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# FIRST THZ LIGHT GENERATED IN HIGH ENERGY SECTION OF FLUTE

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*Abstract*

FLUTE is a compact and flexible linac-based accelerator test facility at the Karlsruhe Institute of Technology (KIT) in Germany. It serves as a platform for a variety of accelerator studies and to generate intense short THz pulses for various photon science experiments. FLUTE will also be used as an injector of sub-100 fs bunches into the VLA-cSR (Very Large Acceptance compact Storage Ring), which is part of the cSTART (compact STorage Ring for Accelerator Research and Technology) project currently in the technical design phase at KIT. Recently, FLUTE's high energy section has been installed and commissioned. This includes the linac, bringing FLUTE beyond 5 MeV to full energy, the bunch compressor, and two corresponding diagnostics sections. A metal foil in the last diagnostics section has been used to generate a first THz signal with high energy (49 MeV) electron bunches.

## INTRODUCTION

FLUTE, the *Ferninfrarot Linac- Und Test-Experiment* (far infrared linac and test-experiment), is a compact linac-based accelerator at KIT with an energy of up to 90 MeV. It mainly serves as a test bench for systematic accelerator physics studies such as the development of novel diagnostic methods for ultra-short electron bunches [1–3].

At a later point in time, it will be used as one of several injectors of sub-100 fs electron bunches into cSTART's VLA-cSR. It will play a vital role in the commissioning of this non-equilibrium ring [4] by delivering well-defined ultra-short bunches. Subsequently, it offers the unique opportunity to perform systematic comparative studies between a classic cavity-based accelerator with a wide tuning range of accelerator parameters and a laser plasma accelerator beam injected into the VLA-cSR [5].

Furthermore, FLUTE is intended to be used as a compact broadband intense THz source for a large variety of experiments ranging from life sciences to material studies. The first measurement of a THz signal using electrons from the high-energy section of FLUTE reported here is an important milestone toward this goal.

## LAYOUT OF FLUTE

FLUTE can be subdivided into several sections, see Fig. 1. The photoinjector electron source, a solenoid magnet for a first focusing of the beam, the laser beam injection module, corrector magnets, and various beam diagnostic elements, including a spectrometer magnet (diagnostics section I) together form the low-energy section. Other diagnostic elements include turbo integrating current transformers (turbo-ICTs), cavity beam position monitors (BPM), and screen stations equipped with Cerium-doped Yttrium aluminum garnet (YAG:Ce) scintillator screens. The spectrometer side arm is equipped with a foil separating the ultra-high vacuum from air after the spectrometer screen station. This setup can be used to do experiments with free electrons in air at low energies up to 5 MeV.

The low-energy section is followed by a traveling wave linac module that can boost the electron energy up to 90 MeV. The subsequent high-energy section starts with the diagnostics section II including a quadrupole triplet. We are currently also integrating an electro-optical spectral decoding (EOSD) setup that will permit the single-shot measurement of the bunch length. After this, the beam enters a chicane consisting of four dipole magnets that together serve as a bunch compressor. The bunch compressor is currently being commissioned. According to simulations, this should allow a compression down to the single-digit femtosecond time scale [6].

The photoinjector electron source and the linac module are powered individually by two separate 3 GHz radio-frequency (RF) klystrons, which are connected via waveguides. The entire RF system, including the klystrons with the waveguide system, the electron source with the associated laser system, as well as the solenoid and its multi-axis support, were recently completely renewed and replaced by new components (see Ref. [7]).

Following the bunch compressor, there is the diagnostics section III. It also includes the THz generation module, a button BPM that is currently being tested for the cSTART project [8], and eventually the beam dump including a Faraday cup for beam charge measurements. The current diagnostics section III in the high-energy section is shown in Fig. 2. In the near future, the beam dump with the Faraday cup will be moved further back to make space for a versatile in-air measurement platform equipped with another thin foil separating the machine vacuum from air. Here, several experiments are planned ranging from biomedical measurements to the development of new diagnostic methods [1–3].

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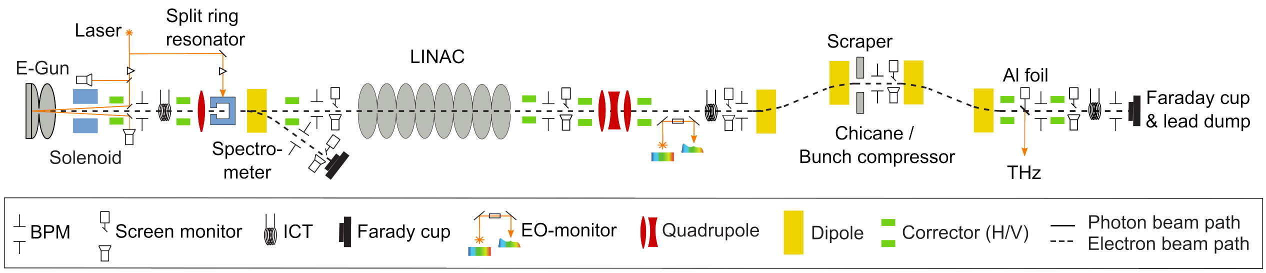


Figure 1: Layout of the FLUTE linac-based accelerator test facility showing the different elements schematically (not to scale). The electron source and a first diagnostics section is followed by the copper linac module followed by the diagnostics section II. Subsequently, the chicane mainly consisting of four dipole magnets allows the tuning of the bunch compression. Then there is the diagnostics section III including the THz generation unit. At the end, the bunch is absorbed in a Faraday cup.

