TRIUMF

ARIEL Accelerator Overview

DarkLight Meeting

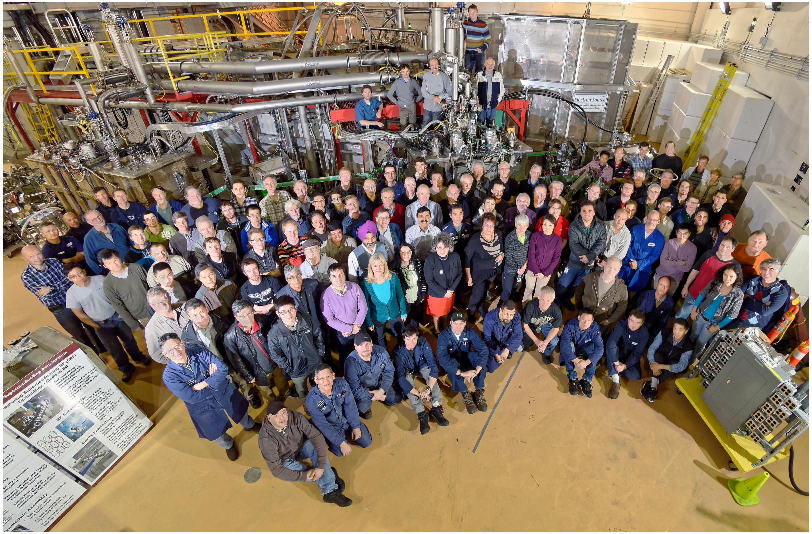
Thomas Planche
e-Linac Facility Coordinator

February 12, 2021

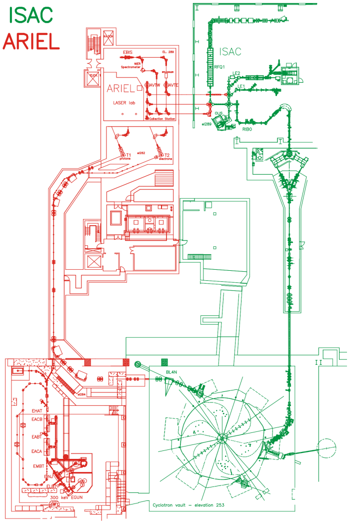
Outline

- Design parameters
- Machine performance
- Subsystems
- Science in the electron hall

ARIEL Electron Linac (since 2014)



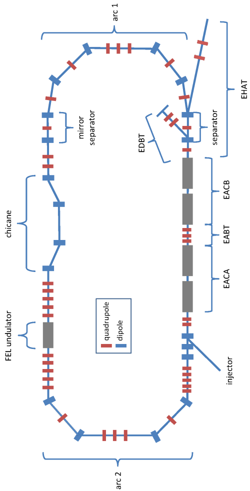
High-Power Driver for ARIEL



Design Parameters

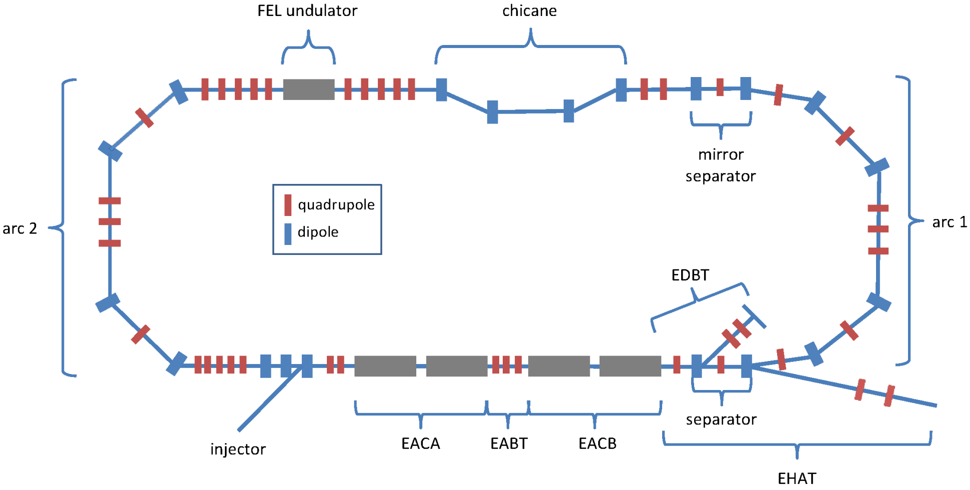
- Nominal electron beam energy 50 MeV (3 cryomodules)
- Beam optics designed for up to 75 MeV
- Average beam power up to 500 kW (3 cryomodules)
- Peak current up to 10 mA
- 650 MHz gun, 1.3 GHz rf
- Beam can be pulsed with duty cycles: 0%–100% and rep. rate: 100 Hz–2 kHz
- Beam energy stability better than 0.1% (2$\times$RMS)

Conceptual Design: Energy Recovery/Energy Boosting Arc



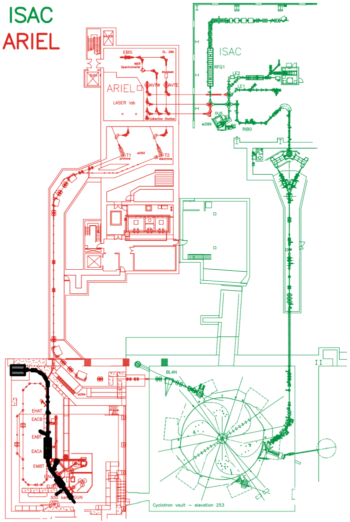
Layout of the design energy recovery/energy boosting arc [Gong, 2015].

