TRIUMF e-linac as driver for FLASH, DarkLight and ARIEL

Outline

TRIUMF – an introduction

The e-linac – one of ARIEL's two drivers

The e-linac – an upcoming multi-user facility

TRIUMF: Canada's particle accelerator centre

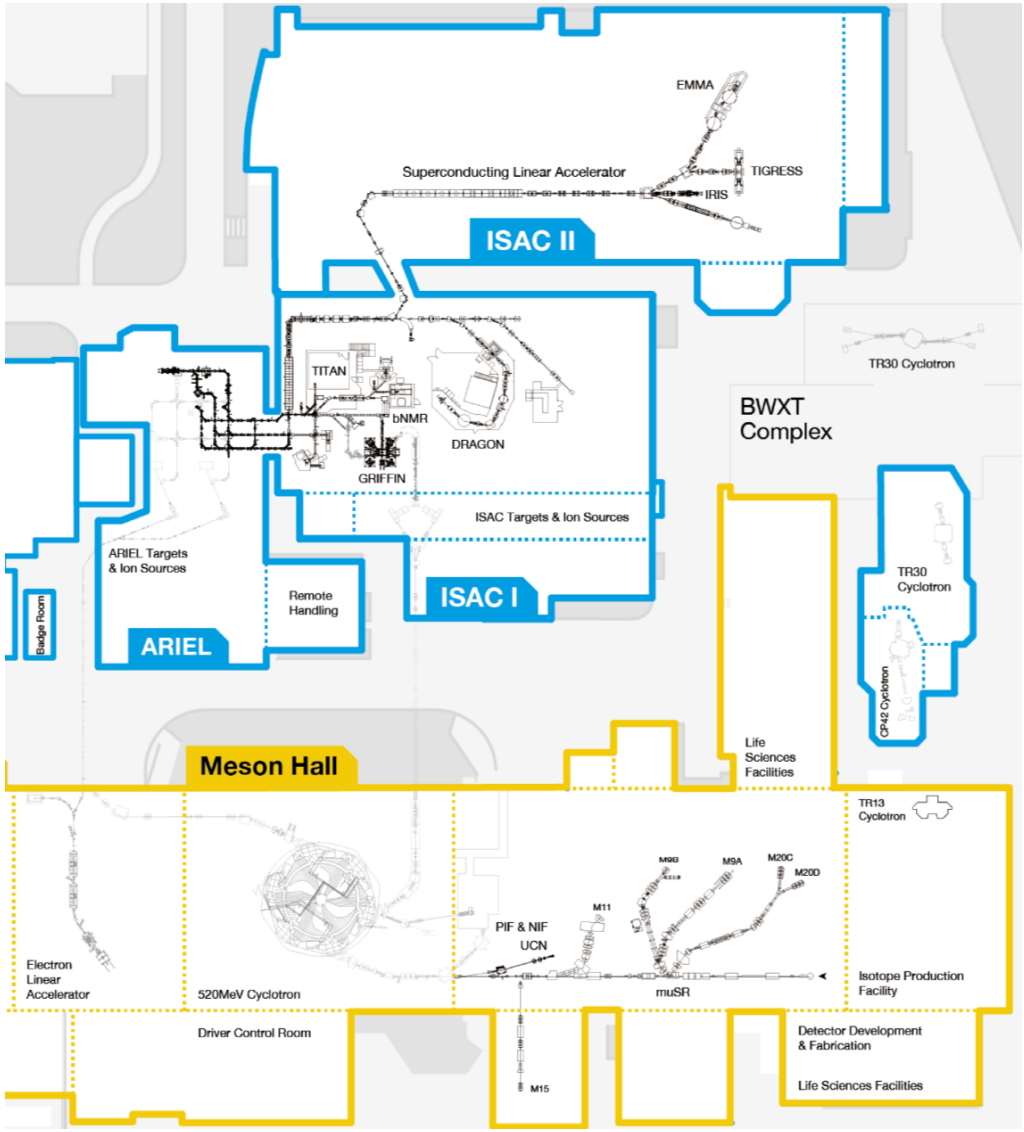
Primary beam driver: cyclotron

- 520 MeV H^- cyclotron
- Produces rare isotopes, neutrons and muons

Isotope Separator and Accelerator facility (ISAC)

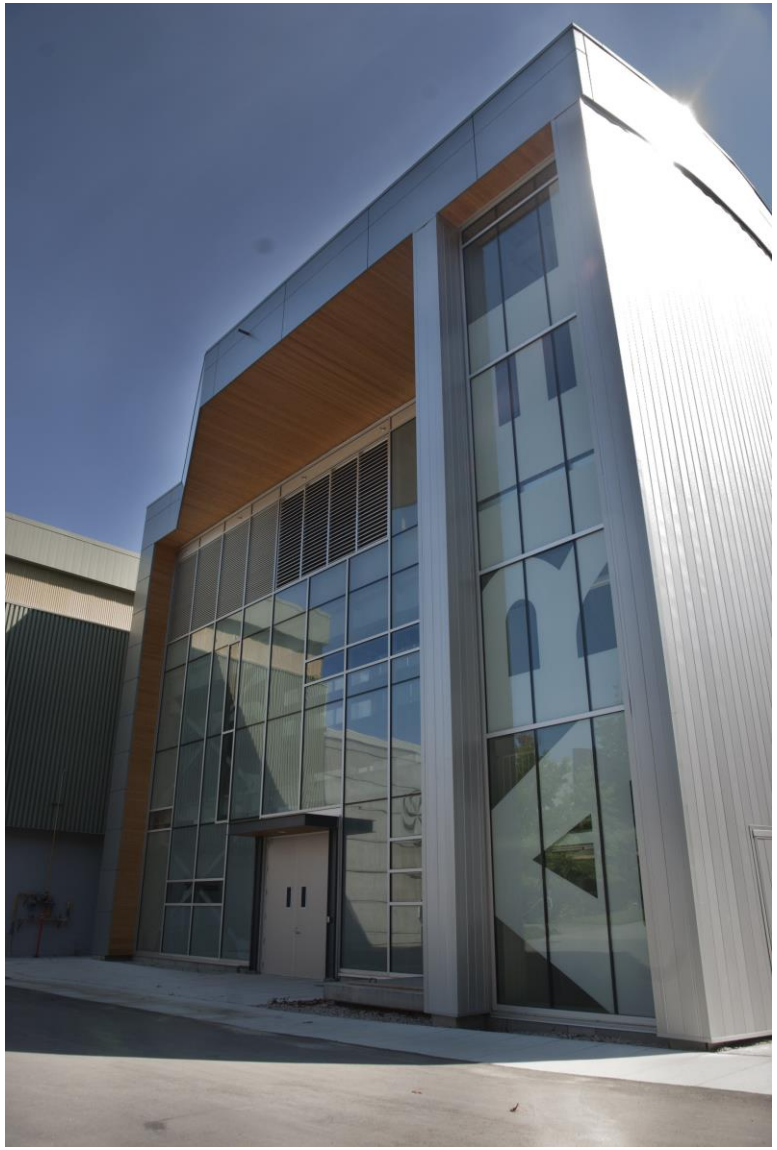
- Isotope Separator Online (ISOL) facility
- ISAC-I: Normal conducting-linac
- ISAC-II: Superconducting-linac

Advanced Rare Isotope Laboratory (ARIEL)



ARIEL: one of the world's most powerful ISOL complexes

- Massively expand our rare isotope research program
  - Providing more exotic isotope species with very high intensities
  - Adding two production targets in parallel to existing ISAC target station
- Three isotope production stations
  - Fully exploit numerous existing experimental facilities at ISAC

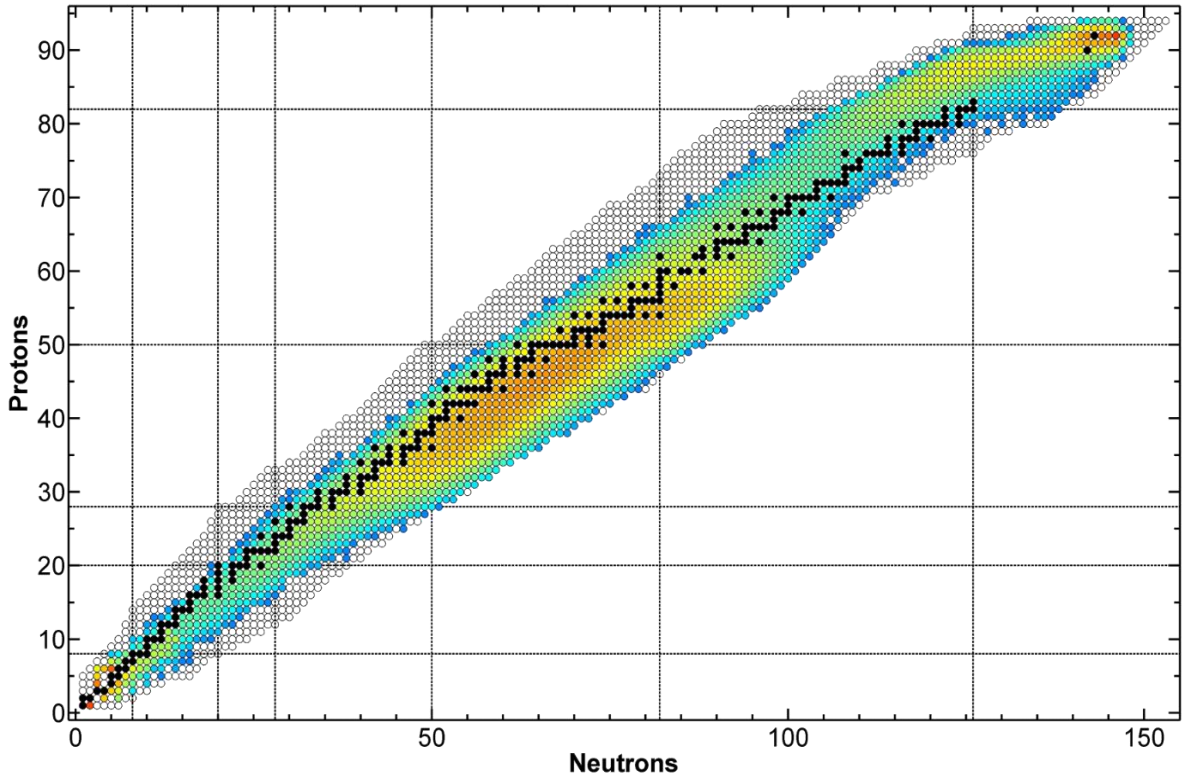


https://www.flickr.com/photos/triumflab/15148509948/in/photostream/

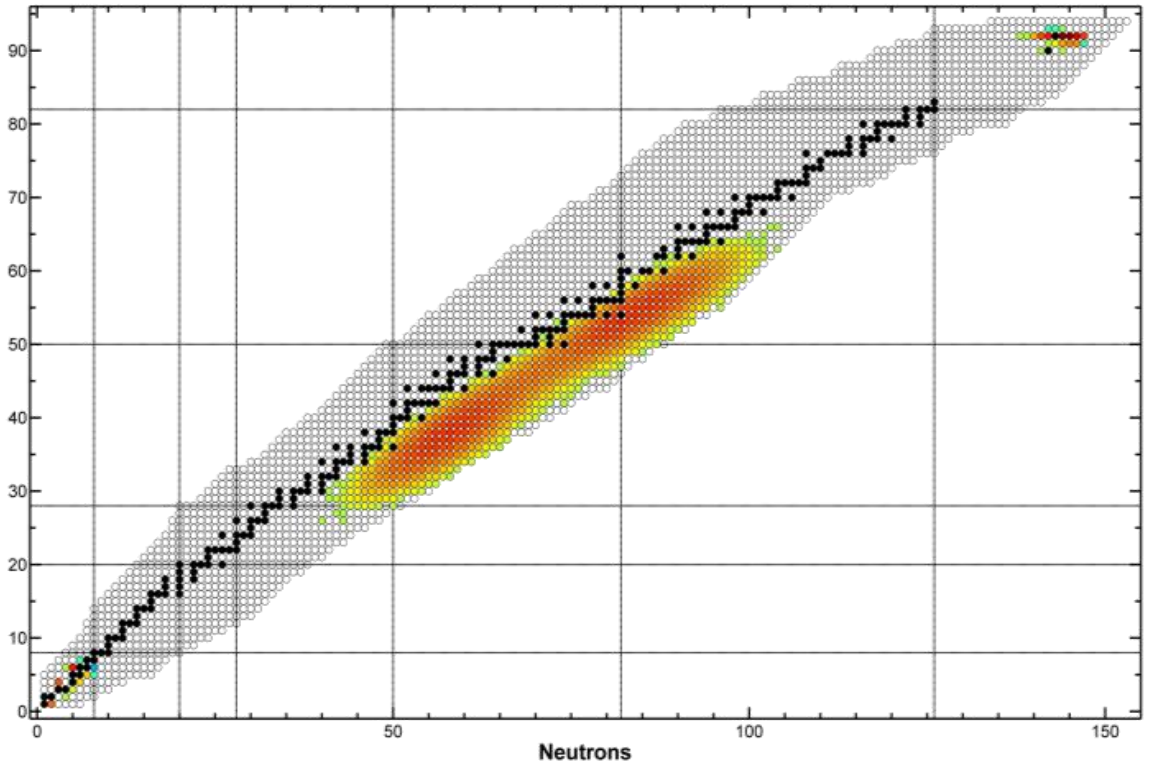
An independent driver for TRIUMF's Rare Isotope Program

