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ARIEL Accelerator Overview

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Abstract. This paper gives an overview of the ARIEL electron accelerator including the existing facility and possible future upgrade possibilities.

1. Overview of the Existing Facility

Fig. 1 shows a schematic layout of the TRIUMF accelerator complex, which is Canada's particle accelerator centre. Users of this unique accelerator complex include both Canadian and international collaborators. The primary beam driver is a 500 MeV H^- cyclotron, currently running at 100 kW with a near-future plan to increase to 150 kW. It is used to produce rare isotopes, neutrons and muons. Several other cyclotrons of energy 14-42 MeV are used for medical isotope production and have a total beam power of about 100 kW.

In addition, there are:

- the Isotope Separator and Accelerator (ISAC) facility;
- the Isotope Separator OnLine (ISOL) facility
- ISAC-I normal conducting linac, 0.15 - 1.8 MeV/u
- ISAC-II superconducting linac, 1.5-16.5 MeV/u .

The Advanced Rare IsotopE Laboratory (ARIEL), currently under construction, will be served by a superconducting electron continuous wave (CW) linac with an energy of 30 MeV and power capability up to 300 kW. This linac is already operational, though with average beam power output currently limited to 10 kW by the rating of the present beam dump.

2. Electron Linac: Design Parameters and Current Machine Performance

Fig. 2 shows a schematic layout of the existing ARIEL electron linac. The main components are:

Electron gun: A 300 kV thermionic gun produces bunches at 650 MHz and delivers up to 10mA average beam current in CW mode [1].

Linac: This consists of three 9-cell 1.3 GHz niobium cavities working at 2 K in two different cryomodules [2, 3, 4, 5]. The injector cryomodule contains one cavity and the second cryomodule contains two. There are two 50 kW RF couplers per cavity.