Conceptual Design: Energy Recovery/Energy Boosting Arc

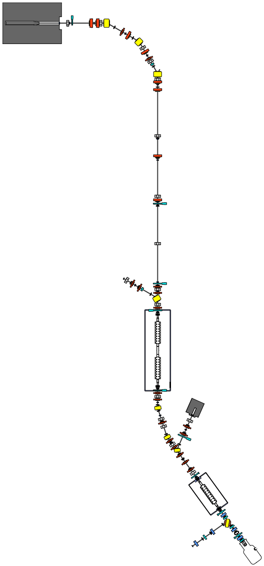


Layout of the design energy recovery/energy boosting arc [Gong, 2015].

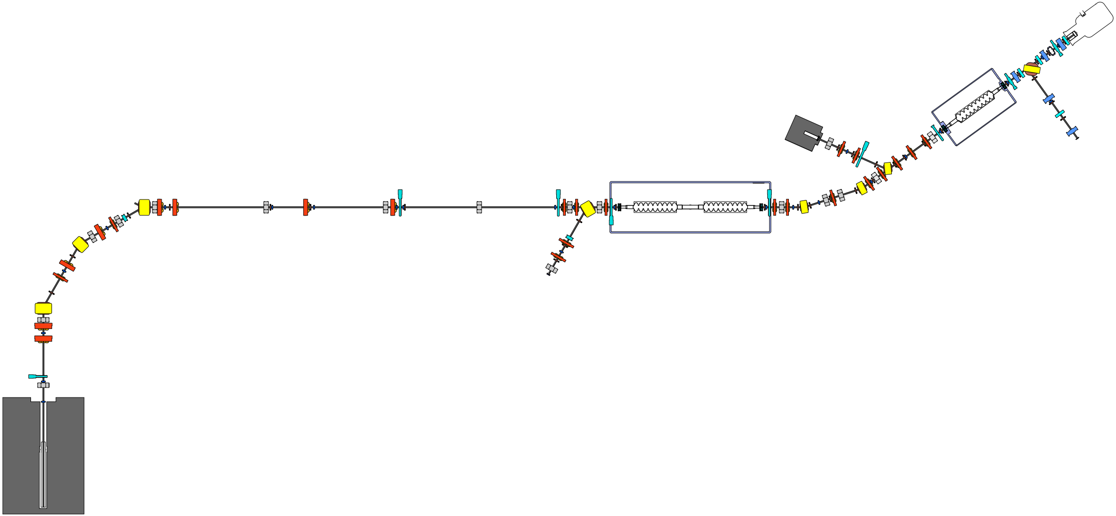
Installed to Date



Installed to Date



Installed to Date



Installed Capability

- 30+ MeV
- CW beam power of up to 300 kW, but nowhere to dump that much power
- 10 kW high-energy beam dump

Demonstrated to Date

- 31 MeV
- 1 kW average beam power
- 0.1% energy stability at 7 MeV, 0.4% at 26 MeV

Commissioning Timeline

Sep. 2014	First High-energy beam (20 MeV)
Sep. 2014	E-hall lockup incident
Jul. 2018	25 MeV at low beam power
Dec. 2019	1 kW 7 MeV
Feb. 2020	31 MeV at low beam power
Dec. 2020	1 kW 26 MeV

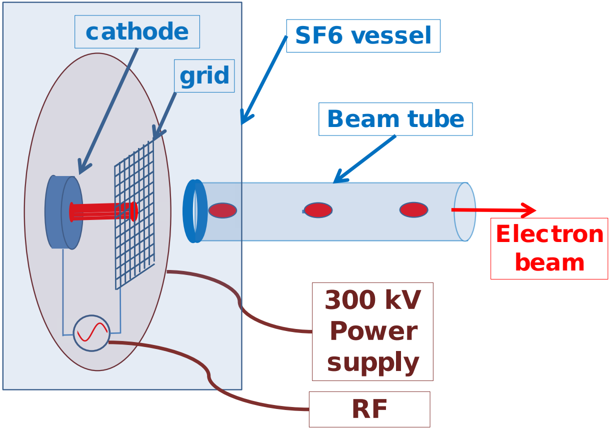
We are on track with our plan to demonstrate 10 kW at 30 MeV by the end of 2021.