production intensity from $^{238}UC_x$

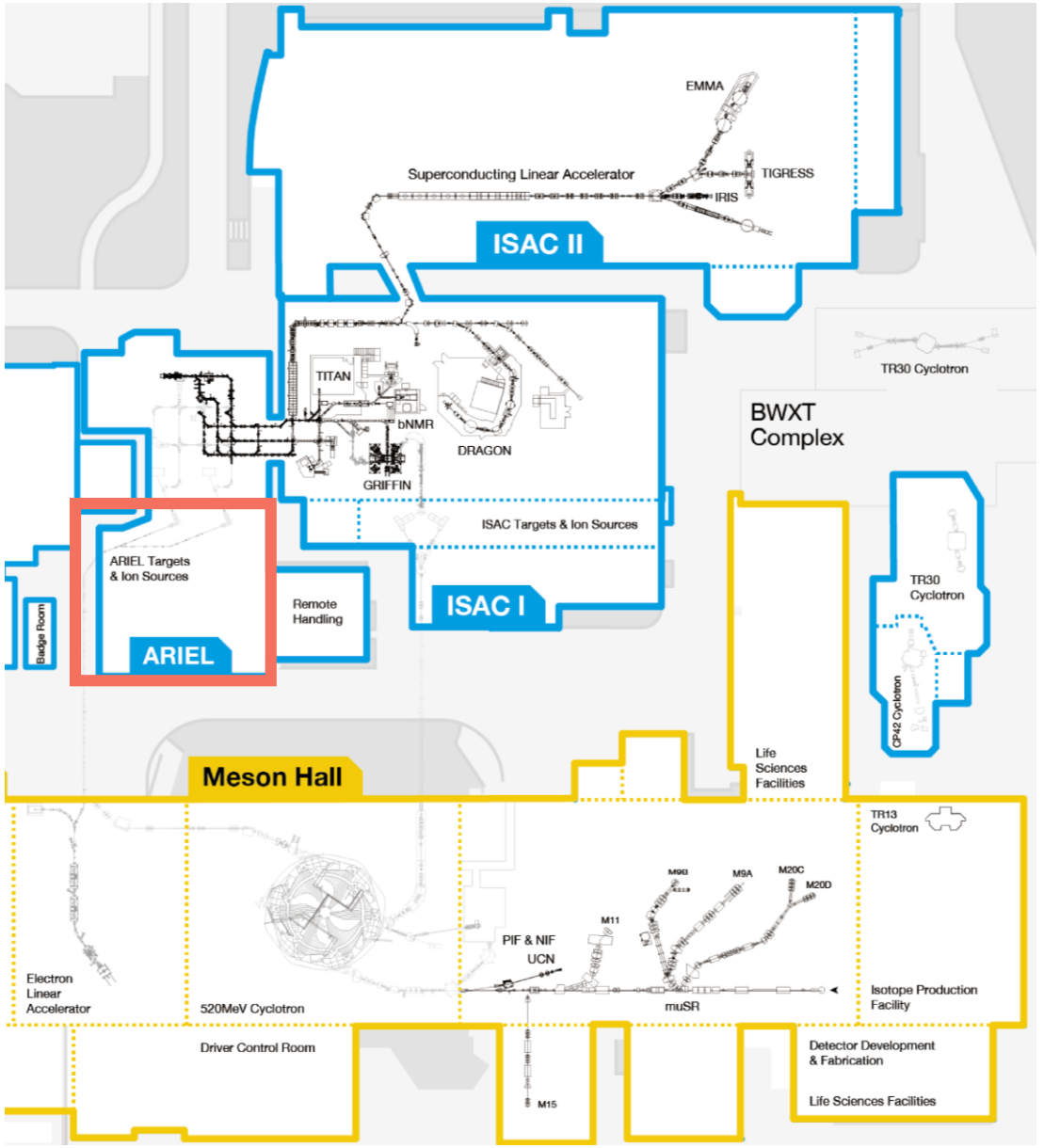
500 MeV x 10 μA protons [1/s]



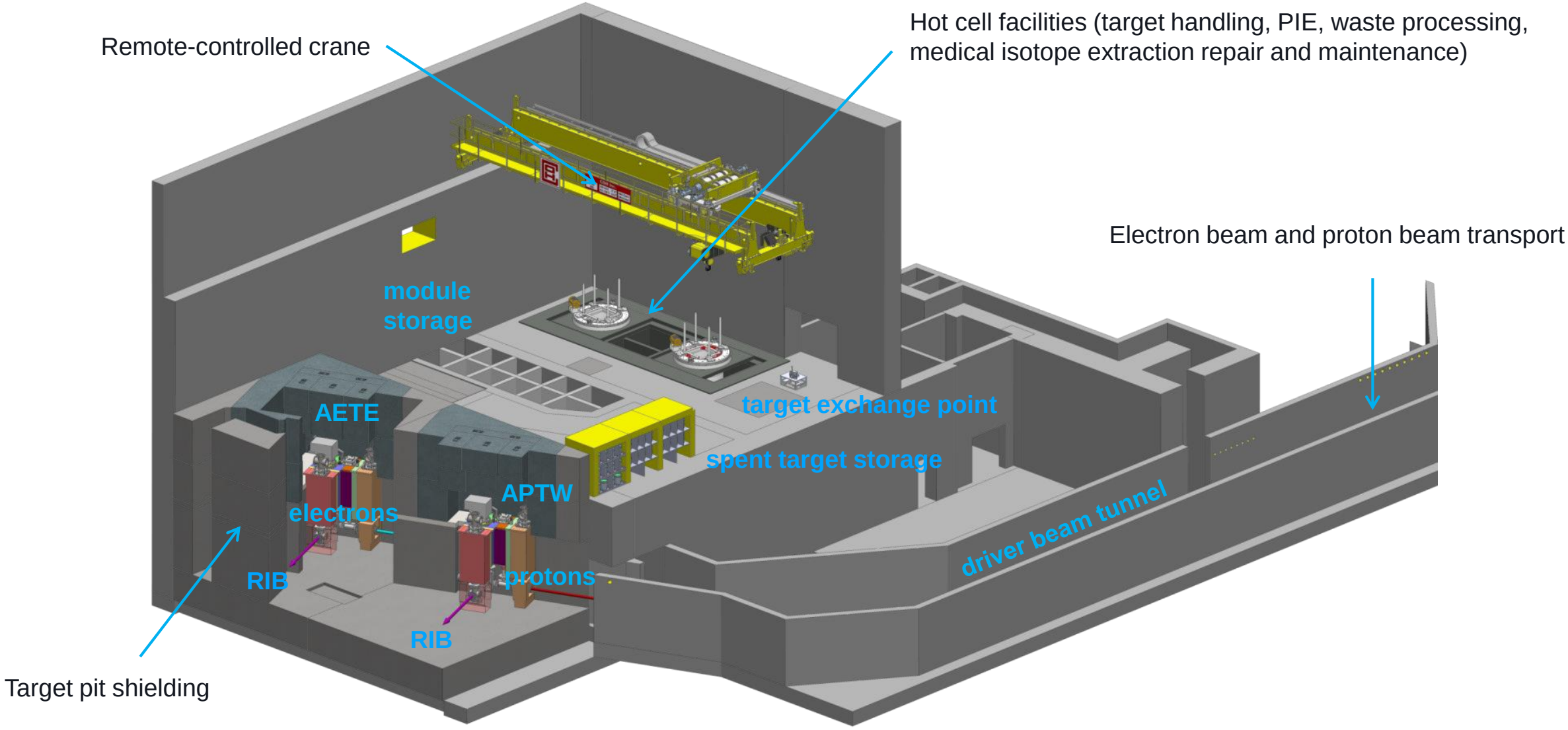
35 MeV x 10 mA electrons [1/s]

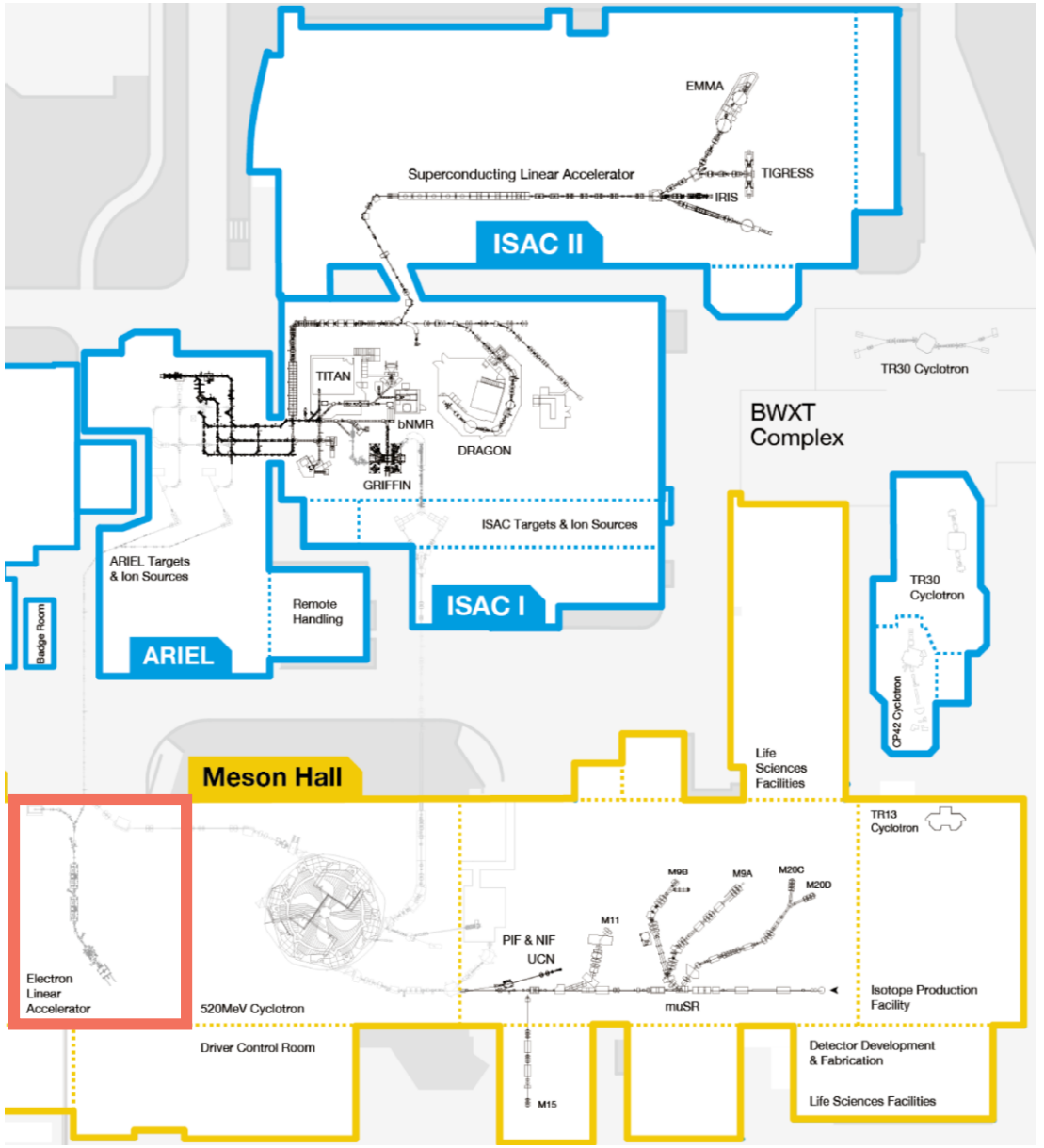


- Pure neutron-rich products from photofission
- Production cross section reduced in comparison to hadrons


EMMA
Superconducting Linear Accelerator
TIGRESS
IRIS
ISAC II
TR30 Cyclotron
TITAN
bNMR
DRAGON
GRIFFIN
BWXT
Complex
ISAC Targets & Ion Sources
ARIEL Targets
& Ion Sources
Remote
Handling
ISAC I
TR30
Cyclotron
Badge Room
ARIEL
CP42 Cyclotron
Meson Hall
Life
Sciences
Facilities
TR13
Cyclotron
M9D
M9A
M20C
M20D
M11
PIF & NIF
UCN
Electron
Linear
Accelerator
520MeV Cyclotron
muSR
Isotope Production
Facility
Driver Control Room
Detector Development
& Fabrication
M15
Life Sciences Facilities

