

# STATUS OF THE ACCELERATOR PHYSICS TEST FACILITY FLUTE

M.J. Nasse\*, A. Bernhard, I. Birkel, A. Böhm, A. Borysenko, S. Hillenbrand, N. Hiller, S. Höninger, S. Marsching, A.-S. Müller, R. Rossmann, R. Ruprecht, M. Schuh, M. Schwarz, B. Smit, S. Walther, M. Weber, P. Wesolowski, KIT, Karlsruhe, Germany  
 R.W. Assmann, M. Felber, K. Flöttmann, C. Gerth, M. Hoffmann, P. Peier, H. Schlarb, B. Steffen, DESY, Hamburg, Germany  
 R. Ischebeck, B. Keil, V. Schlott, L. Stingelin, PSI, Villigen, Switzerland

## Abstract

A new compact versatile linear accelerator named FLUTE (Ferninfrarot Linac Und Test Experiment) is currently under construction at the Karlsruhe Institute of Technology (KIT). It will serve as an accelerator test facility and allow conducting a variety of accelerator physics studies. In addition, it will be used to generate intense, ultra-short THz pulses for photon science experiments. FLUTE consists of a  $\sim 7$  MeV photo-injector gun, a  $\sim 41$  MeV S-band linac and a D-shaped chicane to compress bunches to a few femtoseconds. This contribution presents an overview of the project status and the accompanying simulation studies.

## INTRODUCTION

The objectives of the linear accelerator FLUTE, developed and being constructed at KIT in collaboration with PSI and DESY, range from studying space charge and coherent radiation induced effects to bunch compression studies and systematic comparison of simulation code results with measurements [1]. Furthermore, it will serve as a test bench for advanced diagnostics and instrumentation. The generated intense THz radiation will be used for various experiments for example to study the radiative impact on relevant biomedical tissue. The most important design parameters based on simulations are summarized in Table 1.

Table 1: Main FLUTE Parameters from Simulation

Parameter	Value	Unit
Final electron energy	$\sim 41$	MeV
Electron bunch charge	$\sim 1-3000$	pC
Final electron bunch length (RMS)	$\sim 1-300$	fs
Pulse repetition rate	10	Hz
Energy / THz pulse	up to $\sim 3$	mJ
Power / THz pulse	up to $\sim 5$	GW

## FLUTE LAYOUT

The design layout is depicted in Fig. 1 showing details of the planned diagnostics components. The main components are: the *electron gun*, pre-accelerating the electrons to an energy of  $\sim 7$  MeV, including a focusing solenoid; the *low-energy diagnostics section* comprising two screens, beam

position monitors (BPM), and an integrating current transformer (ICT) for determining the electron beam current, as well as a spectrometer with a quadrupole for energy measurements; the *linac* accelerating the electrons to an energy of  $\sim 41$  MeV, followed by the *first high energy diagnostics section* including an electro-optical longitudinal profile monitor (EOM) for determination of the longitudinal bunch profile [2]; a quadrupole triplet, also located in this section to focus the beam appropriately in both transverse directions; the *bunch compressor* consisting of four dipole magnets [3] including some diagnostics in the dispersive section, directly followed by the *THz out-coupling optics*; the *final diagnostics section* including another EOM and a high-energy spectrometer; the Faraday cup used with radiation shielding as *electron dump*.

## SIMULATION RESULTS

We use several software programs to optimize the layout of FLUTE. For low charges ASTRA [4] is employed for the entire machine. For charges above  $\sim 1$  nC comparisons have shown that especially at the end of the chicane, where the electron bunches become very short, coherent synchrotron radiation (CSR) induced effects become dominant [5]. In these cases, CSRtrack [6] was employed in the chicane. For the calculation shown here ASTRA was used, whereas the generated THz spectra and pulse profiles were computed with in-house developed algorithms [7].

### Electron Beam

To study the influence of the space between the gun cathode and the linac we performed a set of ASTRA simulation runs with different distances. For this comparison the relevant parameters like RF and laser phase, solenoid and quadrupole triplet focusing strength, chicane dipole fields, and laser spot size and length have been optimized for each case separately. Figures 2 and 3 show first results for a cathode–linac distance of 3 m. This distance allows enough space for the low-energy diagnostics components and later for a buncher cavity. Please note, that in this paper CSR-induced effects have not been studied. This is why we restrict ourselves here to a bunch charge of  $\leq 100$  pC where these effects are relatively small.

