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# STATUS AND FUTURE PERSPECTIVE OF THE TRIUMF E-LINAC

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*Abstract*

The currently installed configuration of TRIUMF's superconducting electron linac (e-linac) can produce an electron beam up to 30 MeV and 10 mA. Low beam power commissioning of the e-linac spanning the section from the electron gun to the high energy dump took place in summer 2018 and 2019 with an achieved beam energy of 30 MeV. As the driver of the Advanced Rare Isotope Laboratory (ARIEL[1]) project, the e-linac will deliver electrons to a photo-converter target station to produce neutron-rich rare isotope beams (RIB) via photo fission. The e-linac will have sufficient beam power to support the demands of other user community as well. This driver accelerator could serve as a production machine for high field THz radiation and as irradiation centre. A recirculation of the beam would be beneficial for RIB production at higher beam energy and would allow for high bunch compression to generate THz radiation. Such a system would also allow for the investigation of a high beam intensity energy recovery linac. To this end, TRIUMF is investigating the design of an alternate circulation path and the beam dynamics as a first step.

## INTRODUCTION

TRIUMF's e-linac is a driver accelerator established within the ARIEL project which was proposed in 2008 [1]. The description of the scientific program can be found in [2, 3].

The layout of the e-linac is shown in Figure 1, including DC gun, bunch compressor and third cryomodule EACB. Currently still in the commissioning phase, the e-linac is operating in a continuous wave (cw) mode with 100 W beam power. This is limited by the present license for beam energies above 10 MeV.

With its final beam specification of 30 MeV and 10 mA the e-linac is an ideal test driver for a high power, high intensity THz photon source. Application for THz radiation are of high-field nonlinear spectroscopy, imaging (including microscopy), biology and medicine as well as in industrial applications.

The Canadian photon science community has a high demand and needs for light sources, therefore the e-linac is a potential drive for a high brilliance source for an IR-FEL. [4]

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## COMMISSIONING UPDATE

This year TRIUMF continued commissioning the e-linac. In 2018 the commissioning team achieved several milestones while guiding the beam from the source to the main high energy dump with a low power beam, see Figure 1. A detailed description of 2018 commissioning can be found in [5]. Also, during the commissioning the machine protection system (MPS) along the beamline has been commissioned step-by-step to the entrance of EACA.

### *Electron Gun*

The e-linac uses a 300 kV RF-modulated thermionic electron source. The source has been commissioned and operating parameters have been verified. More detailed results can be found in [6, 7]. The origin of recent high voltage problems, which prevented operation above 270 kV, has been identified. They are caused by discharges along a high voltage cable, which connects the power supply to the source. An improvement of the design is being implemented.

### *Machine Protection System*

The e-linac beam loss monitors (BLM) of the MPS are undergoing commissioning [8]. Currently the BLMs in the low and medium energy sections of the e-linac (300 keV and 10 MeV) have been commissioned with a combination of BGO scintillator coupled to a Photo-Multiplier Tube and long ionization chambers. The BLM commissioning in the high-energy section (300 MeV) is underway. Once the BLMs have been commissioned, the power will be slowly increased above 100 W to test the various components of the accelerator, including the 100 kW beam dump.

### *RF*

After passing an injection cryo module that boost the electron beam energy to 10 MeV, the main acceleration happens in the main superconducting acceleration module equipped with two 1.3 GHz nine-cell radio frequency (rf) cavities. Both cavities are driven by one single klystron in a self-excited loop (SEL) in vector sum control [9]. During the 2018 commissioning both cavities were locked and successfully driven together. Instabilities seeded by microphonics and sustained by ponderomotive effects (internal electromagnetic pressure [5]) limited the beam acceleration to an energy of up to 25 MeV with a beam energy stability outside specification.

This year environmental vibration and consequent microphonic effects were reduced at most frequencies by passive means. This was accomplished by adding damping materials or modifying design of several systems including the LN2 cryogenic system and the interfaces to the rf waveguide