Road map towards operations at 10 kW at 30 MeV

- ✔ Until Jan 21: run 7h/day on temporary power and demonstrate 1 kW at 25 MeV.
  - ✔ MPS commissioning,
  - ✔ optics commissioning,
  - ✔ rf studies including adaptive feed forward.
- → 3-month shutdown to:
  - reprocess the injector cavity,
  - install an AC current transformer,
  - install the repaired transformer.
- Until the end of 2021: demonstrate 10 kW at 30 MeV:
  - refine adaptive feed forward for pulsed regime,
  - run over extended periods.
- From 2022: focus on reliable operations. Improve reliability, train operators, complete operation's manual, accumulate run-time statistics.

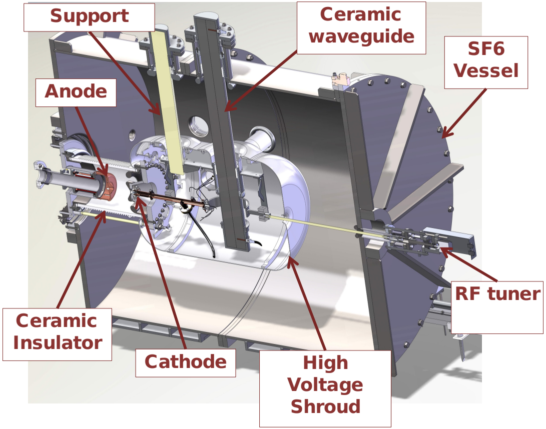
300 keV Thermionic Gun

Produces bunched at 650 MHz using an rf grid [Ames et al., 2016].

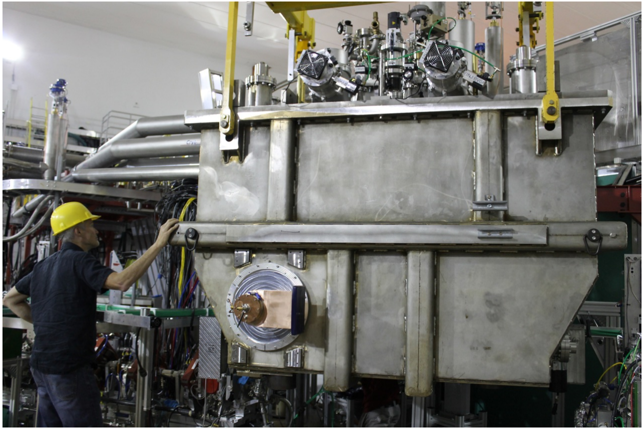


300 keV Thermionic Gun

The electron source is inside a pressurized SF_6 vessel to avoid breakdown of the 300 kV DC voltage. Bunch forming 650 MHz rf is fed into the gun using a rigid ceramic waveguide.

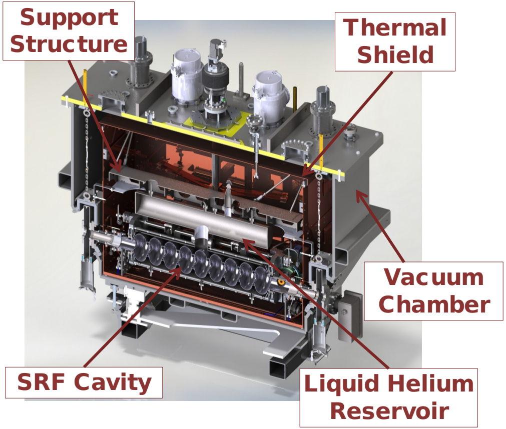


Injector Cavity



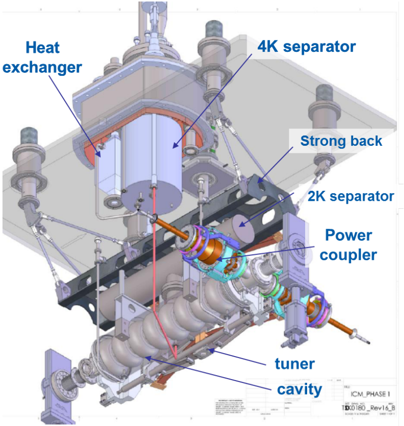
Injector Cavity

9-cell elliptical superconducting niobium cavity, operated at 2 K [Zvyagintsev et al., 2011, Ma et al., 2015].



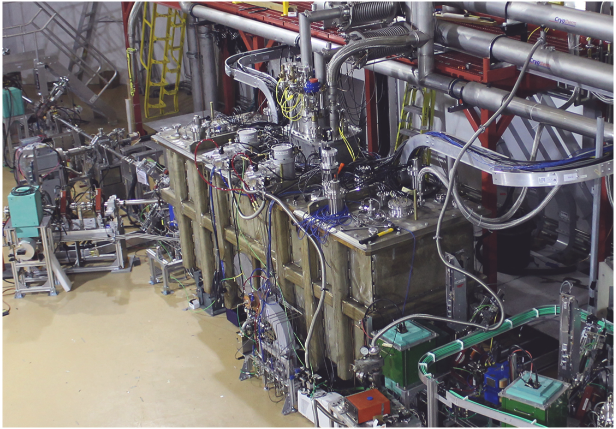
Injector Cavity

2 power couplers capable of delivering 50 kW each.