The ARIEL Target Hall

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UCN
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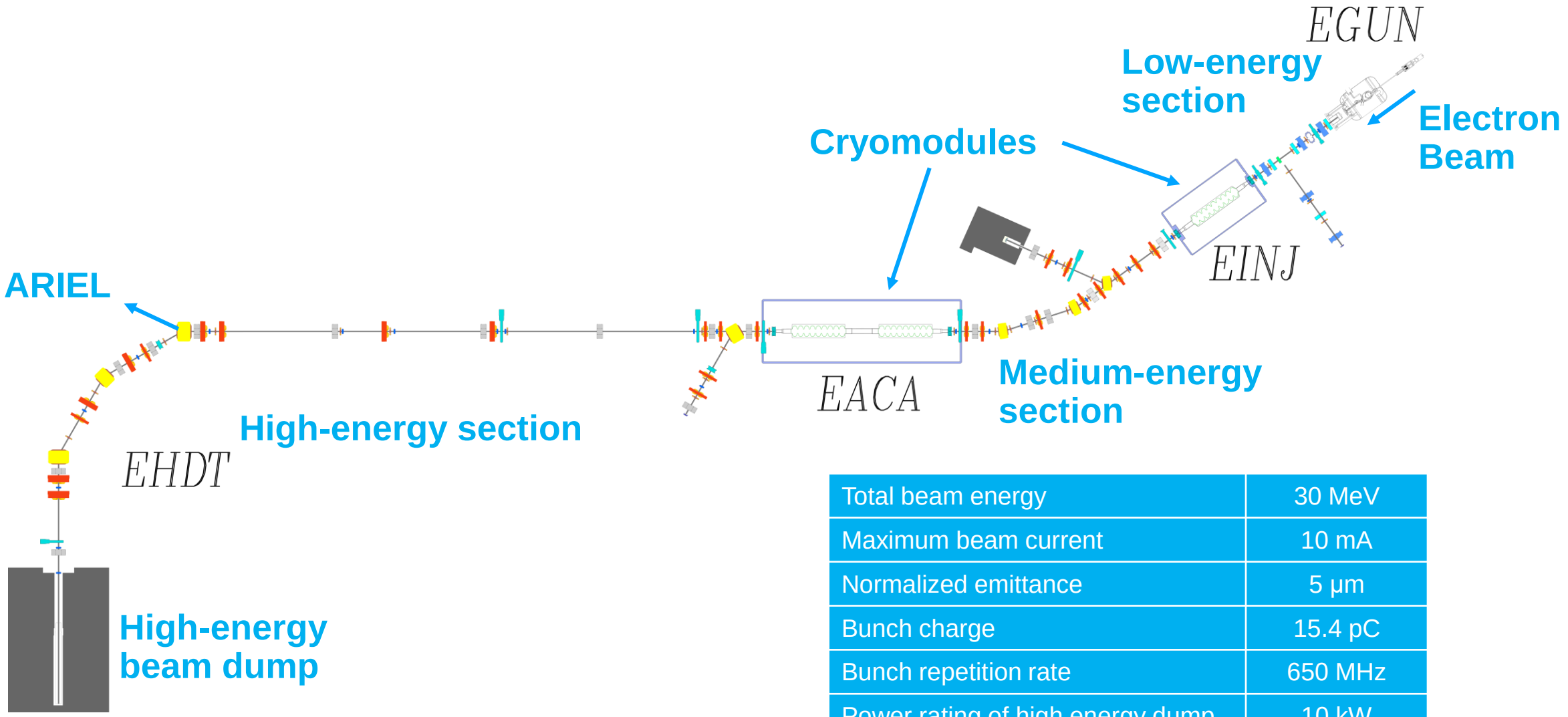
Linear
Accelerator
520MeV Cyclotron
muSR
Isotope Production
Facility
Driver Control Room
Detector Development
& Fabrication
M15
Life Sciences Facilities

The e-linac in its hall

e-linac overview

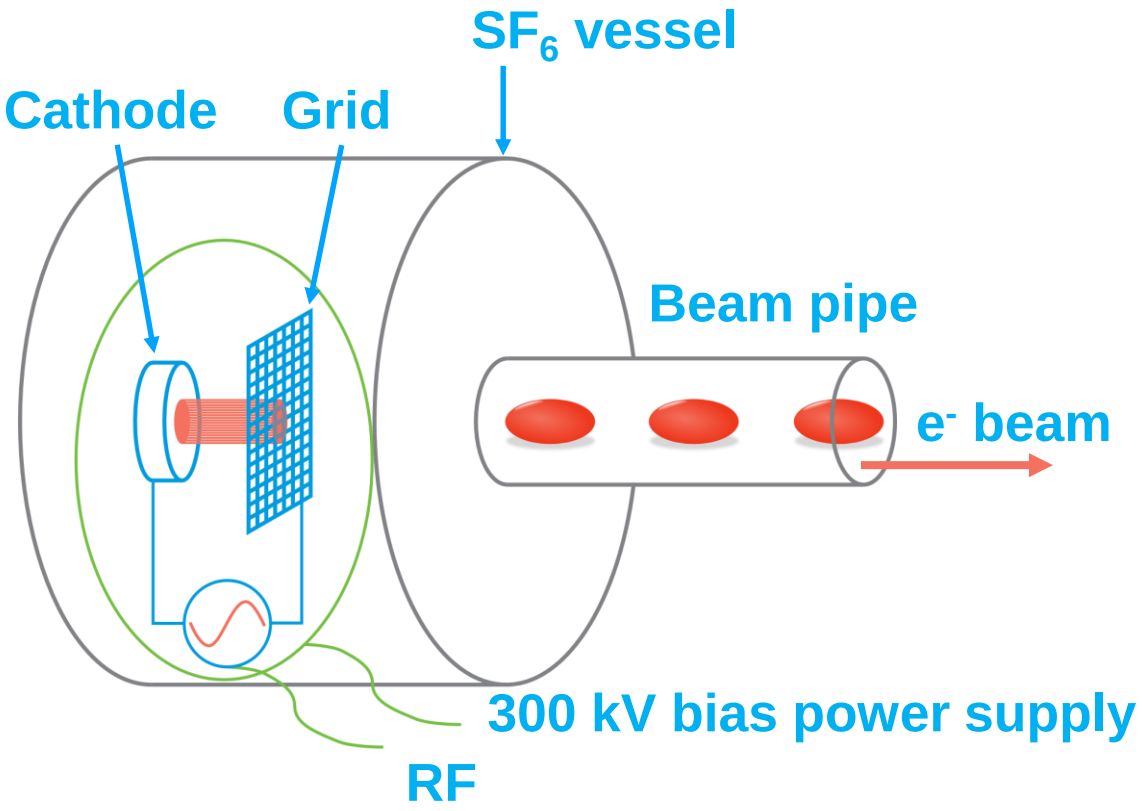


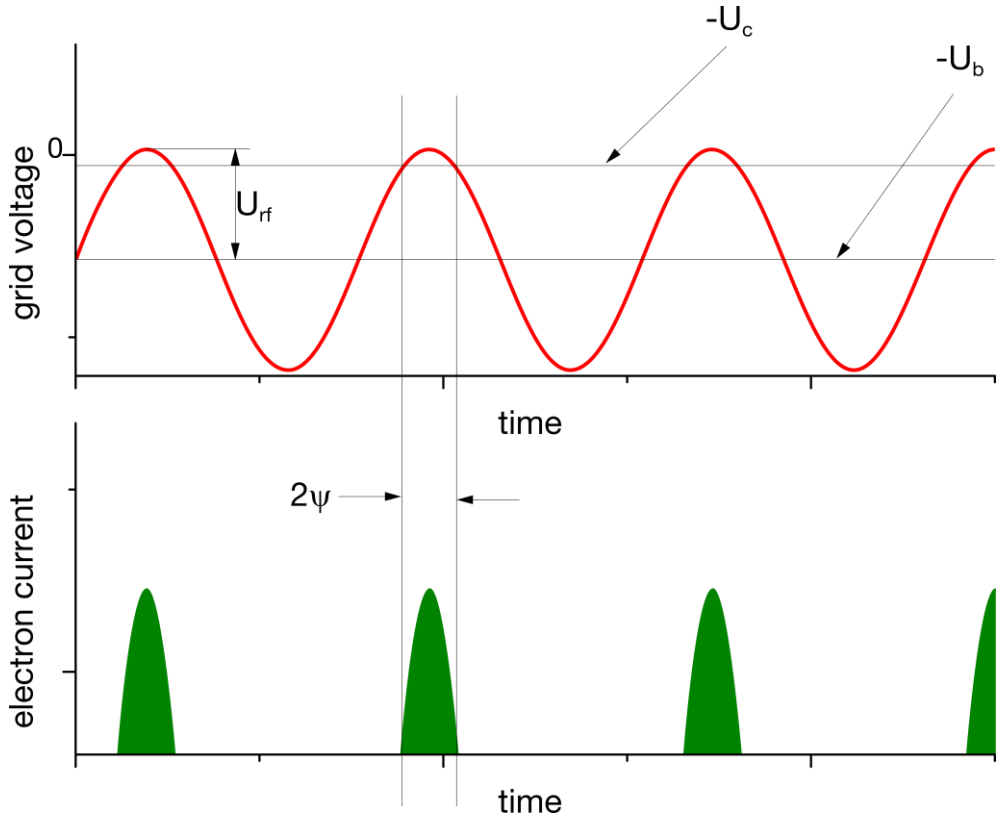
Total beam energy	30 MeV
Maximum beam current	10 mA
Normalized emittance	5 μm
Bunch charge	15.4 pC
Bunch repetition rate	650 MHz
Power rating of high energy dump	10 kW

300 kV thermionic electron gun

- The electron source is housed inside a pressurized SF_6 vessel to avoid breakdown of the 300 kV voltage
- RF is fed into the e-gun using a ceramic waveguide to form bunches at 650 MHz
- Allows CW mode

300 kV thermionic e-gun

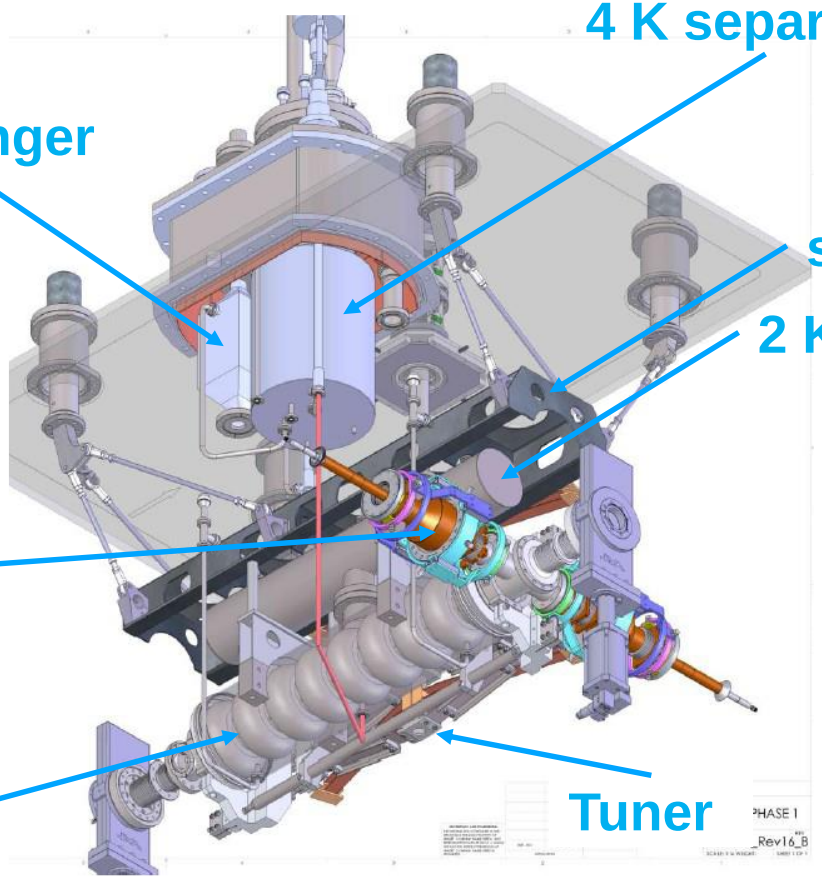




- Cathode has grid with suppressing voltage and RF modulation

F. Ames et al., "The TRIUMF ARIEL RF modulated thermionic electron source", 2016

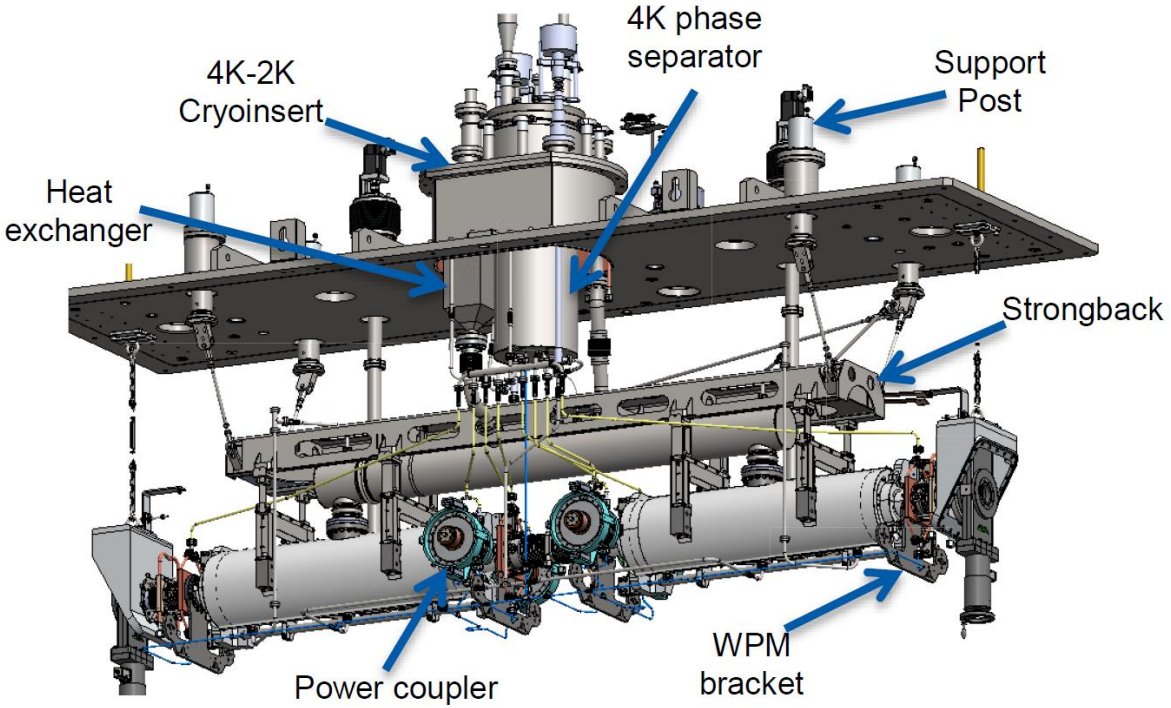
First cryomodule to accelerate beam to 10MeV