The transverse RMS beam size plotted in Fig. 2 for both 1 pC and 100 pC bunch charges show that the size after the gun, but before the linac can be kept below 1.4 mm. Furthermore, we reach a small bunch size of  $\leq 105 \mu\text{m}$  at the end

\* Michael.Nasse@kit.edu

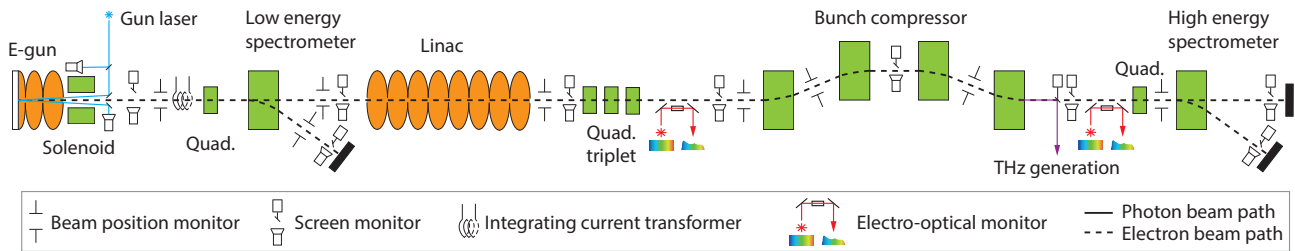


Figure 1: Overview of the FLUTE facility including various diagnostics elements. RF components are marked in orange and magnets in green. Not to scale.

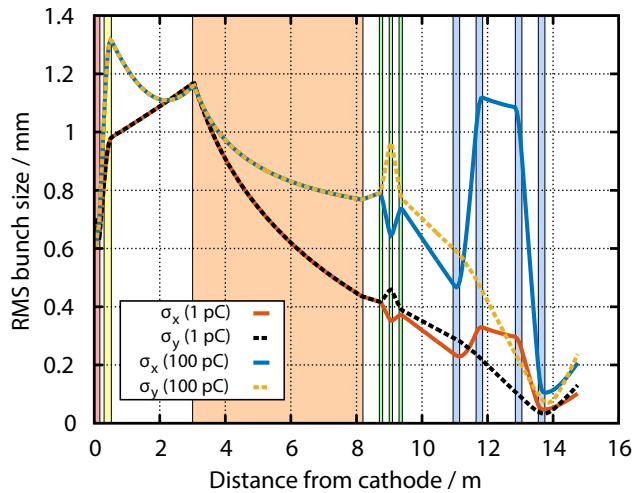


Figure 2: Transverse RMS beam size for 1 pC and 100 pC bunch charge. The colored vertical stripes in the background indicate the position of the main components: electron gun (red), solenoid (yellow), linac (light red), quadrupole triplet (green), and chicane dipoles (blue).

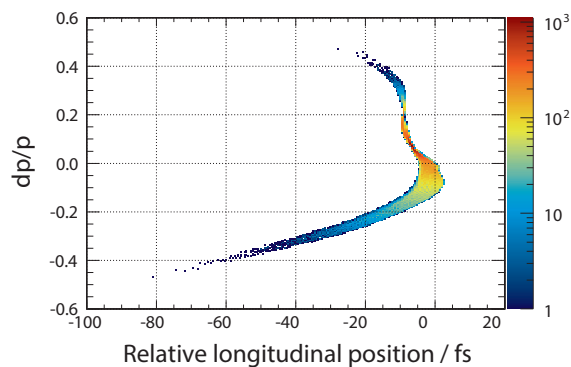


Figure 3: Longitudinal phase space at the end of the bunch compressor (1 pC charge). Here, the RMS bunch length is 4.94 fs.

of the chicane in all cases. Figure 3 shows the longitudinal phase space for the 1 pC case. Most importantly, here the longitudinal RMS bunch length is found to be below 5 fs.

### THz Radiation

Next, we consider the electromagnetic properties of the generated THz radiation. Figure 4 shows the single particle

spectra of synchrotron, transition and diffraction radiation (SR, TR, and DR, respectively). For details see [8]. TR

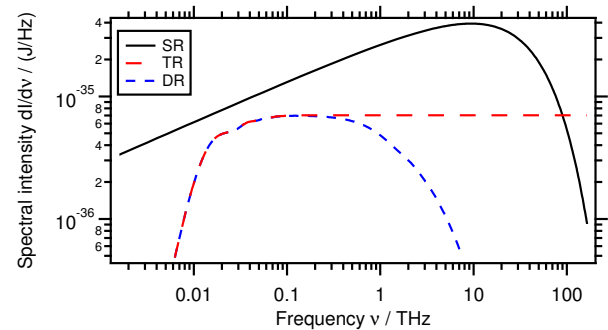


Figure 4: Calculated single electron (incoherent) spectra of SR, TR, and DR (assumed hole size of 0.5 mm). Details, see text.

and DR are modeled with a screen, here assumed to have a diameter of 148 mm; DR has an additional hole at the center, here taken to be 0.5 mm. Both have a low-frequency cut-off due to the finite screen size. While DR has an additional high-frequency cut-off because of the finite hole size, TR is frequency independent for higher frequencies.