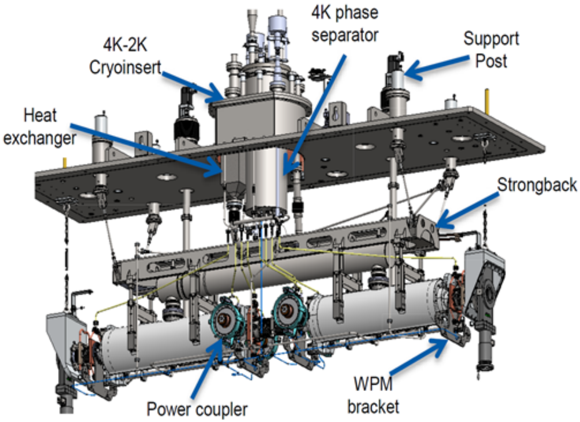
Second Cryomodule

Contains two 9-cell cavities, equipped with two 50 kW power couplers each [Laxdal et al., 2017, Ma et al., 2018].

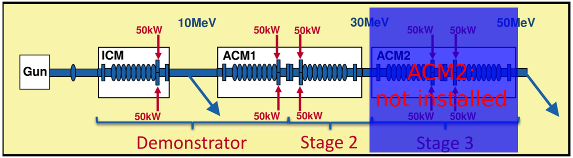


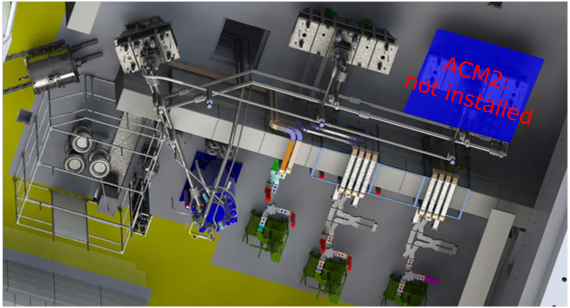
Second Cryomodule

Contains two 9-cell cavities, equipped with two 50 kW power couplers each.