- 9-cell elliptical superconducting niobium cavity at 1.3 GHz, operating at 2 K
- 2 power couplers capable of delivering 50 kW each

D. Yosifov et al., "ARIEL's E-linac and beam transport line vacuum systems", 2012

Second cryomodule to accelerate beam to 30MeV



- Two 9-cell elliptical superconducting niobium cavity at 1.3 GHz, operating at 2 K
- 4 power couplers capable of delivering 50 kW each

Y. Ma et al., "First RF results of two-cavities accelerating cryomodule for ARIEL E-Linac at TRIUMF", 2018

10 kW tuning dump

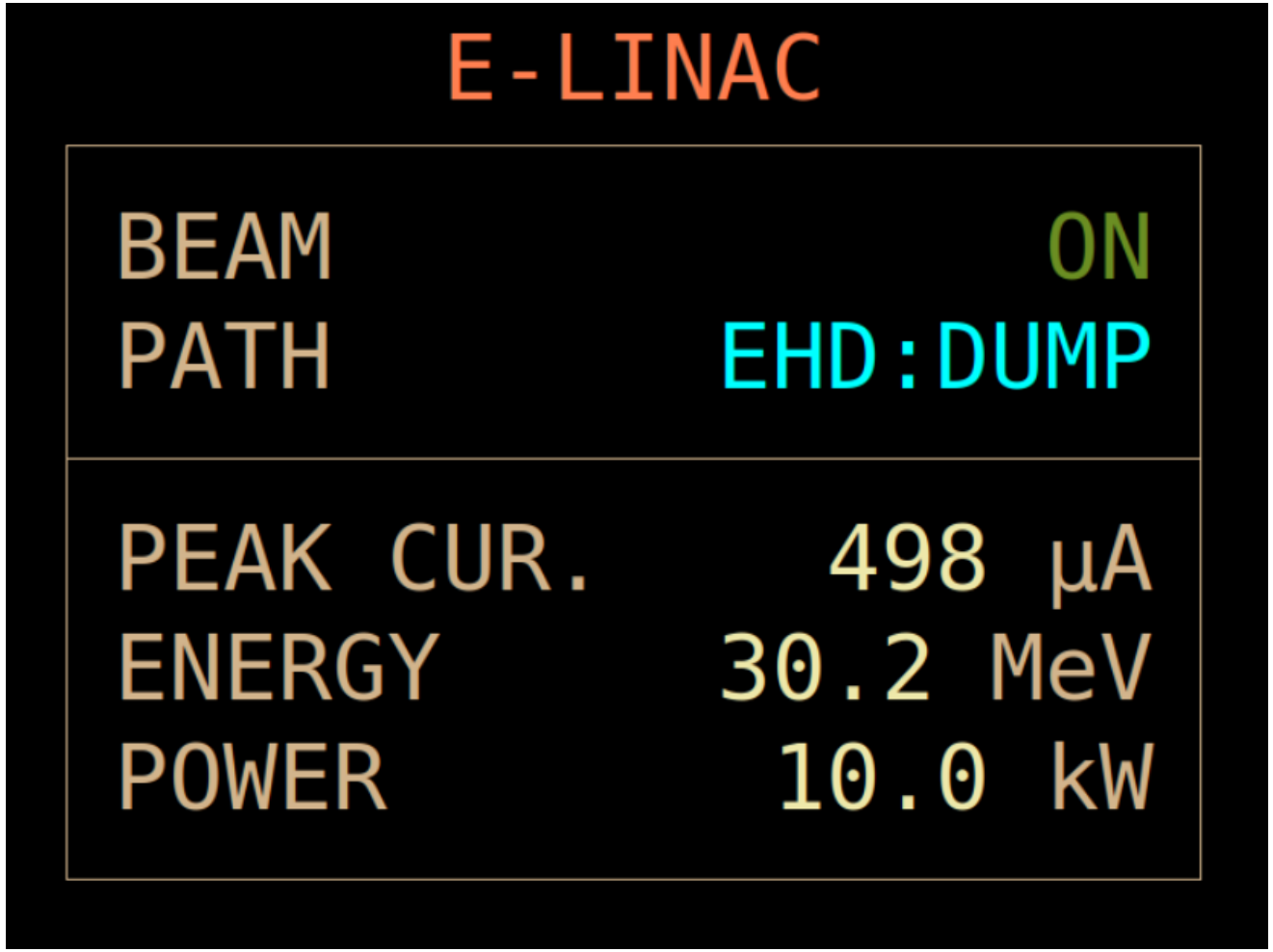
High energy beam dump

To ARIEL

The e-linac commissioning was completed in September 2021

After multiple years of commissioning, we achieved a 10 kW beam at 30 MeV for the first time

Next milestone: Reliable beam delivery by March 2023

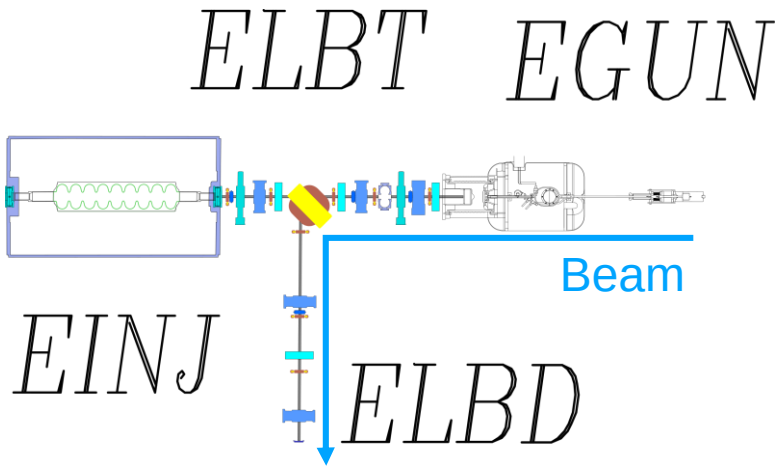


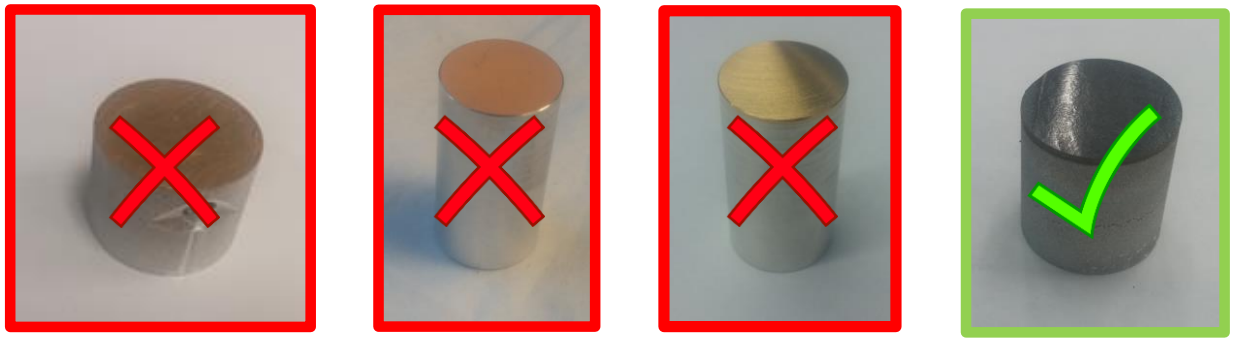
ARIEL electron target will be ready to receive beam in 2025

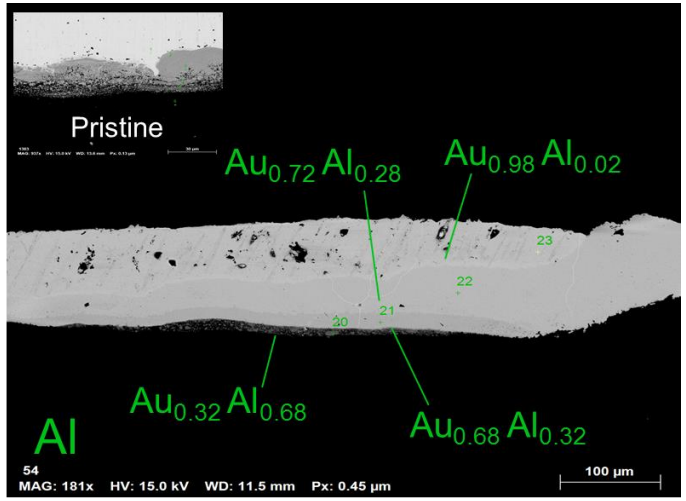
https://web.accel.triumf.ca/Elog_Attachments/elinac_elog/2021-09/2021-09-13-14:23:14.grab.h6pRsk.png

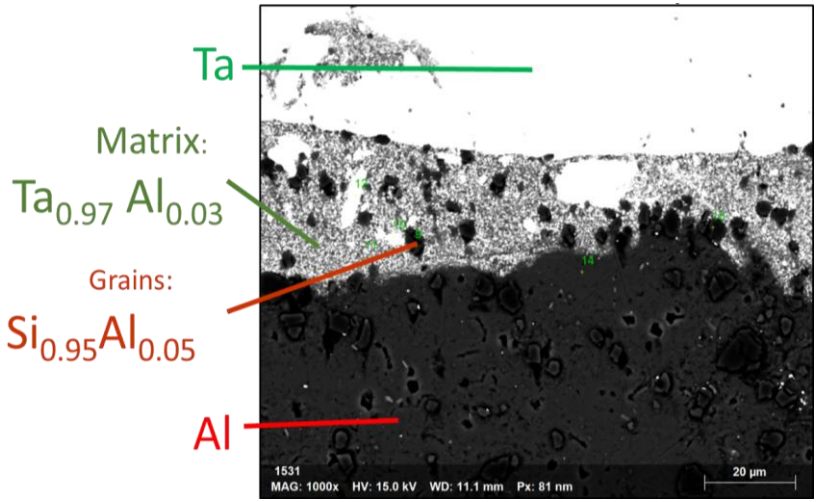
Entering a new era: The e-linac as an upcoming multi-user facility

300keV Converter Test Stand: validated target materials for ARIEL

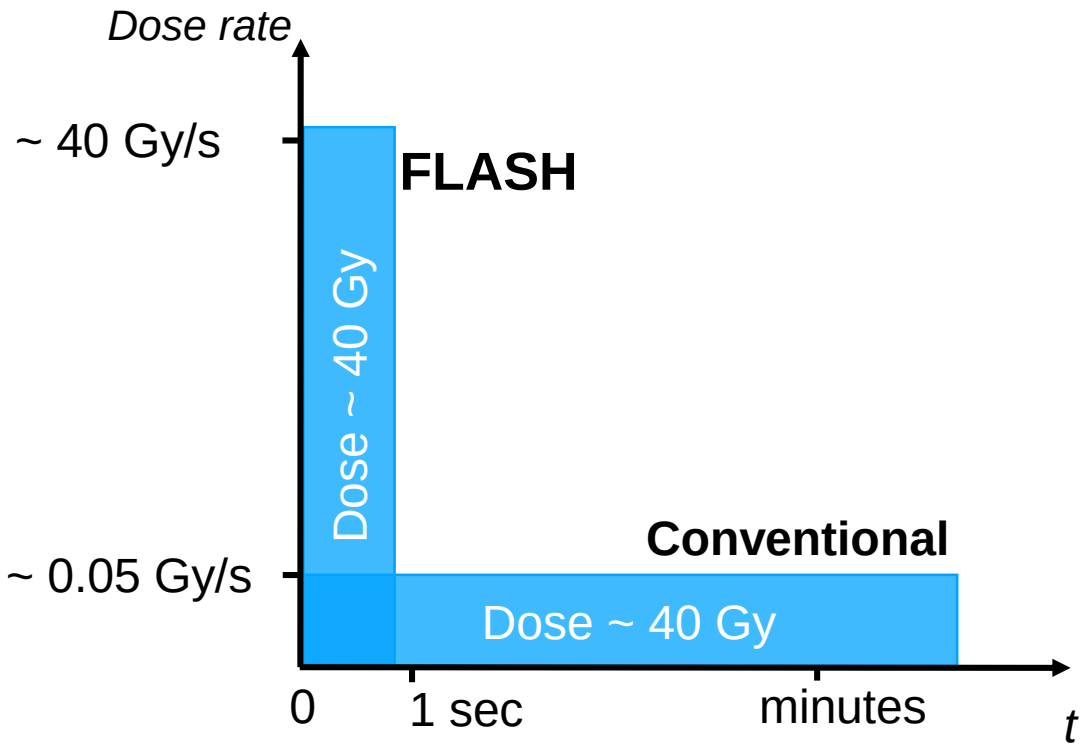








FLASH – Radio Therapy Research



FLASH dose rated allow for sub-second treatments to reduce normal tissue toxicity compared to low dose rate (conventional) treatments

