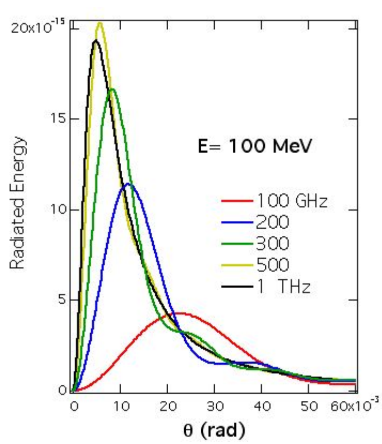

Figure 2: CTR intensity angular distribution at different frequencies and calculated for a perfectly reflecting and finite target at 100 MeV electron beam.

In Fig. 3 the energy/pulse and the fluence/pulse figures of merit of the THz CTR emission at SPARC (and also at the planned SPARX machine) are plotted in comparison to those of many others THz sources. The present SPARC THz source shows a gain with respect to many other THz sources, like the coherent synchrotron radiation emitted at the III generation machine Elettra and Bessy-II, as well as the THz radiation emitted at dedicated FELs and energy recovery linac (Jefferson Lab). In particular a gain of about two orders of magnitude with respect to laser based table-top emitters can be observed.

The radiation will be extracted using two parabolic 90°off-axis aluminum mirrors. The first mirror, positioned in front of the z-cut quartz with the focus on the CTR source plane, collimates the radiation that is focused by the second mirror on the detector. Both the reduced optical path and the mirrors diameter (50 mm) provide the possibility to collect most of the emitted radiation.

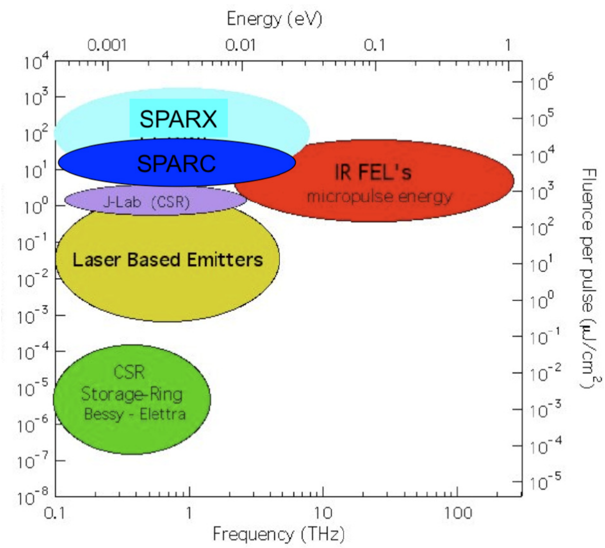

Figure 3: Plot of the THz Energy/pulse and Fluence/pulse figures of merit of SPARC machine calculated through a modified Ginzburg-Frank formula [10]. The gain with respect to other THz sources (see text) and in particular over table-top emitters based on near-infrared laser transduction can be well observed.

The detector will be mounted on two remote controlled slits, in order to span the xy plane, perpendicular to the optical trajectory of the radiation. The detector position along the optical path can be controlled as well, to optimize the focal position.

The experimental planning foresees to characterize the intensity distribution properties of the THz radiation in the xy plane, its dependence on the main machine parameters as well its polarization. After these tests, we plan to implement both a Michelson and a Martin-Pupplet interferometer in order to measure the frequency distribution of the radiation as well the pulse duration.

PHASE 2 RADIATION SIMULATIONS FOR COMB BEAMS

In view of the phase 2 run, when comb beams experiments are foreseen, dedicated simulations for the radiation emitted by an electron beam train through a dipole have been performed using the RETAR simulation code. The simulated beams are the ones discussed in [7]. The goal of this study was to investigate the frequency components, the electric field and the emitted power of the comb beams and compare these estimations with the form factors evaluated directly from the electron comb beams.

The RETAR simulation results are consistent with the simple evaluation from the fft and form factor of the electron comb beams. Moreover, an estimate of the total energy emitted by the beam can be given. The beam is sent in a 100 Gauss, 5 cm long bending magnet while the radiation is collected on a spherical surface, centred on the middle of the magnet, with a radius of 3 m.