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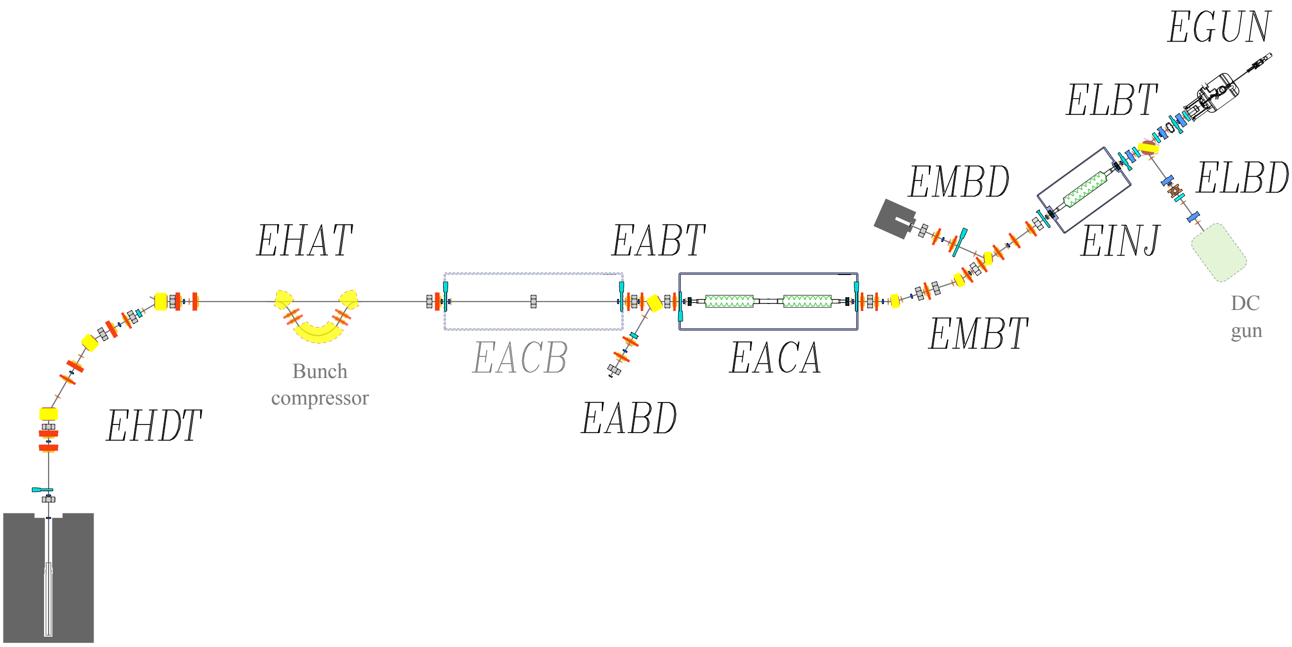


Figure 1: Sketched plan of e-linac including a potential second cryo module (EACB) and feasible position for a bunch compressor and a DC gun delivering beam for THz radiation production.

system. However, additional migration is required to reduce vibrations another order of magnitude.

The theoretical understanding of ponderomotive instability with two cavities under SEL vector sum control has been improved [10–16]. With the new understanding and more stable mechanical systems an operating regime has been identified and 30 MeV acceleration was reached but still limited by oscillation instability. The beam stability in this new configuration will be tested in November 2019.

## THZ PRODUCTION BASED ON E-LINAC

When an ultra-relativistic electron bunch is bent on a curves path, a broad spectrum of radiation is emitted. To produce high power, high-intensity THz radiation coherent synchrotron radiation is the key [17]. Therefore the electron bunch length must be short enough so the electrons emit in phase. Thus, the electrons emit radiation with the same wavelength at the same time when synchronous emission is achieved. The power of the emitted light is quadratic to the number of electrons taking part of the process. Such a short bunch is ideally produced at the source and can be further compressed by a magnetic compressor as discussed in [18].

The idea using the e-linac as a photon source at TRIUMF in a recirculating linac configuration with FEL option was considered from its very first beginning [1, 19]. So far the built beamline consists of the electron gun, low, medium and high energy sections with corresponding beam dumps as well as the main dump at the very end. This layout is shown in Figure 1, excluding DC gun, bunch compressor and third acceleration module EACB. In the last couple of years the interest of the Canadian scientific community changed towards THz based light sources. Spearheaded by the University of Waterloo the community is preparing to submit a proposal to the Canadian Foundation of Innovation (CFI) to construct a national FEL program. TRIUMF has been asked to support this program using the existing e-linac.

Table 1: General Beam Requirements

| Beam parameter | THz mode | RIB mode | Unit |
|---|---|---|---|
| Bunch rep. rate | 0.001 – 1 | 130 | MHz |
| Charge per bunch | > 200 | 26 | pC |
| Beam energy | 20 | 30 | MeV |
| Bunch length | < 50 | 10 | ps |
| Trans. emittance | < 50 | < 10 | mm mrad |
| Beam power | < 5 | 100 | kW |
| Energy stability | $10^{-4}$ | $10^{-3}$ | |

To utilize the e-linac as a test driver for such a program, it must be upgraded and key technologies need to be explored. To be capable of producing short and high charge bunches a new electron source is necessary. Therefore a 500 keV DC photocathode with accompanying driver laser must be designed and built. The design of such a DC gun can be modelled on existing gun designs, e.g. [20, 21]. To secure the e-linac's main purpose being the driver for ARIEL a new photocathode gun will be installed in addition to the existing thermionic electron source. To compress the bunch to even shorter bunch lengths a magnetic bunch compressor will be designed and built. Both DC gun and bunch compressor will be integrated at a feasible position in the current e-linac. The complete layout is shown in Figure 1. In addition, a second accelerator cryo module is included as well. Thus it would be possible to accelerate the beam to higher energy up

