Five Year Plan 2025 – 2030 Accelerator Division

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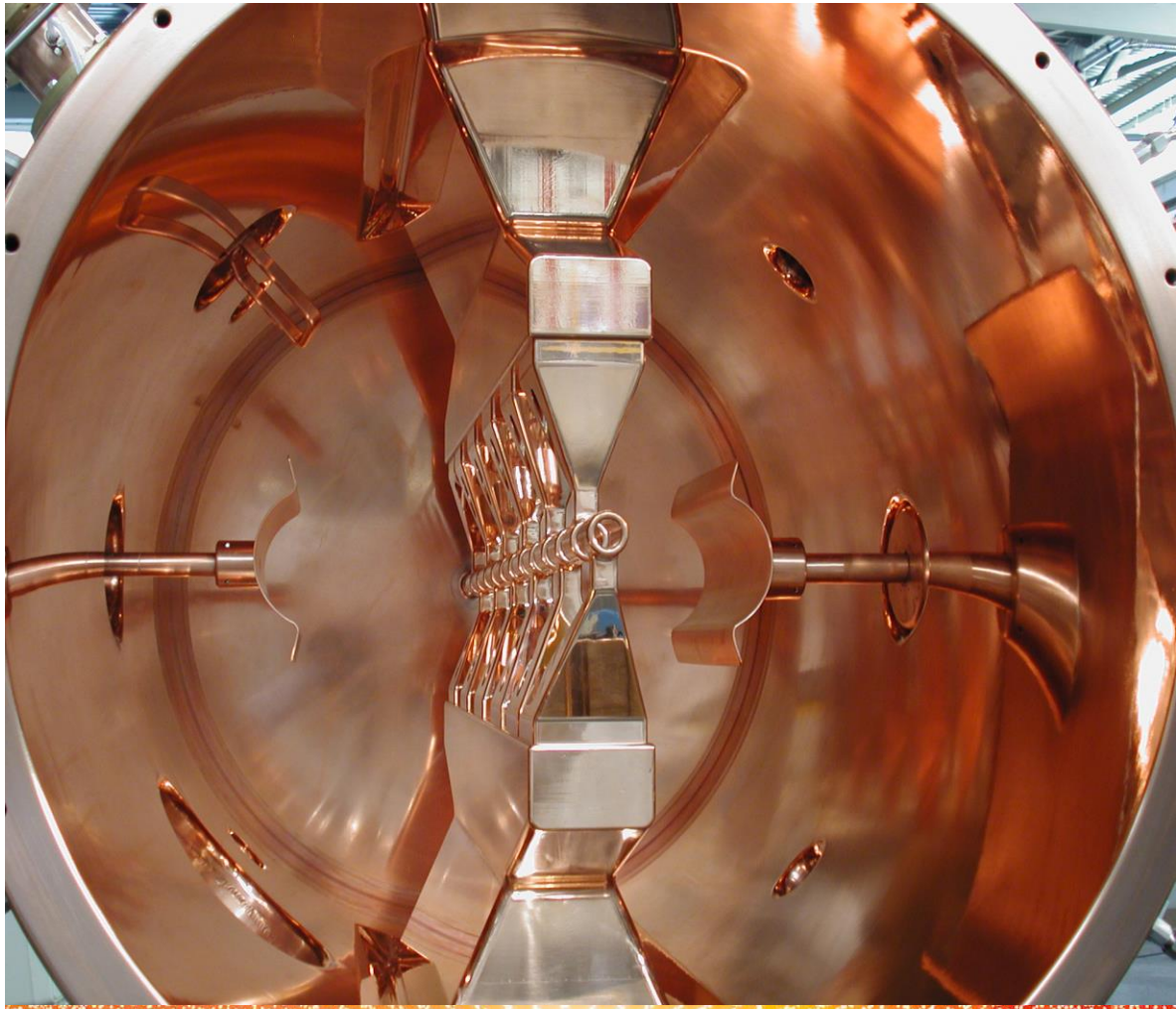
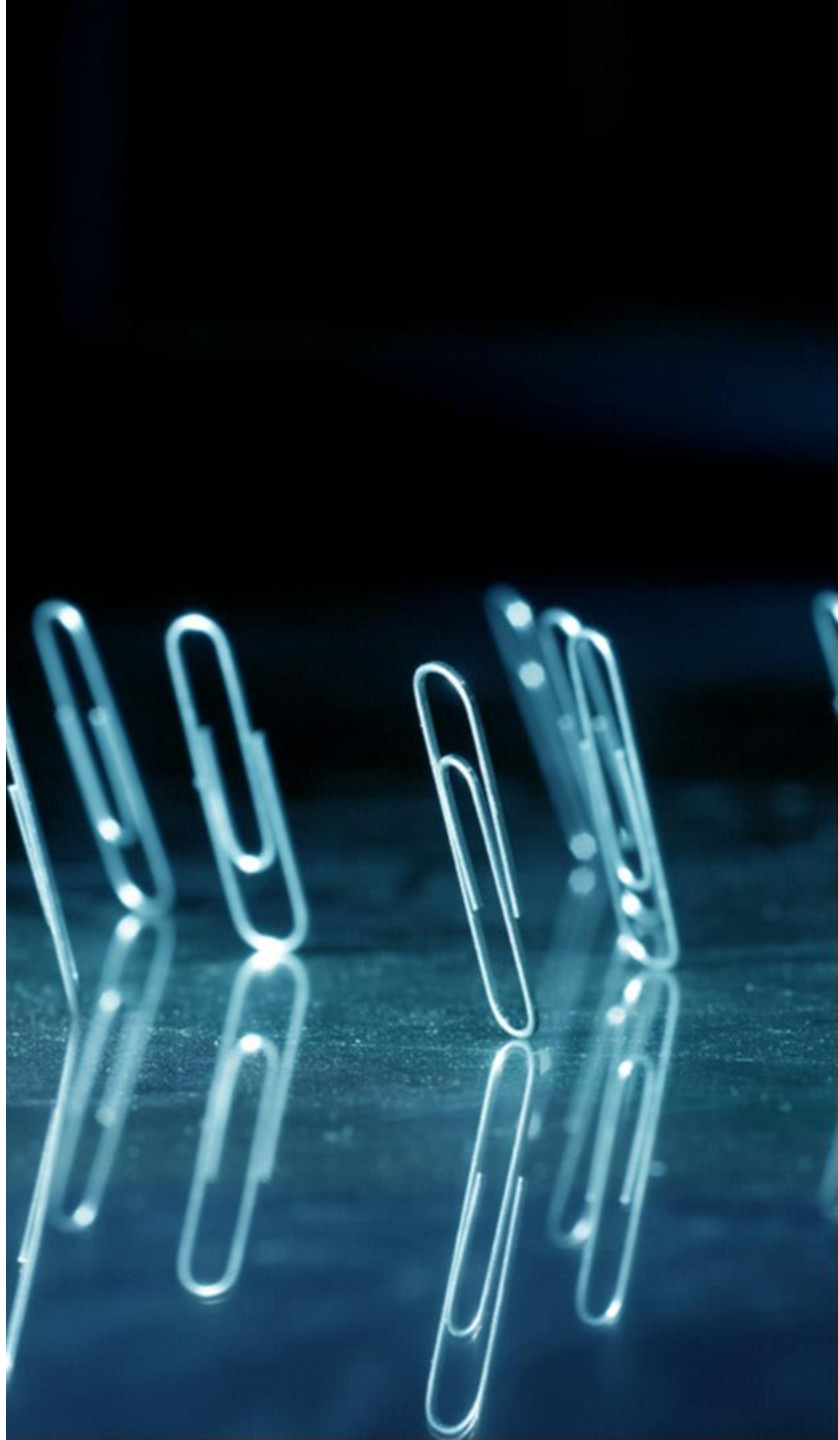
TRIUMF Science week
July 24, 2024