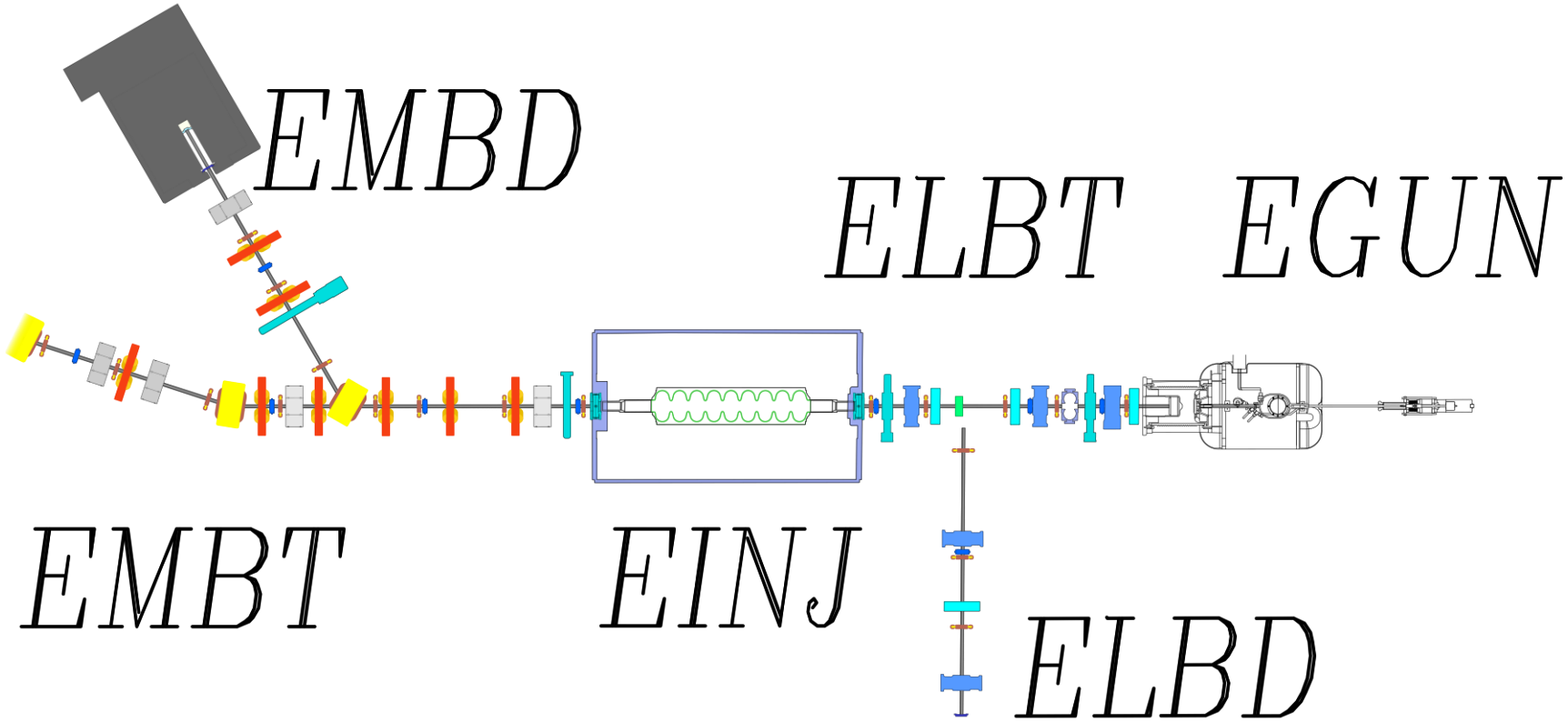
Objective: build e^- to photon converter

- $t < 1s$, $\dot{\bar{D}} > 40\,Gy/s$ (ultra-high dose-rate)
- Energy ≤ 10 MeV (world first)

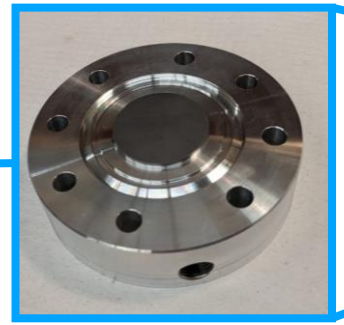
June 7, 2022, 1:15 PM

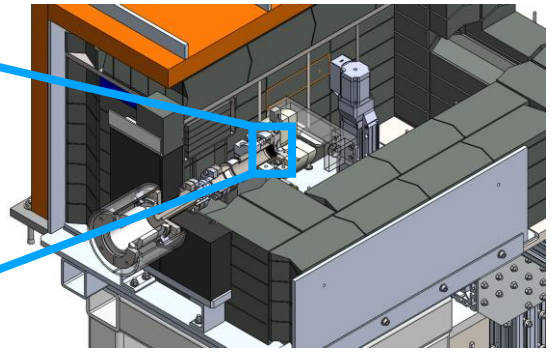
A. Gottberg: "(I) Novel cancer treatment in a FLASH – development towards reducing side effects of cancer therapy using X-rays, electrons and protons at TRIUMF"

E-Linac medium energy dump modification



ARIEL-inspired converter

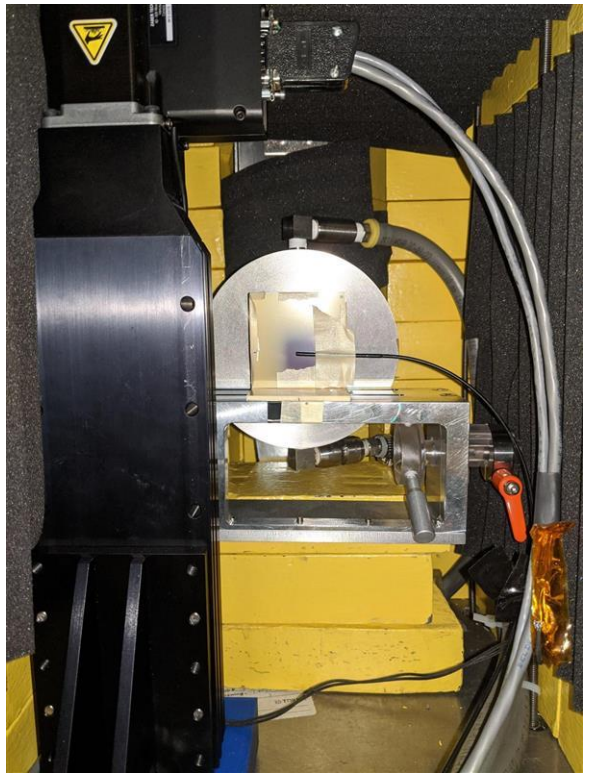


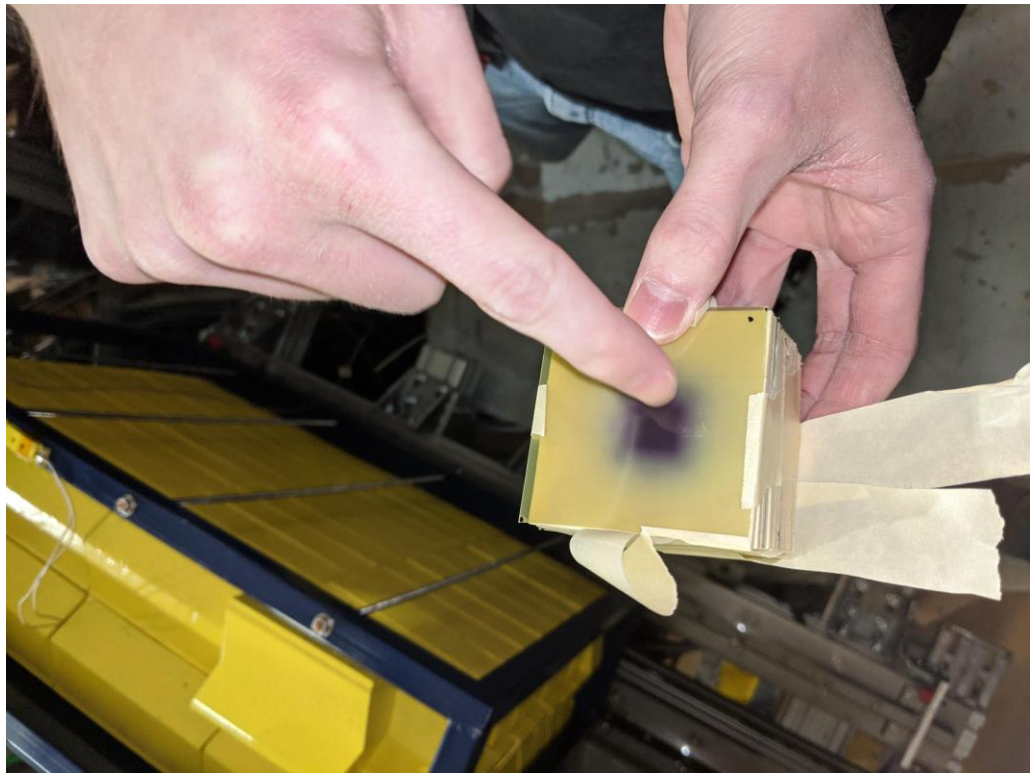


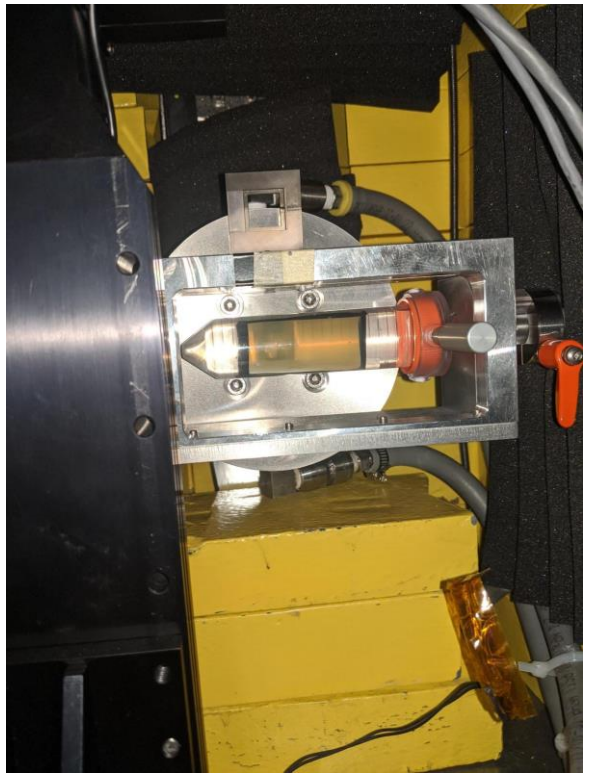
Stephanie Diana Rädel

N. Esplen et al., "Design optimization of an electron-to-photon conversion target for ultra-high dose rate x-ray (FLASH) experiments at TRIUMF", 2022

Dosimetry with dosimetry films and water-filled tubes







FLASH – a challenging user

ethics approval #AUP#21-0060

- Limited time window (1 hr) to accommodate safe animal handling procedures
- Key: develop lockup procedure

In accordance with animal care protocol

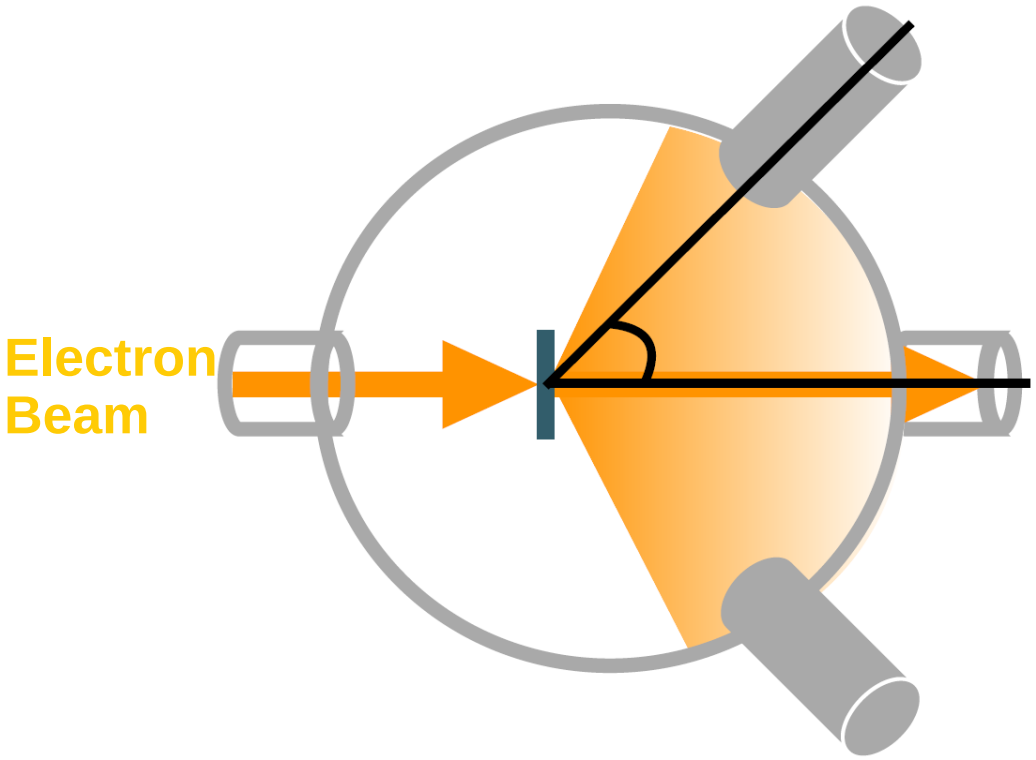
FLASH beamtime – first successful experiment March 22nd 2022

- 12 in-vivo irradiation in total
  - 6 FLASH and 6 CONV
- 8 samples of Drosophila fly larvae

This is just the beginning!