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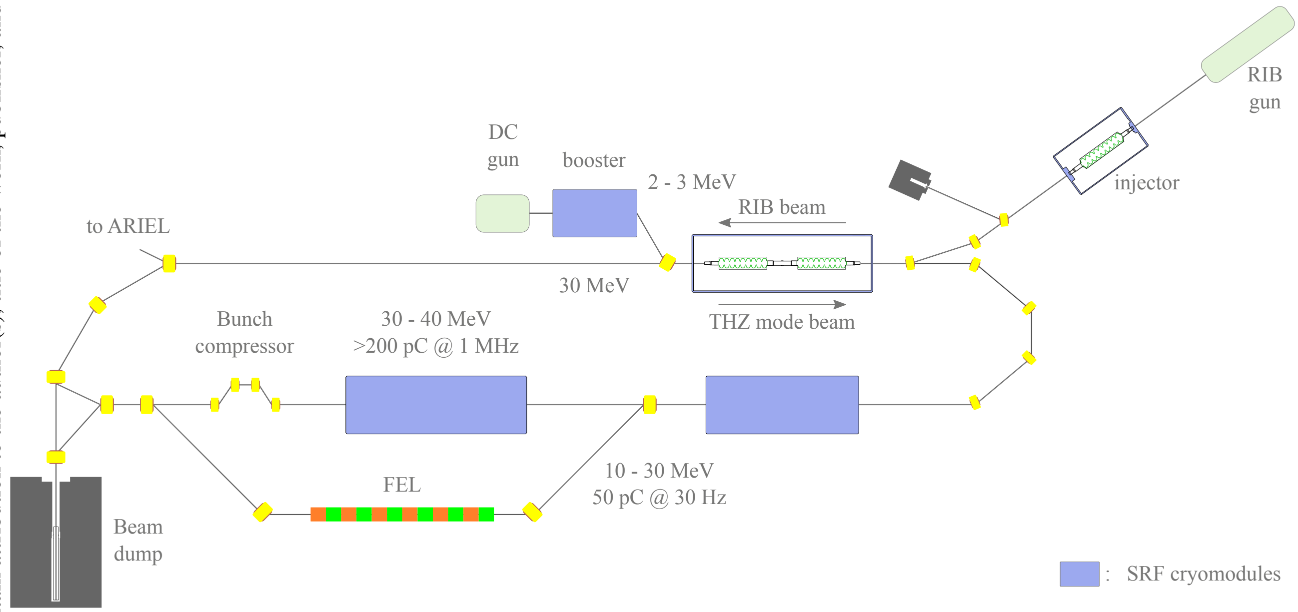


Figure 2: Sketched overview of a potential future layout for the e-linac to provide simultaneous operation of THz mode beam and beam for ARIEL (RIB beam).

to 50 MeV as well as give the beam a desired energy spread for the bunch compression. Necessary corresponding beam dynamic simulations of the e-linac with integrated DC gun will be started in January 2020. The beam requirements of the DC photocathode for both, the electron beam delivered to ARIEL and the electron beam for the THz radiation production are presented in Table 1.

Another part of the e-linac upgrade is the construction of the required THz light infrastructure. The laser light to the photocathode gun and the THz radiation must be transported between the e-linac vault and the optical laboratory that houses the laser and THz radiation equipment. Ideally the laser supplies green light to the NaKSb cathode. Ideally diagnostics will be foreseen to characterize the produced THz radiation in situ.

## POSSIBLE FUTURE DEVELOPMENTS

In the future TRIUMF will explore the use of the e-linac for users using THz radiation for pump-probe experiments. Once demonstrated future capabilities of the TRIUMF e-linac can be expanded with the construction of an infrared Free Electron Laser (IR FEL) and expanding towards a users program. A potential layout for this e-linac expansion is shown in Figure 2. The design includes two possible radiation production paths, THz radiation as well as IR radiation produced by an undulator, in a recirculation setup. Thus TRIUMF would be able to explore ERL beam physics and technologies. Hereby the design is chosen in a way to combine two different beam modes and to be flexible and adapt to users needs. For the THz FEL beam mode the bunch charge should be increased to a range from 500 pC to 1 nC. Within the presented layout the operation of the RIB beam and the beam for THz radiation or IR FEL radiation can be simultaneous.

## CONCLUSION

The TRIUMF e-linac is an ideal machine to support several research areas. Aside driving the ARIEL electron target station, it can serve as a source for high field THz radiation and in a recirculation set-up also for high intensity ERL studies. During this year commissioning progress in many areas has been made. The MPS was recommissioned in the low and medium energy section while the commissioning in the high energy section is ongoing. Vibration and microphonic amplitudes were reduced by passive means. Due to the improved theoretical understanding of ponderomotive instabilities together with a more stable mechanical system, a 30 MeV acceleration was reached but still limited by oscillation instability.

The e-linac will be expanded by a DC photocathode, a bunch compressor and a potential second cryo module with two cavities to produce THz radiation. This radiation production is a first stage to a possible future THz FEL in a recirculating setup.

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