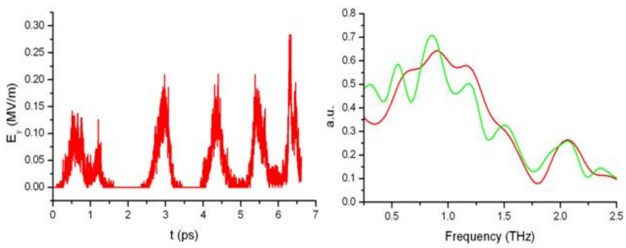

Figure 4: Electric field component y for the five pulses bunch (left) and comparison between the field FFT, in red, and the beam form factor, in green (right).

The choice of the bending field strength has been done in order to have a frequency cutoff of the order of ~10 THz for a point particle in the same configuration. Results of the simulation, for the five pulses beam, are given in Fig. 4. The left plot shows the y component of the electric field, normal to the plane of motion: though some amount of numerical noise, due to charge discretization, is present, the field time dependence is in perfect agreement with the beam current profile. The right plot shows a comparison between the bunch form factor and the electric field FFT, showing a good agreement between the two quantities. The total energy emitted by the process has been calculated integrating in time the flux of the Poynting vector **S** through the spherical surface, giving a yield of 13.6 μJ.

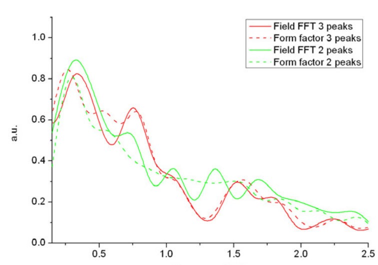

Figure 5: Field FFT and bunch form factor for the two and three pulses bunches case.

A similar analysis has been conducted for the two and three pulses bunches with 300pC/peak, that gave a yield of 14.2 and 29.9 μJ respectively. The difference is due to the charge content. In Fig. 5 we present the field FFT and the form factor for both cases, showing a fair agreement between the two quantities. Differences are mainly due to the transverse dimensions of the bunch (of the order of the wavelength), taken into account by RETAR in calculating the fields but not by the form factor. Moreover, transverse dynamics doesn't play a significant role since the bunch remains substantially stable while travelling across the bending magnet.

EXPERIMENTAL RESULTS

Velocity bunching measurements have been successfully performed recently [2]. The form factor of the measured compressed beam (charge of 200 pC) is shown in the upper plot of Fig. 6, together with the one obtained from a simulation [7]. The simulated form factor is slightly wider in frequency due to a slight difference in the longitudinal shape, as appears in lower plot of Fig. 6. The two beams are similar in terms of energy (~90 MeV), bunch length (~200 fs) and shape. The agreement between measurement and simulation is quite good. This analysis demonstrates the possibility of producing THz radiation at SPARC with a single short pulse using rf compression instead of the magnetic one, foreseen only in phase 2.

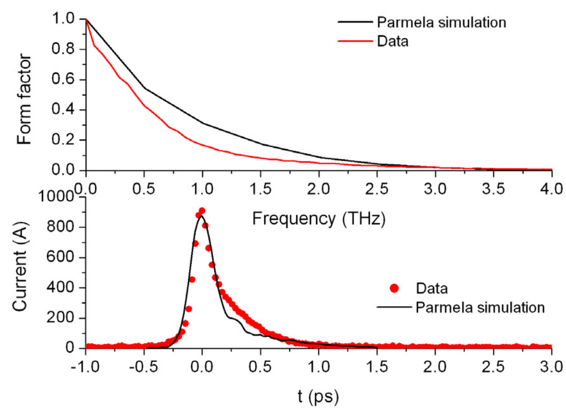

Figure 6: Form factor of the measured compressed beam compared to the simulated one (upper) and corresponding longitudinal beam distribution (lower).

CONCLUSIONS

A dedicated beamline for the THz radiation is foreseen at SPARC for THz experiments. First tests for the THz radiation production will start without the magnetic compressor feature, collecting radiation produced by a single bunch through a TR target. A full description of the experimental set-up has been presented. Measurements with the velocity bunching technique [2] are promising in terms of the THz production. The RETAR code has been used for start-to-end simulations for the phase 2, allowing a detailed analysis of the radiation produced by comb beams.

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