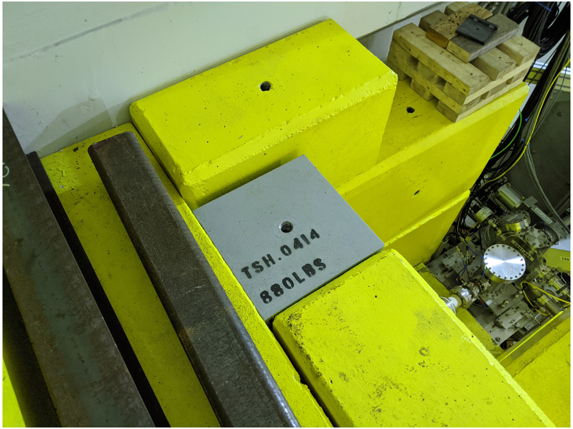
Cold Box, Klystrons

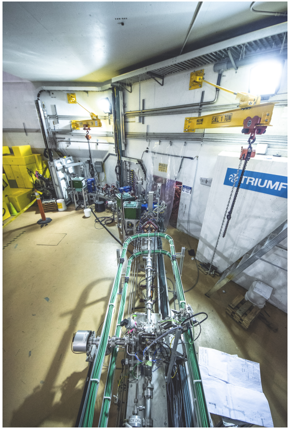




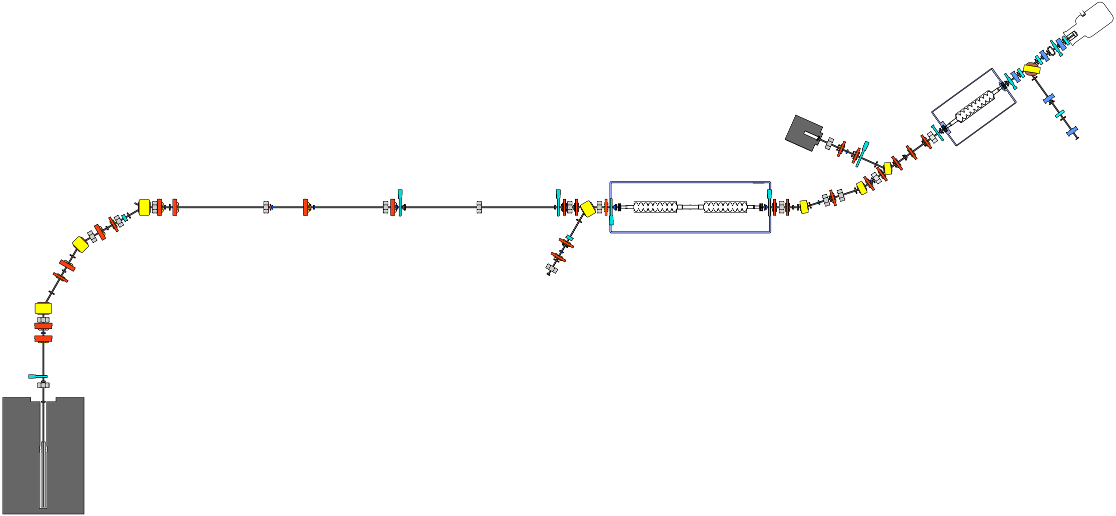
High-Energy Dump

Dump designed to take 100 kW. Shielded rated for 10 kW





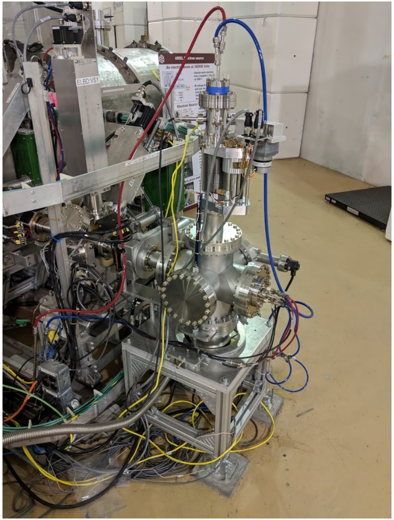
Recap



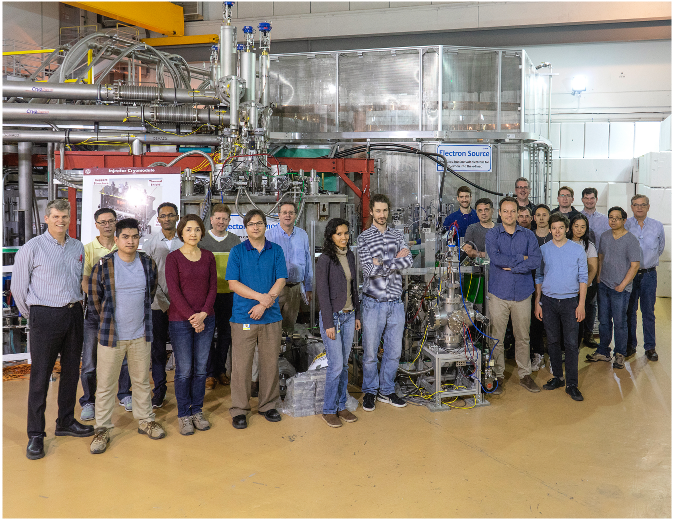
Science with the e-Linac

The e-linac is built to deliver beam the the ARIEL electron target. But it has the potential to become a multi-purpose, multi-user facility.

Converter Test Stand



Converter Test Stand



Converter Test Stand

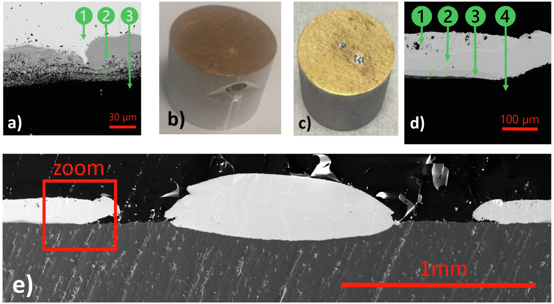


Fig. 4. Sample 1 before (b) and after (c) irradiation for 50 h. Al % in pristine sample (a): 1) 3.5% 2) 51% 3) 97% Al % in irradiated sample (d): 1) 1.5% 2) 28% 3) 32% 4) 98% Zoomed-out SEM interface where gold gaps are evident after irradiation (e).

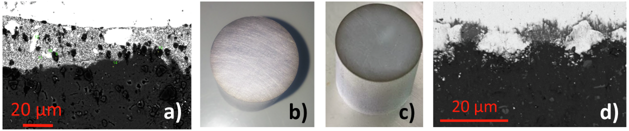
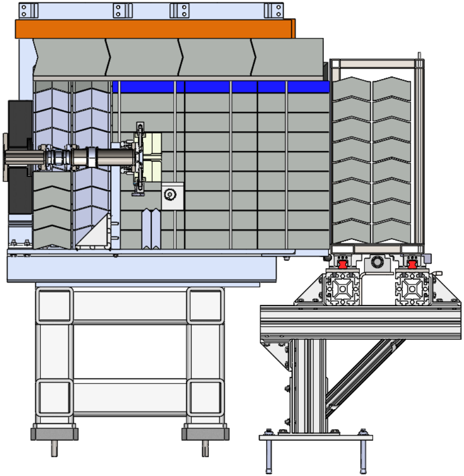


Fig. 5. Sample 4 interface before (a,b) and after (c,d) irradiation for 500 h, with no major morphological or chemical change.

For more details, read [Egoriti et al., 2020].