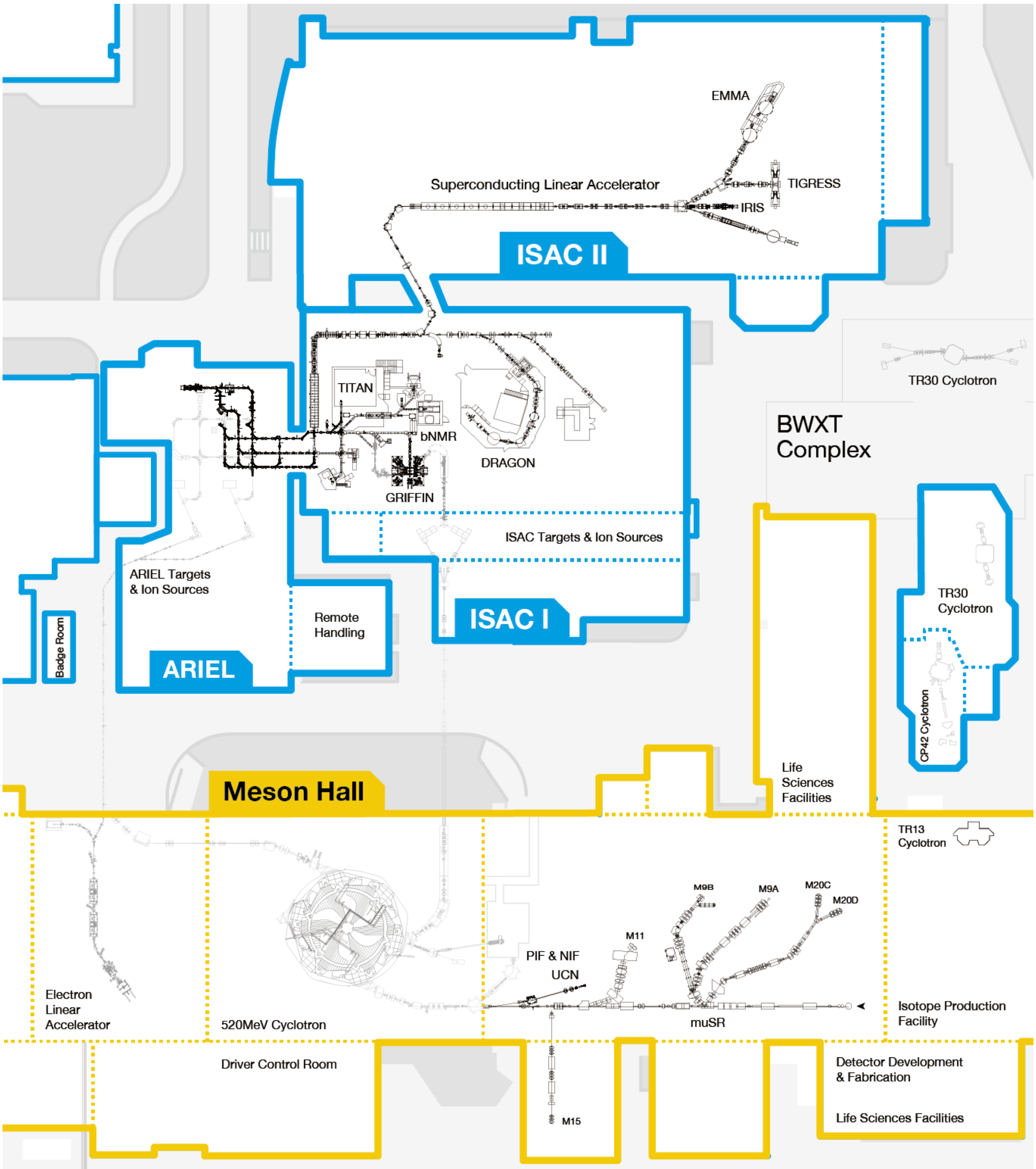

Figure 1. Schematic layout of the existing TRIUMF accelerator complex.

RF sources: There are two CPI 290 kW 1.3 GHz klystrons in the e-hall, each with a power supply positioned on the e-hall roof. A single RF source is used for the two cavities in the second cryomodule.

Cryogenics: A 800W (@4 K) helium liquefier is used. There are three 2 K Busch sub-atmospheric pumps in operation, with one 'spare'.

Beam dump: The current beam dump is rated at 10 kW.

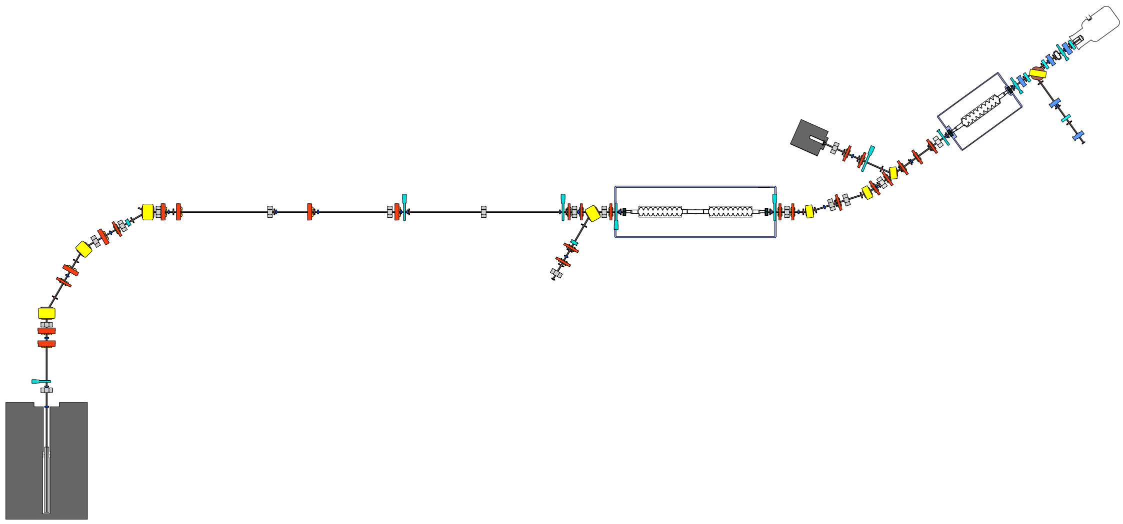

Figure 2. Schematic layout of the existing ARIEL electron linac (in red).

Since September of 2021, the e-linac has demonstrated ability to run at 30 MeV energy and 10 kW power. However, reliability of beam delivery is not yet meeting specifications. This can be seen in Figure 3, which shows the peak beam current in a typical day's running at 10 kW. The sharp drops in current correspond to beam trips and overall instability.

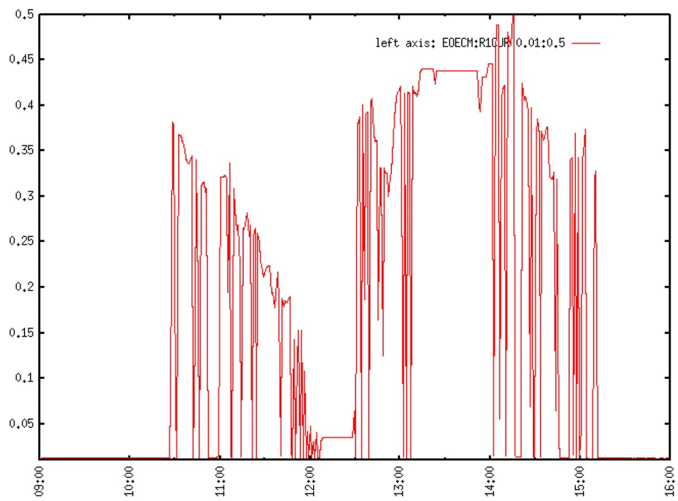

Figure 3. Example peak beam current in mA from a run at 10 kW. The fluctuations show unreliable operation.