More FLASH days are coming

DarkLight – an upcoming experiment



June 7, 2022, 1:30 PM

K. Pachal: "(I) Hunting for new particles at TRIUMF with the DarkLight experiment"

Looking for dark matter with thin-target scattering experiment

- ATOMKI experiment
  - Observed possible boson with mass circa 17MeV/c^2 ("X17")
- Incoming electron interacts with target and creates γ rays … and X17?
- Measure energy spectrum of electron-positron pairs created by γ or X17

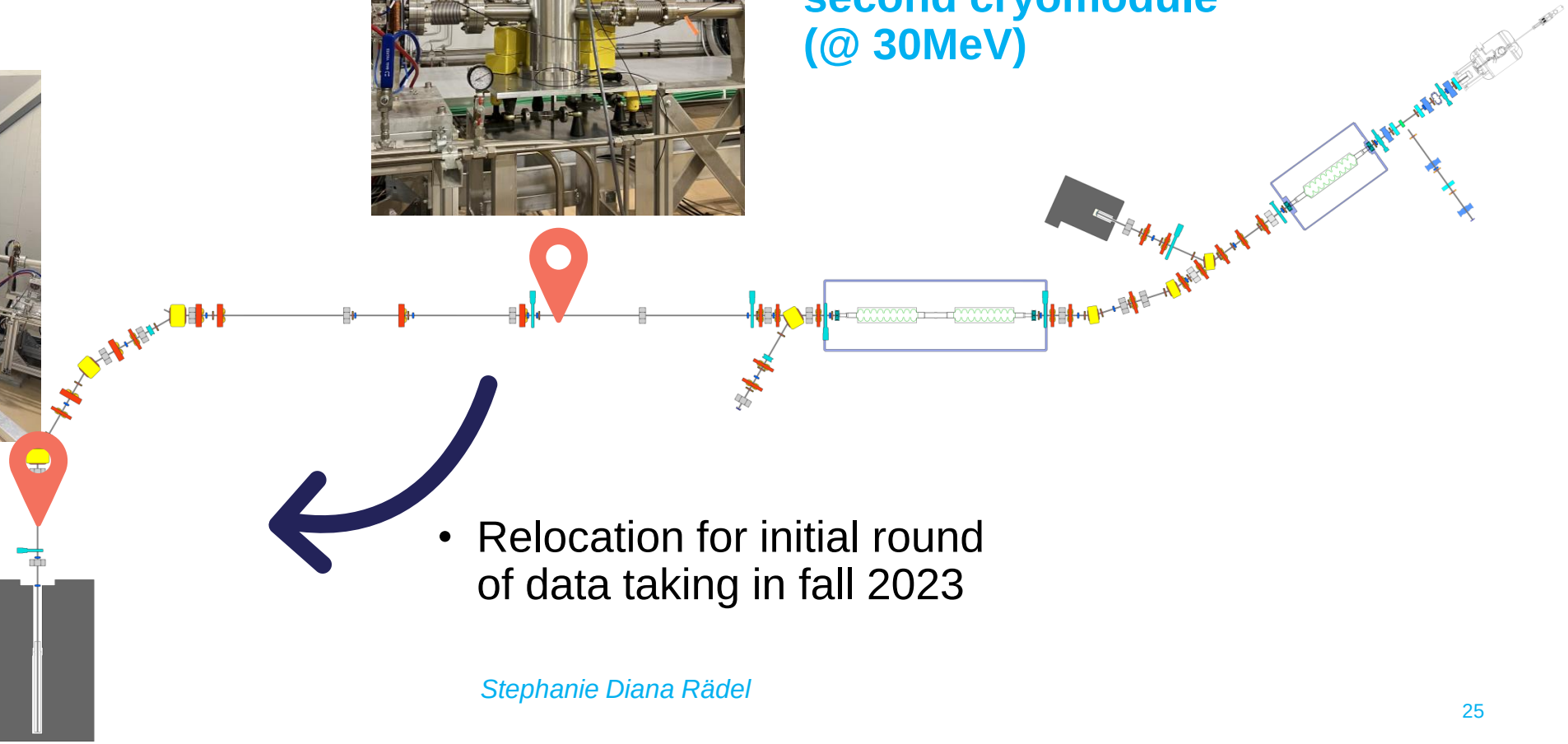
What can TRIUMF offer for this collaboration?

- High intensity electron beam in CW
- Energy upgrade to 50 MeV

Relocating the DarkLight experimental chamber

2023: right upstream high energy dump

Now: downstream of second cryomodule (@ 30MeV)



- Relocation for initial round of data taking in fall 2023

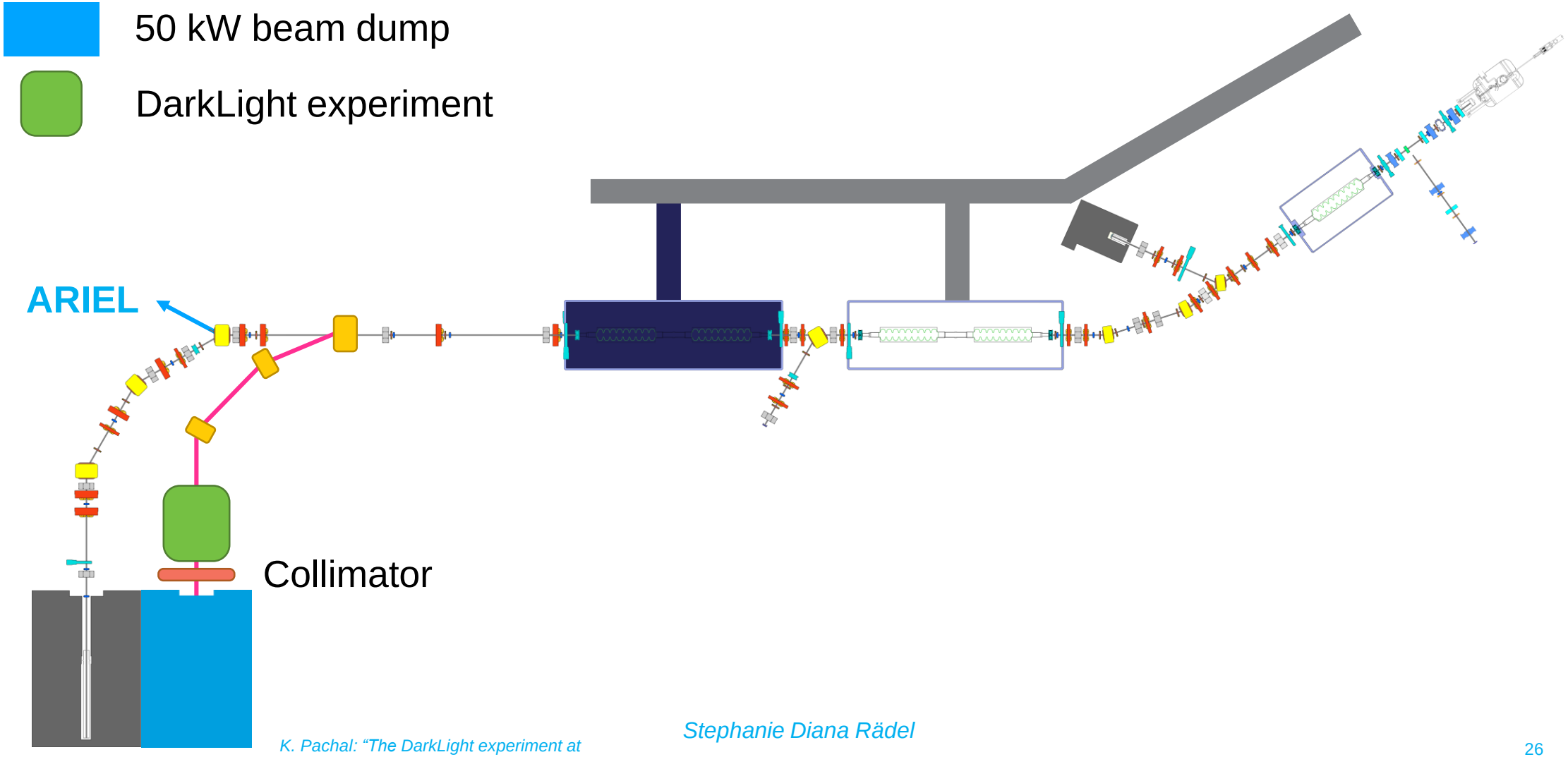
T. Planche, "New Scientific Opportunities with the TRIUMF ARIEL e-linac", 2022