FLASH Radio Therapy Reserach

The medium energy dump is going to be replace this year by this irradiation facility:



High-Brightness THz/IR Photon Source

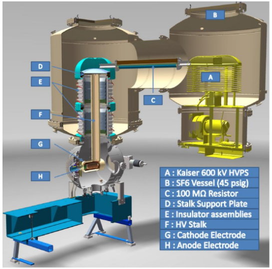
- Due to its parameters (CW beam, 30 MeV) our e-linac is an ideal driver for a high-intensity THz/IR photon source. There are only a few similar accelerators in the world.
- The project, lead at TRIUMF by Victor Verzilov, is a part of the proposed National IR FEL program lead by the University of Waterloo.

High-Brightness THz/IR Photon Source: Stage 1

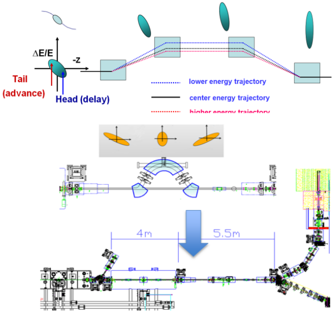
Producing THz light requires sub-mm high-charge electron bunches, and some THz production stations (OTR or synchrotron radiation).

Major deliverables

DC gun will be based on KEK/Cornell designs.
Both achieved 500 keV.



Bunch compressor is a well known device.
Will include a bypass for RIB transport

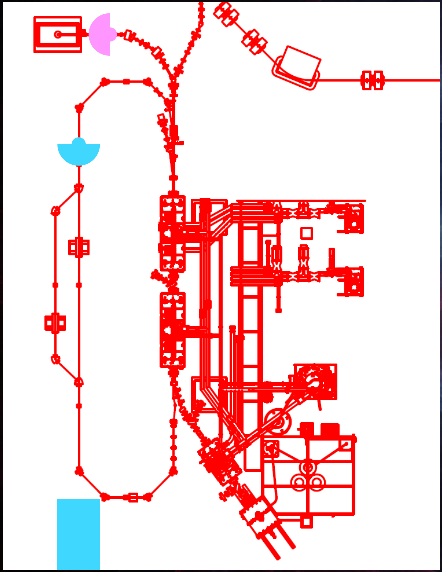


CFI project (proposal), objective: demonstrate production of high intensity(∼MV/cm) broadband radiation, and establish a users' community

DarkLight?

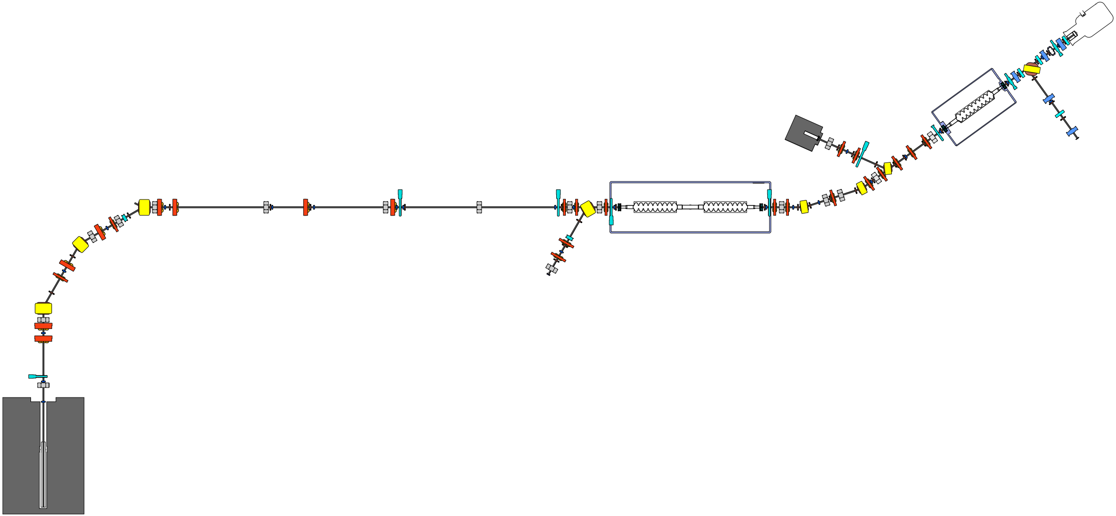
Could we fit your experimental setup upstream of our high-power dump?

Possible locations



- Minimal modification
- Could use exisiting beam dump
- Cleaner environment: Beam dump far away
- Might be able to recover beam energy

Space Available to Install the DarkLight Experiment



Stages?

Stage 0 Accelerator as is. Reachable energies: 10→30+ MeV

Stage 1 Recirculating arc for energy boost to 50 MeV

Stage 2 Third cryomodule for energy boost to 75 MeV

Bibliography:

Ames, F., Chao, Y., Fong, K., Koscielniak, S., Khan, N., Laxdal, A., Merminga, L., Planche, T., Saminathan, S., Storey, D., et al. (2016).
The triumf ariel rf modulated thermionic electron source.
In *Proc. 28th Linear Accelerator Conf.(LINAC'16)*, pages 458–461.