The top four issues causing e-linac downtime are:

e-Gun: High voltage and beam current stability present ongoing challenges.

Tunability: Many procedures depend on tedious manual interventions. This also complicates the training of operators.

Spurious trips: The origin of these trips is understood. They are caused by a series of hardware, interlock and diagnostics related issues, which are being addressed in our current reliability campaign.

Lack of spare parts: Simple failures can cause long delays.

The team has established strategies to address these issues over the coming year. The objective is to demonstrate three-day continuous beam delivery by March 2023.

3. Pre-ARIEL Science in the Electron Hall

The ARIEL electron target will be ready to take its first beam in 2025. Although the e-linac was built to deliver beam to the ARIEL electron target, it has the potential to become a multi-purpose, multi-user facility. With the e-Linac already capable of producing 30 MeV beam, the intervening time before ARIEL comes online enables the establishment of an early science program using the e-linac for other experiments. The following experimental programs have been established in the e-hall and are or will be completed before ARIEL begins taking beam.

ARIEL targets: A converter test stand was used to validate the target technology planned for ARIEL. The 300 keV test stand operating at powers up to 3 kW can simulate the sort of power density that will be encountered in the future 30 MeV/100 kW ARIEL targets. These tests allowed a gold-on-aluminum option to be ruled out and a tantalum-on-aluminum target to be validated as a viable option [6].

FLASH: An experiment to research radio therapy is in progress. This is a life science experiment situated at the 10 MeV beam dump and exploring high dose rate radiotherapy [7].

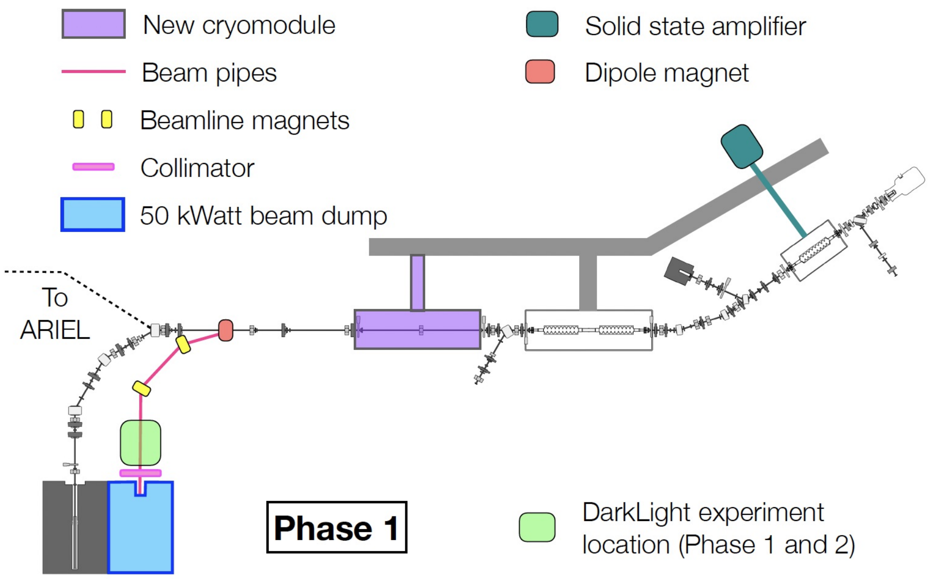

Figure 4. Schematic layout of the DarkLight experiment in Phase 1 (2024), when it will operate at 50 MeV as a single, dedicated user at the e-linac.

DarkLight: The CW, high-intensity electron driver for ARIEL is ideal for the type of thin-target scattering experiment proposed by the DarkLight collaboration. The DarkLight target will be placed close to the existing high-power dump for an initial round of data taking in the fall of 2023. The current beam energy of 30 MeV is somewhat low for the physics goals of the experiment and an energy upgrade to 50 MeV is required to probe the 17 MeV mass range of the anomaly observed by the ATOMKI experiment [8]. This energy upgrade will be achieved by the addition of another two-cavity cryomodule matching the existing second cryomodule to the beamline and is expected to complete in 2024. A schematic of the experiment and beamline at this stage is shown in Figure 4.

4. Future of the Electron Linac as a Multi-user Facility

After 2025, when the ARIEL project is complete, the e-linac must serve its primary purpose of delivering beam to that facility. Several proposed projects and/or e-linac modifications can, however, proceed in parallel without disrupting beam delivery to ARIEL. These include:

DarkLight Phase 2: With the addition of a septum magnet and RF deflector to the beamline setup for DarkLight Phase 1, it will be possible to direct alternate electron bunches to the ARIEL targets and to the experimental site in front of a new high-powered beam dump built to serve DarkLight. In 2025 and the years immediately after, this site will support DarkLight. After its physics program finishes, the same site could be used for other experiments in future. The layout of DarkLight in Phase 2 is shown in Figure 5.