DarkLight – Stage 1 in 2024: single user at 50 MeV

New cryomodule

50 kW beam dump

DarkLight experiment



K. Pachal: "The DarkLight experiment at TRIUMF and the hunt for a new boson"

Stephanie Diana Rädel

DarkLight – Stage 2 in 2025: multi-user at 50 MeV

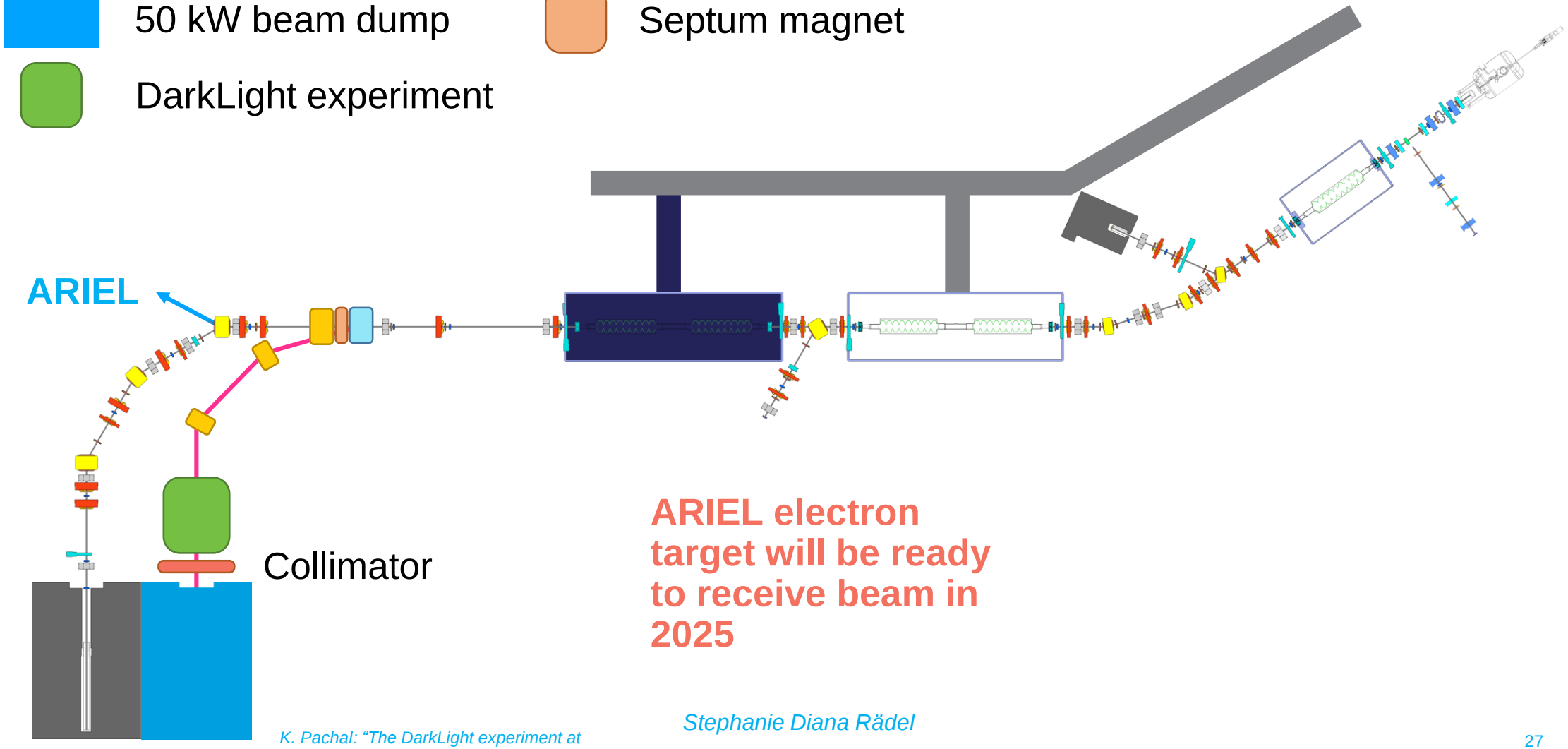
New cryomodule

RF deflector

50 kW beam dump

Septum magnet

DarkLight experiment



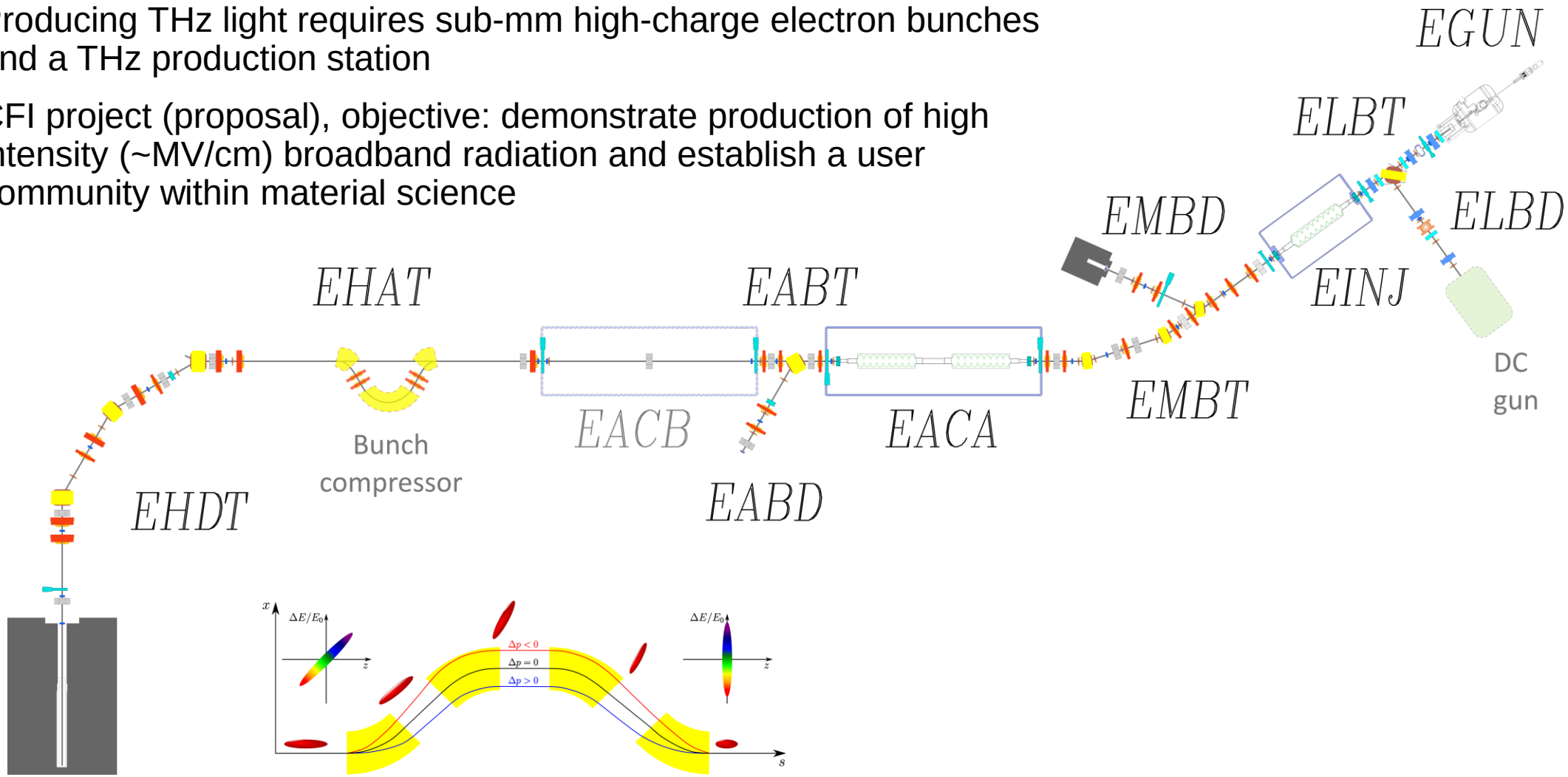
ARIEL electron target will be ready to receive beam in 2025

K. Pachal: "The DarkLight experiment at TRIUMF and the hunt for a new boson"

Stephanie Diana Rädel

High-Brightness THz/IR Photon Source (Stage 1)

- Producing THz light requires sub-mm high-charge electron bunches and a THz production station
- CFI project (proposal), objective: demonstrate production of high intensity (~MV/cm) broadband radiation and establish a user community within material science



S. D. Rädel, "Status and Future Perspective of the TRIUMF E-Linac", 2019

S. D. Rädel, "On space charge driven microbunching instability in bERLinPro", 2017

Summary

- Overview of electron linac
- The electron linac commissioning was completed in 2021
  - Next step reliability
  - ARIEL electron target ready for beam in 2025
- Converter Test Stand (experiment for ARIEL electron target) in low energy section was our first user
- FLASH:
  - 12 in-vivo irradiation in total
    - 6 FLASH and 6 CONV
  - 8 samples of Drosophila fly larvae irradiated
- DarkLight introduction and its impact on delivering electron beam
- Proposed e-linac becoming a THz source

TRIUMF

Thank you
Merci

www.triumf.ca

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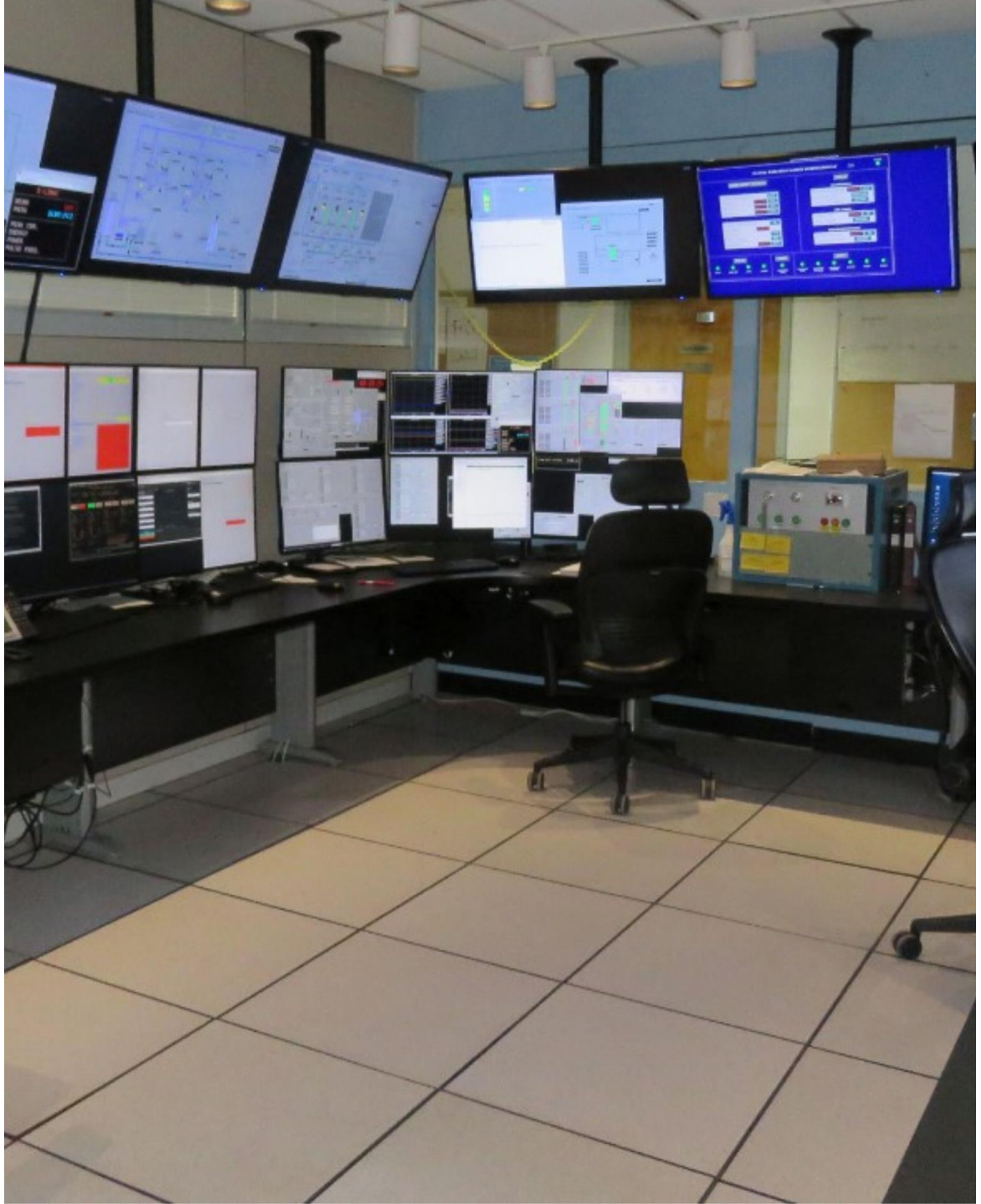
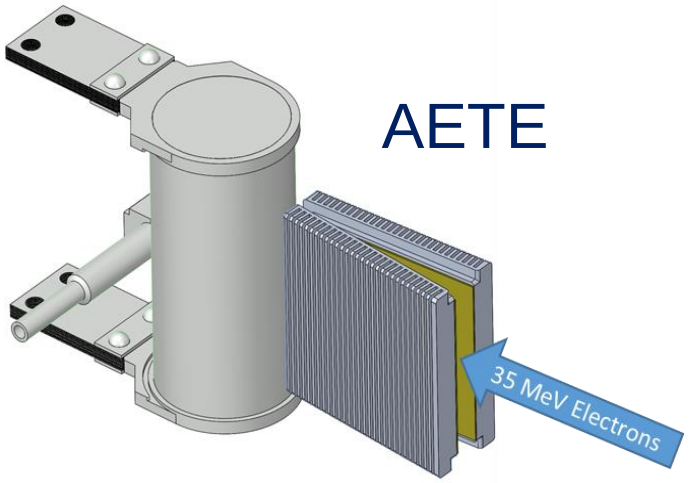
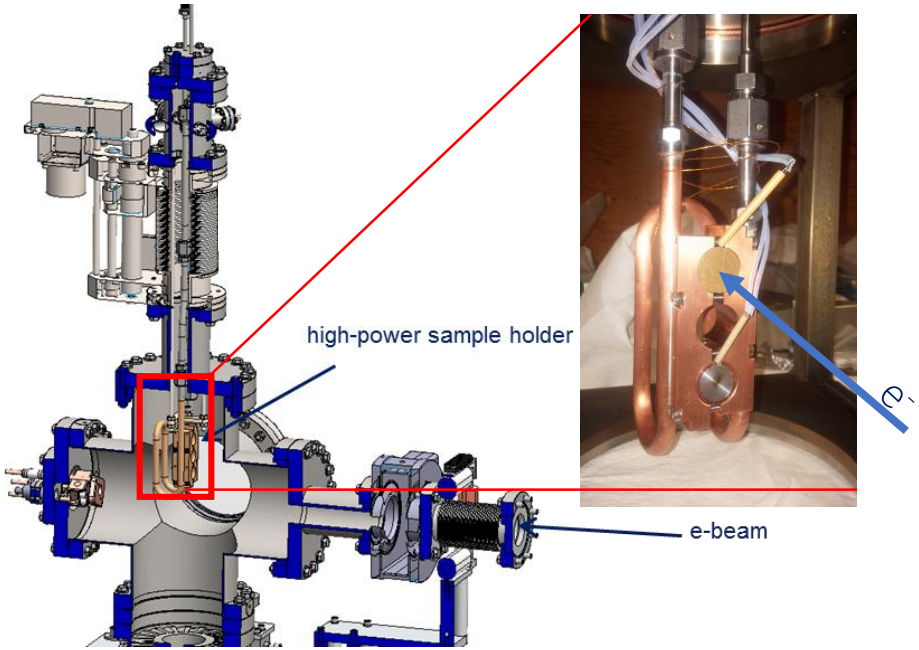


BACKUP SLIDES

ARIEL e-γ Converter Test Stand (TRIUMF, UBC, UVic, SLAC)





Existing irradiation capability: 300 keV to 35 MeV, up to 1023 electrons/cm^2/day