Egoriti, L., Cervantes, M., Goodacre, T. D., and Gottberg, A. (2020).
Material development towards a solid 100 kw electron-gamma converter for triumf-ariel.
Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 463:232–236.

Gong, C. (2015).
A novel optimization platform and its applications to the TRIUMF energy recovery linac.
PhD thesis, University of British Columbia.

Laxdal, R., Ang, Z., Au, T., Fong, K., Kester, O., Koscielniak, S., Koveshnikov, A., Laverty, M., Ma, Y., Storey, D., et al. (2017).
The 30mev stage of the ARIEL e-linac.
In *18th International Conference on RF Superconductivity.(SRF2017), Lanzhou, China*.

Ma, Y., Ang, Z., Fong, K., Keir, J., Kishi, D., Lang, D., Laxdal, R., Nagimov, R., Yao, Z., Waraich, B., et al. (2018).
First rf test results of two-cavities accelerating cryomodule for ARIEL e-linac at TRIUMF.
In *Proc. 9th Int. Particle Accelerator Conf.(IPAC18)(Vancouver, Canada, Apr.-May 2018)*, pages 4512–4515.

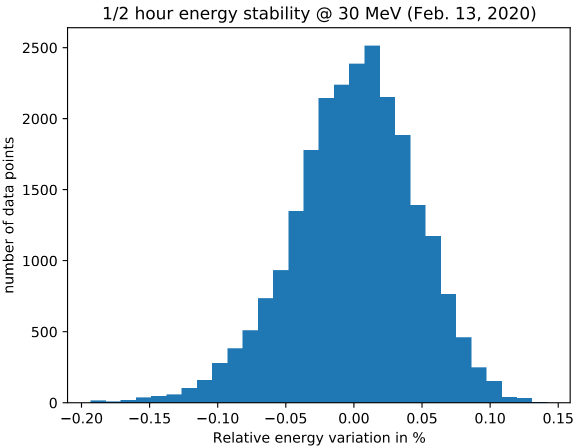
Ma, Y., Zvyagintsev, V., Laxdal, R., Waraich, B., Lang, D., and Harmer, P. (2015).
High power coupler test for ARIEL SC cavities.
THPB103, SRF2015, Whistler, Canada.

Zvyagintsev, V., Beard, C., Grassellino, A., Kaltchev, D., Kolb, P., Laxdal, R., Longuevergne, D., Waraich, B., Ahammed, M., Bolgov, R., et al. (2011).
Nine-cell elliptical cavity development at triumf.
In *Proceedings SRF 2011 Conference, Chicago, IL*.