Outline

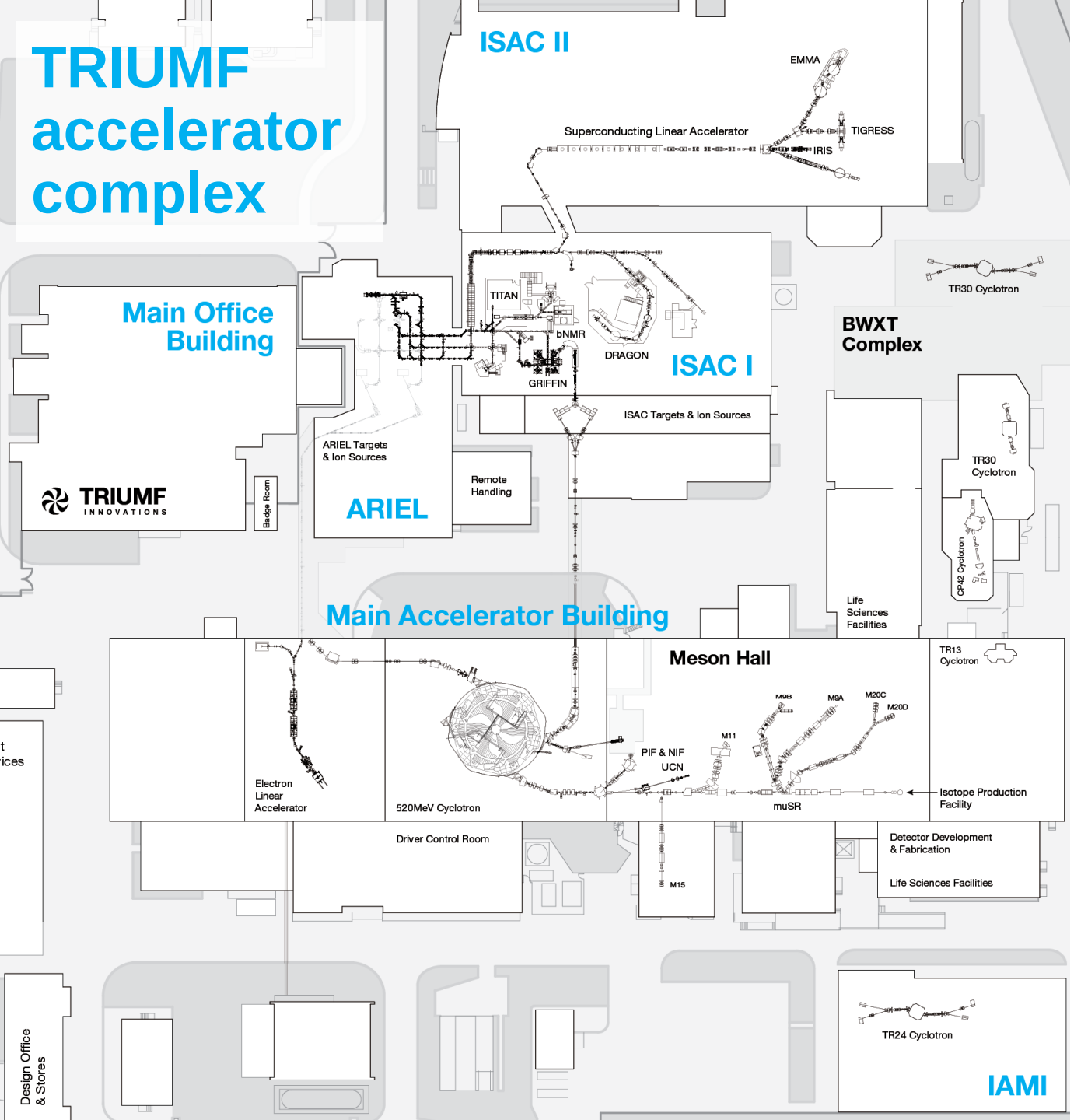
- The TRIUMF accelerator complex - overview
- Planned activities in the next 5YP
  - Keeping the TRIUMF accelerator complex on high performance
  - Gain in efficiency
- Increase of research capacity - ARIEL
  - ARIEL CFI project completion
  - The path towards regular ARIEL beam operation
- Benefit of the scenario 2
  – long shutdown in 2026



ACC division mission statement

- The TRUMF accelerator division safely operates the TRIUMF accelerator complex with high performance and availability.
- We develop and implement new accelerator facilities and related technologies to support world class science nationally and internationally.
- We lead accelerator physics research in Canada and foster TRIUMF's position at the forefront of accelerator science. We advance our core competencies and transfer our knowledge to industry for the benefit of society.
- We leverage infrastructure and expertise to provide world class training of HQP in accelerator physics and engineering.