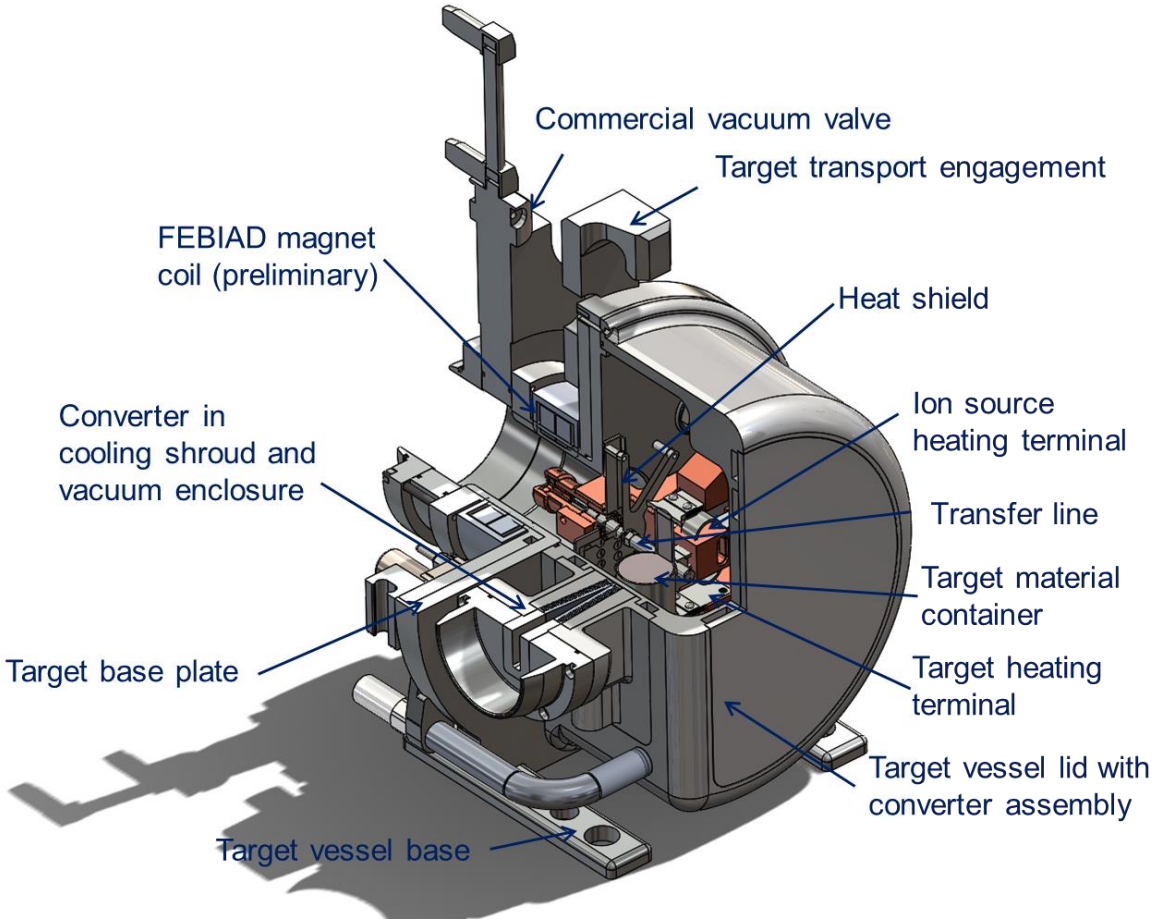
High-Z / aluminum interface at risk:

- Thermal stresses (100 kW beam, thermal cycles)
- Radiation damage / radiochemistry
- Irradiations of up to 3 weeks

Experimental setup:

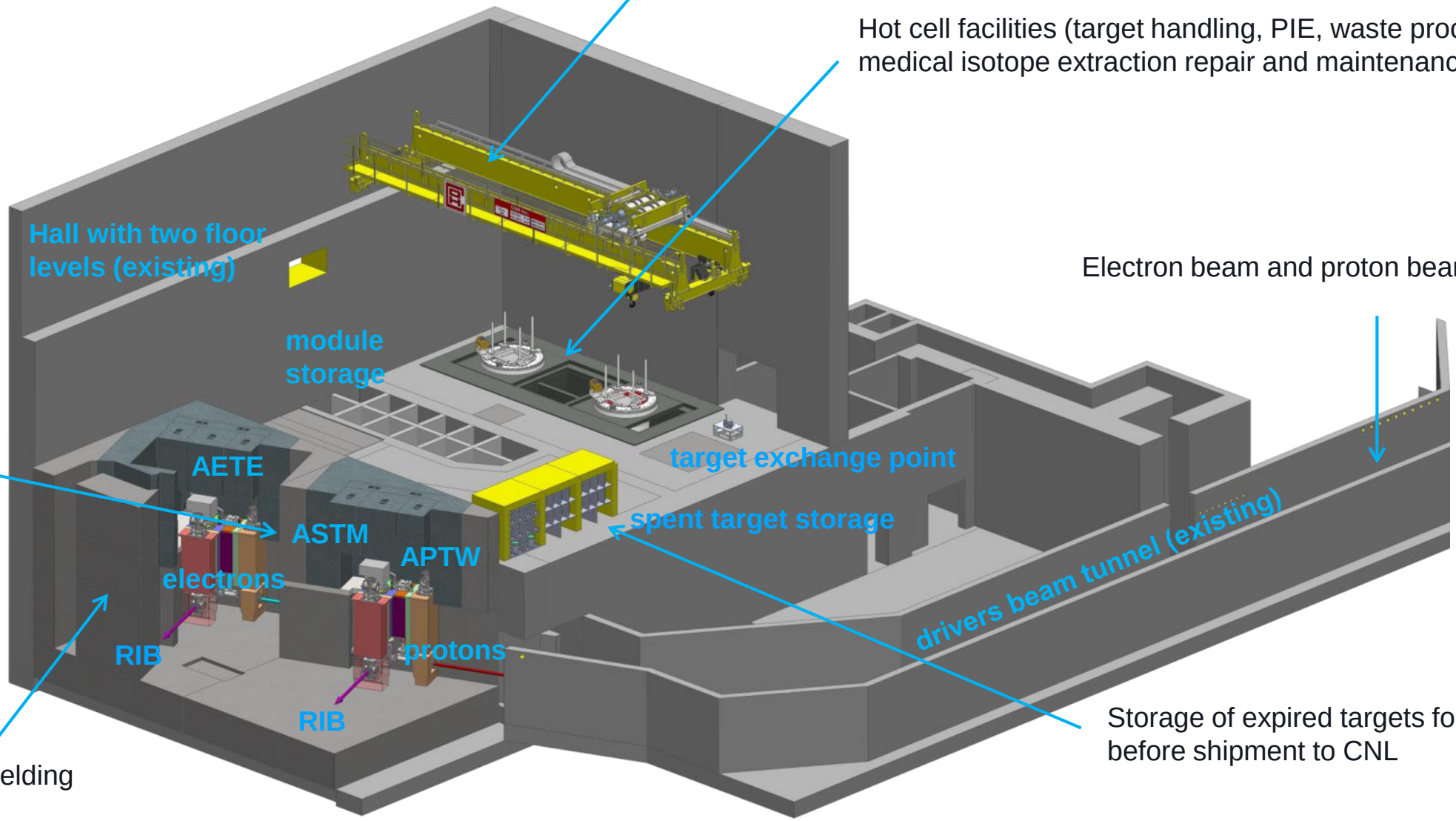
- Water-cooled sample holder
- Several high-Z materials tested
- Beam power density matching online value
- 300 keV beam to avoid activation (online 35 MeV)

ARIEL Hermetic Target Vessel



- Increased development space for new ion source and transfer line concepts (cold transfer line, variable temperature transfer line, quartz transfer line, improved FEBIAD, low work function cavity, IG-LIS^2)
- Hermetic enclosure allows for the use of air-sensitive target materials
- Service connections with provisions for future ion source and target concepts
- Converter integrated into target vessel lid allows for routing additional cooling for high power target operation
- Vessel volume increased for new target concepts (liquid targets, new converters, etc.)

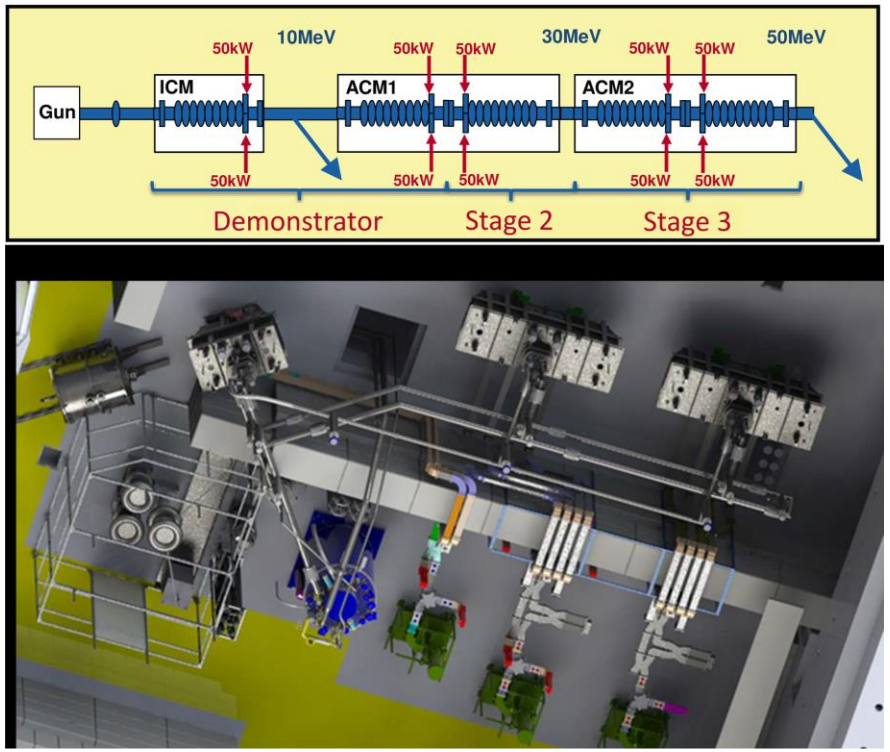
The ARIEL Target Hall



Cryo

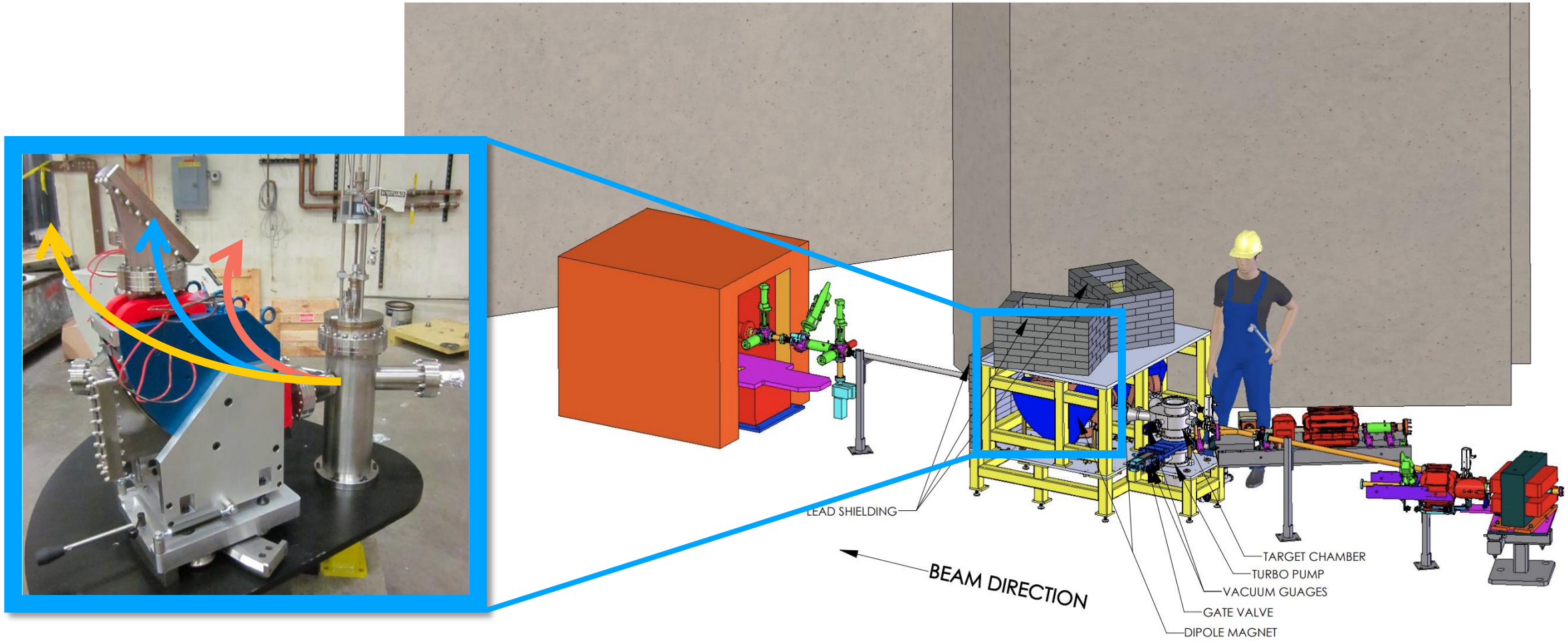
ALAT LL Cold Box, KAESER (FSD571SFC) main compressor (112 g/s), Cryotherm - distribution

4 Bush combi DS3010-He pumping units specified and installed (1.4 g/s @ 24mBar each)



T. Planche, "New Scientific Opportunities with the TRIUMF ARIEL e-linac", 2022

DarkLight – Experimental apparatus



K. Pachal: "The DarkLight experiment at TRIUMF and the hunt for a new boson"