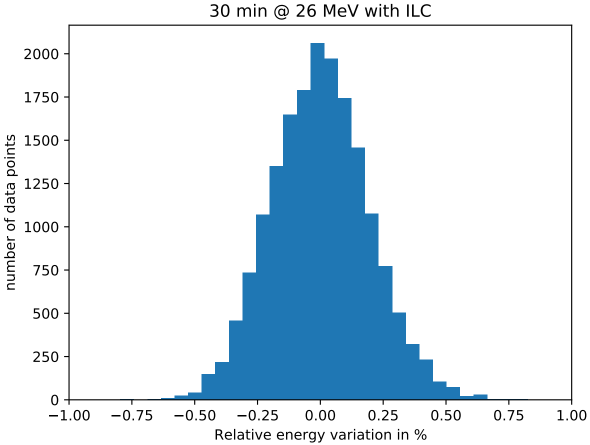
Thank you

Merci

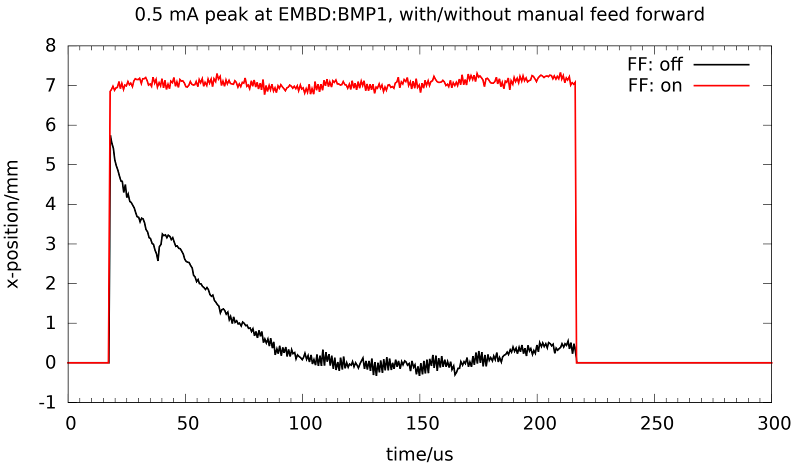
Energy Stability at 7 MeV



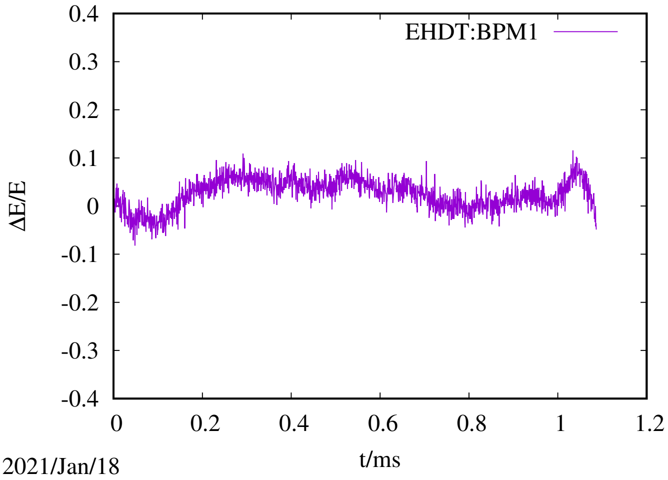
Energy Stability at 26 MeV, 1kW



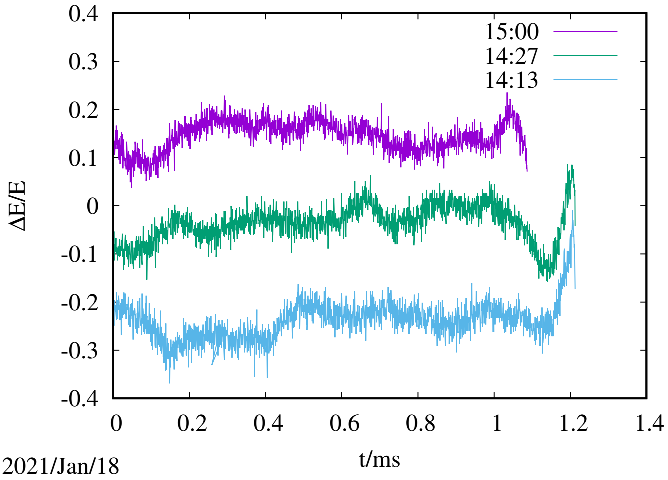
Feed Forward



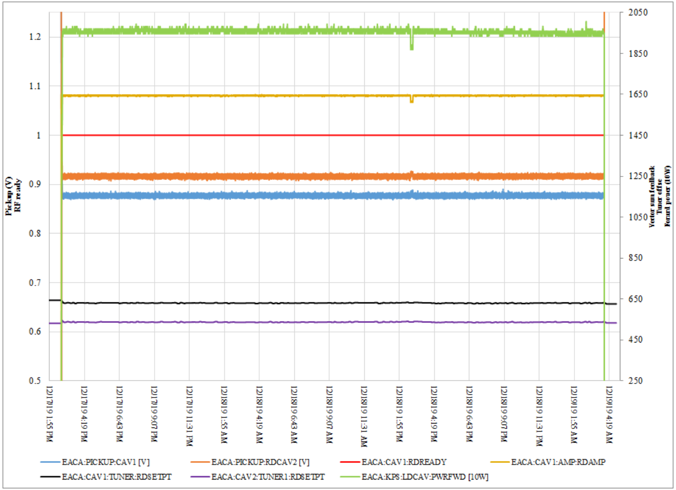
Pulse Energy Profile at 26 MeV



Pulse Energy Profile at 26 MeV



Long Term Stability of the RF

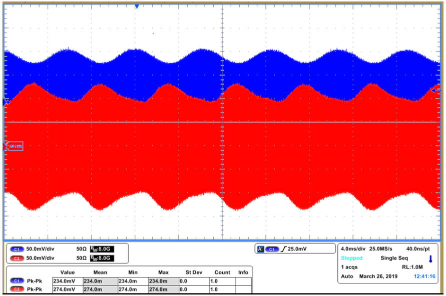


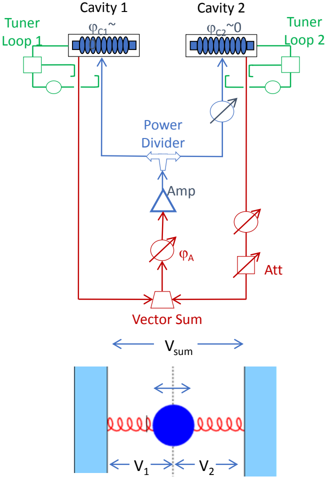
ACM1 RF Stability

- ACM1 cavities are driven by a single klystron in Vector Sum
- Under certain conditions, individual cavity voltages can oscillate in counterphase causing an instability in the beam energy
    - The instability is driven by coupling between cavity mechanical vibrations and `the Lorentz force
    - Mitigation: 1. reduce microphonics 2. appropriate choice of detuning parameters 3. add piezos to tuner stack

V1

V2





LLRF compensation and mitigation of two cavity instability. Ramona LEEWE ,TTC2019,Vancouver