An in-house developed algorithm is used to obtain the electric field profile in time domain shown in Fig. 5. These

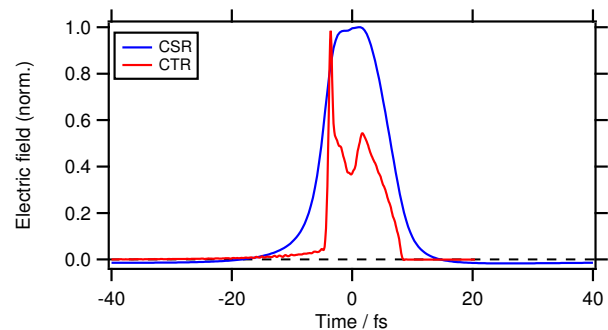


Figure 5: Electric field of the SR and TR THz pulses as a function of time. Both curves are normalized to the SR maximum.

calculations are based on the longitudinal electron bunch profile output of ASTRA at the end of the chicane. The plots show (both curves are normalized to the SR max.) that the peak field of SR is comparable to the peak field of TR. This

is in contrast to the spectral maximum depicted in Fig. 4, where the SR is roughly  $\sim 10$  times higher. This is due to the fact that the SR drops exponentially for frequencies above the critical frequency, here  $\sim 10$  THz, whereas the TR remains constant. This also leads to a "smoothing" of the SR peak shape as opposed to the TR pulse, where the underlying electron bunch shape is still visible. More importantly, this also means that a further reduction in bunch length would, in contrast to the TR, not change the SR pulse shape significantly as it is already limited by the drop in the SR spectrum at the critical frequency. More details can be found in [8] and references therein.

## CONSTRUCTION PROGRESS

The renovation of the FLUTE building is completed, the integration of the necessary infrastructure (electricity, cooling system, network etc.) is being finished. FLUTE will be built in three phases. For phase one (comprising the electron gun and the low-energy diagnostics section), which is currently being assembled, and phase two (including the linac and the first high-energy diagnostics section) most components have been delivered. For phase three (bunch compressor and second high-energy diagnostics section) the design is under way.

The electron gun laser (Coherent Astrella [9], wavelength: 800 nm, pulse energy: 6 mJ, FWHM pulse length:  $< 35$  fs, rep. rate: 1 kHz; see Fig. 6) is set up in an air-conditioned clean room (ISO class 6,  $\Delta T = \pm 1$  K, RH  $\leq 45$  %). The low-

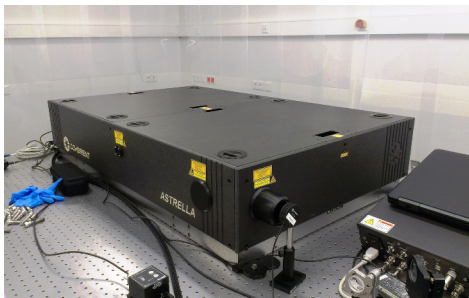


Figure 6: Ti:Sa gun laser in the newly built clean room.

level RF system and the laser timing and synchronization system is currently being assembled in close collaboration with DESY [10]. A third harmonic generator (conversion efficiency reaches up to  $\sim 19$  %) triples the laser frequency to yield UV pulses (267 nm) that will subsequently be sent to the electron gun cathode. A commercial optical feedback system (Aligna 4D from TEM Messtechnik [11]) will be installed to stabilize the pointing of the UV pulses on the gun cathode. This is necessary because the laser will pick up vibrations while being transported over a distance of  $\sim 35$  m from the laser clean room through the measurement room to the opposite corner of the experimental hall, where the gun is located. This layout, however, has the advantage that we can keep the THz beamline leading from the THz out-coupling port after the chicane to the measurement room relatively short. This is important as, compared to the laser

beam, the transport of THz radiation is more demanding due to its longer wavelength and its relatively broad spectrum making larger tube and optics diameters, as well as the use of Gaussian telescopes mandatory.

A solenoid (see Fig. 7) is used to focus the electron beam into the linac. It will be mounted on a motorized stage that

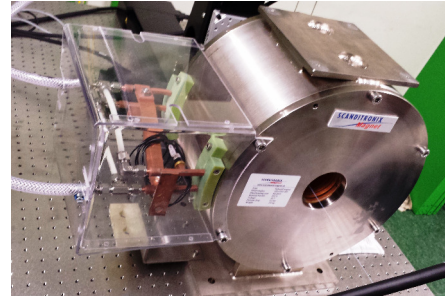


Figure 7: Solenoid from Scanditronix for focusing the electron beam generated by the electron gun.

permits the fine-adjustment of pitch and yaw, as well as of both transverse directions. This way it can also serve as the first steering magnet to compensate small positional changes for example after a cathode change. Its magnetic field ( $\sim 0.39$  T) is currently being accurately mapped with a new magnet test stand [3] equipped with a motorized hall-probe and stretched-wire setup.

## ACKNOWLEDGMENT

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