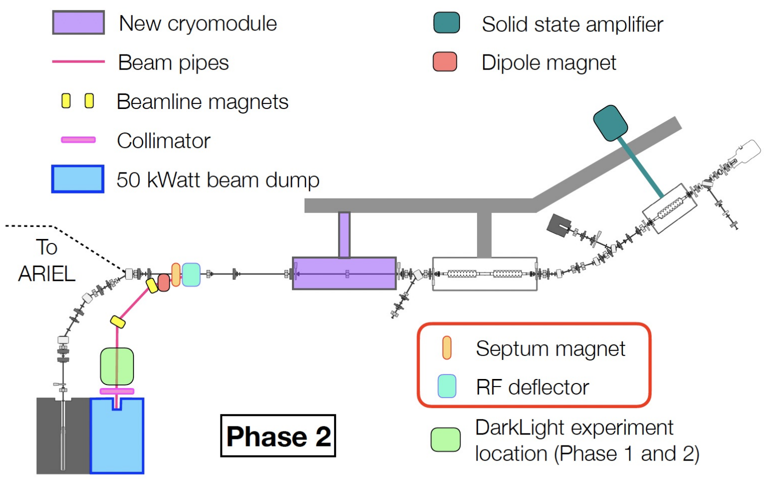

Figure 5. Schematic layout of the DarkLight experiment in phase 2, when it will be able to operate in parallel with ARIEL.

TeraHz: Due to its parameters (CW beam, 30 MeV) the ARIEL e-linac is an ideal driver for a high-intensity THz near-infrared (IR) photon source. There are only a few similar accelerators in the world. The project, led at TRIUMF by Victor Verzilov, is part of the proposed National IR free electron laser program led by the University of Waterloo. Producing THz light requires sub-mm high-charge electron bunches, and some THz production stations (optical transition radiation or synchrotron radiation). A project has been proposed with the objective of demonstrating production of high intensity (MV/cm) broadband radiation, with the ultimate goal of establishing a users' community.

Energy Recovery Linac: Finally, an upgrade of the e-linac to an Energy Recovery Linac (ERL) has been envisaged since the inception of ARIEL. A conceptual design has been developed involving an energy boosting arc [9]. This design can fit alongside the new DarkLight beamline in the e-hall with no anticipated space conflicts and is compatible with the needs of the THz program as well. A schematic of the ERL layout is shown in Figure 6.

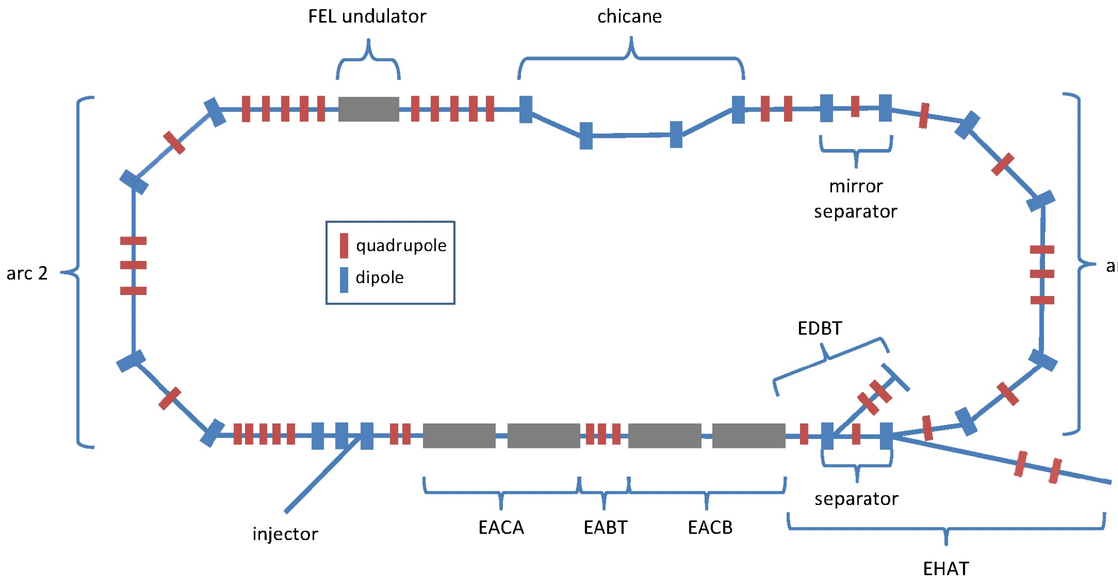

Figure 6. Schematic layout of the ERL upgrade to ARIEL.

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