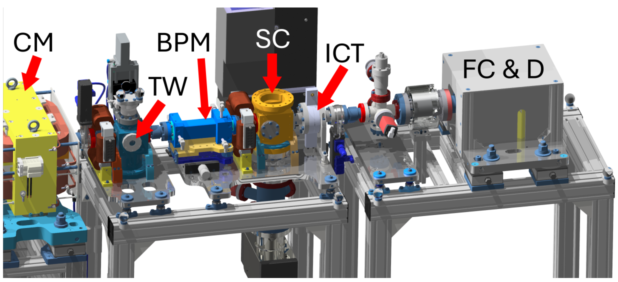


Figure 2: CAD drawing of the high-energy section of FLUTE after the last chicane magnet (CM). This section mainly comprises the chamber with the aluminum foil and the THz window (TW), a cavity-BPM, a YAG screen station (SC), an ICT, and a Faraday cup (FC) housed in a lead shielding dump (D).

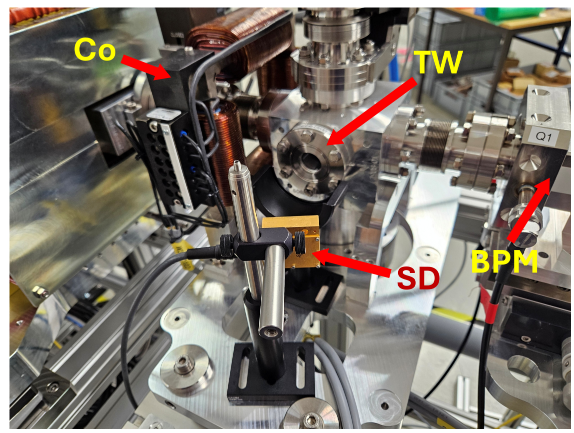


Figure 3: Photo of the chamber with the aluminum foil and the z-cut quartz THz window (TW). The Schottky diode (SD, slightly tilted to minimize back-reflections) is mounted in front of the window without additional focusing optics. Co indicates a corrector magnet.

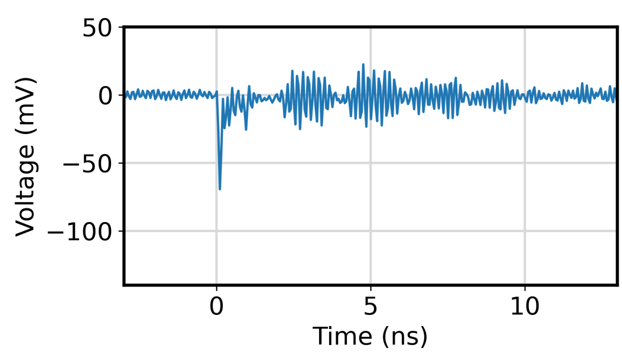


Figure 4: First THz signal measured in the high energy section of FLUTE. It was generated by an electron bunch with a charge of about 27 pC and an energy of around 49 MeV going through a thin aluminum foil. We had 7.7 MW of RF power in the photoinjector electron source and 18.6 MW in the linac module.

## FIRST THZ LIGHT FROM HIGH-ENERGY ELECTRONS

To generate a first THz light from high-energy electrons, we installed a chamber in the last section of FLUTE, after the linac and the chicane (see Figs. 2 and 3).

This chamber contains a holder with a free-standing aluminum foil with a thickness of around 18 µm. A pneumatically driven arm allows inserting or removing the foil from the electron beam path. The foil is mounted at an angle of 45° relative to the beam axis, so that the generated transition radiation is emitted perpendicular to the electron beam axis. It exits the vacuum chamber through a z-cut quartz window. We used a fast, broadband (100 GHz – 1 THz) zero-bias quasi-optical Schottky diode detector equipped with a silicon lens from Virginia Diodes, Inc. (VDI) to detect the signal on a 6 GHz oscilloscope. The latter limited the bandwidth of the measured signal. The detector was mounted next to the window without focusing optics. The obtained signal for an electron beam with a charge of around 27 pC and an energy of about 49 MeV is shown in Fig. 4. We measured the electron beam energy with the first two bunch compressor dipole magnets and the following BPM, see also Ref. [7]. The first strong negative peak at 0 ns corresponds to the transition radiation emitted by the electron bunch going through the aluminum foil. The employed Schottky diode detector is designed to act as a rectifier, and we therefore ex-

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pect only a unipolar (negative in this case) signal. However, the oscillations following the first strong negative peak are bipolar. This is why we suggest that they are coming from trailing low-frequency wakefields generated along the machine, guided by the beam pipe, reflected by the aluminum foil and finally coupling directly into the printed circuit board of the detector independent of the diode response. This type of diode is known to be very sensitive to such low-frequency signals. Further experiments are needed to elucidate the exact source of this signal.

## SUMMARY AND OUTLOOK

We presented the first THz signal generated by high-energy electrons at the FLUTE test accelerator. This is the first important step towards using FLUTE as a source for ultra-short and intense THz radiation pulses for a large variety of experiments.

As a next step, we plan to measure the spectrum of the generated radiation. Once the commissioning of the bunch compressor and the EOSD setup are finished, we will start systematic studies of the THz signal properties as a function of the bunch characteristics, especially the bunch length. For instance, we will measure the spatial polarization-dependent distribution of the THz radiation exiting the window.

In the long run, it is planned to install a dedicated THz measurement platform in the experimental hall and also a THz beamline, so that experiments can also be performed outside of the radiation-controlled area.

## ACKNOWLEDGMENT

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