TRIUMF accelerator complex



A diversity of accelerators from:

- High-power to rare-isotope beams
- Cyclotrons & Linacs
- Normal conducting to superconducting structures
- High intensity proton and electron beam lines and RIB beam transport

Supporting:

- Flexible RIB delivery for science
- Medical isotope research & prod.
- Neutron & muon science
- Accelerator science R&D

Advanced Rare Isotope Laboratory (ARIEL)

New infrastructure on all fronts: driver, targets & RIB

Operational Model Accelerator Division

- Core operation (Running and maintaining the accelerators, break fixes)
  → MRO costs and work forces – Staff and machine operation costs, costs for running the labs of the expert groups)
- Keep capability and do capacity development (can have an opportunity component)
  - Divisional MRO activities - refurbishment activities (deferred maintenance)
    → 520 MeV cyclotron, RIB facilities and ACC infrastructure
  - Divisional MRO projects and LDRD-type projects managed by PMOG/QRPP
    → ARIEL-II completion, ARIEL operations ramp-up and reaching e-linac design performance
- Science delivery
  - Grant driven projects like HL-LHC, EIC contributions, DarkLight, THz radiation capabilities, PC-CANS
  - Accelerator R&D (NSERC, NFRF), WFO, commercial projects

Impact of scenario 2 on ACC Division

- No operation of the accelerator complex except the medical isotope production cyclotrons
- Saving the effort of one winter shutdown by not running for one year.
- Planned budget distribution for the $400M scenario must change to fund ARIEL Operations and ramp-up of beam hours.
  → This requires a shift of budget from the MRO and the refurbishment budget to ARIEL Operations. This reduction of the refurbishment funds will be requried for any scenario where ARIEL will be brought into regular beam delivery stage.
- Acceleration of design work and procurement for ARIEL and re-baselining ARIEL schedule and resources planning. A significant fraction of the refurbishment work must be shifted to 2027 and beyond.
- BL1A triplet and collimator B exchange which will require a long shutdown (> 6 months) of BL1A can be incorporated into the long shut down (LS) scenario.
- Scenario 2 is the only implementation of the 5YP that will allow the project completion and regular beam delivery from ARIEL to experiments before the end of the 5YP.

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Planned activities in the next 5YP

Summary of Accelerator topics in the next 5YP

Driver accelerators:

- Cyclotron operation (maintenance), refurbishment and upgrades including Cyclotron Control System (CCS) upgrade
- e-linac towards full performance and for new experiments
- BL1A refurbishment

RIB facilities:

- ISAC operation, target hall consolidation, target module refurbishment, labs, ISAC-I Linac, beam delivery improvements
- Target ion sources – Laser ion sources and polarizer and Remote Handling

ARIEL project completion and potential ramp up of operation

Infrastructure:

- TCC – TRIUMF Control Center (combines Driver and RIB control rooms, but requires CCS upgrade)

Research and education:

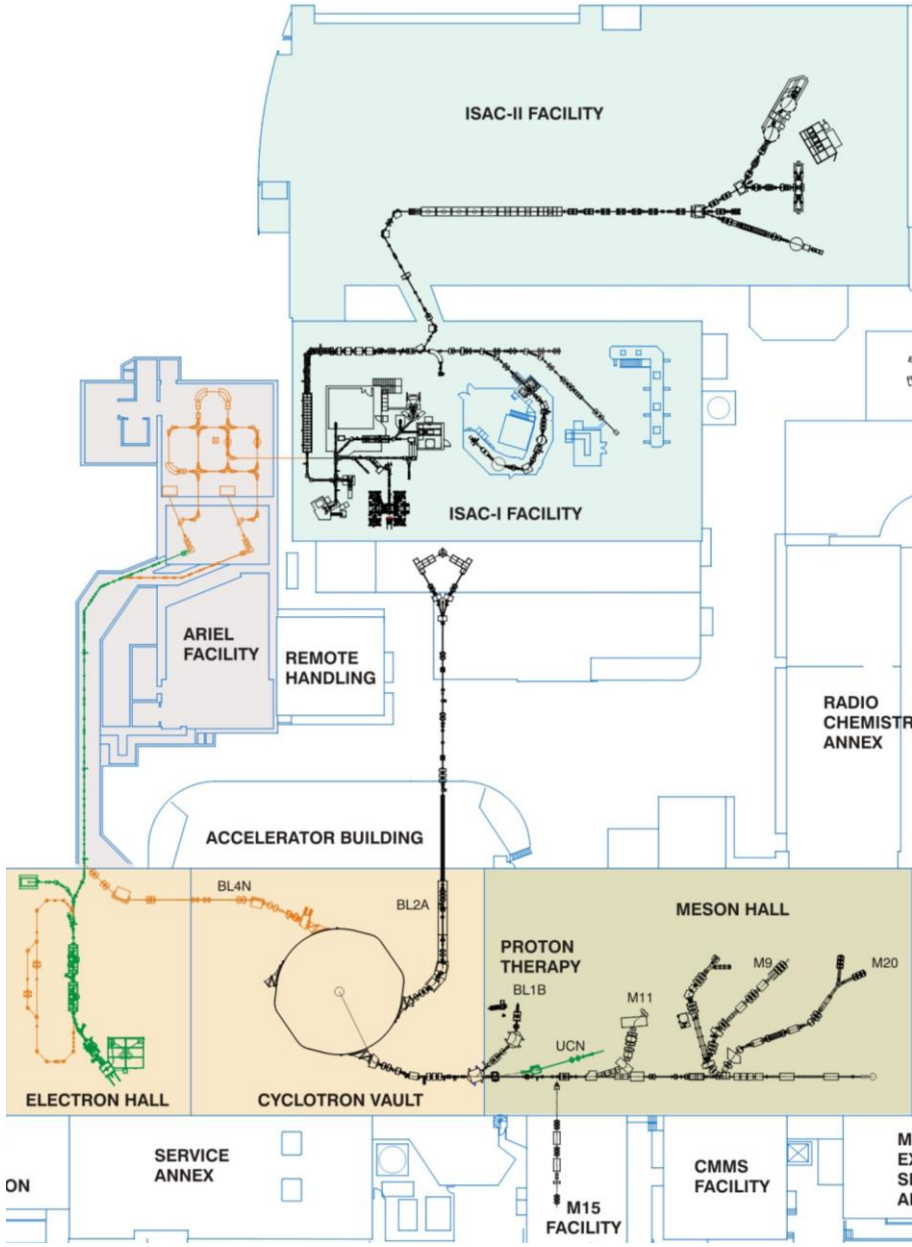
- HLA, model coupled beam tuning, machine learning and high-power beams – e-linac, HL-LHC, EIC
- Cyclotron technology (injection, high beam intensity operation → beam loss reduction)
- SRF research: Plasma conditioning, heat treatments, particulate migration, cavity development, SRF materials and fundamental limits
- High power targetry and material R&D, Laser Ion Sources R&D

Domestic and international projects:

- THz radiation, DarkLight, FLASH irradiation and PC-CANS
- CERN HL-LHC, EIC

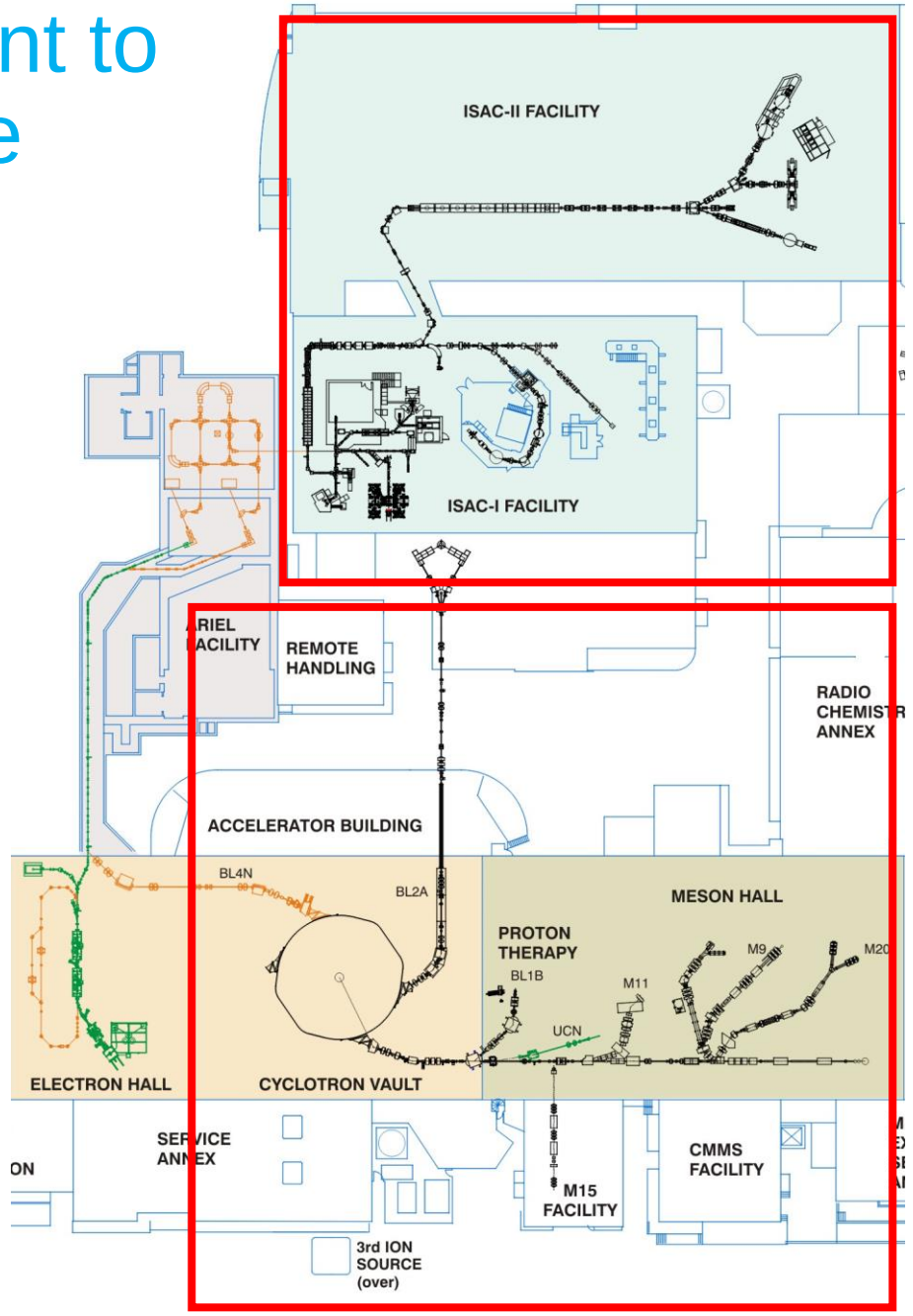
Core operation of the TRIUMF accelerator complex

- Core operation of the complex accelerator complex:
  520 MeV cyclotron, proton beam lines and target stations, RIB beam lines and post accelerators ISAC-I and ISAC-II.
- Divisional funds for
  Computer and Software, office equipment, staff training and memberships, coop students, travel and visitors.
- ARIEL added equipment:
  SC e-linac and CANREB, which need to be maintained and tested
- As soon as ARIEL target station will become operational, two target stations and two beam transport line (e-linac and BL4N) will be added to accelerator MRO and operation.
- Operation of an accelerator requires expert groups and laboratory equipment for a variety of technologies:
  Vacuum, beam instrumentation, power supplies, beam line elements (magnets, electrostatic systems), RF systems and Superconducting RF, particle sources, cryogenics
  Target technologies, laser applications, remote handling, controls and accelerator operations / control rooms, beam physics



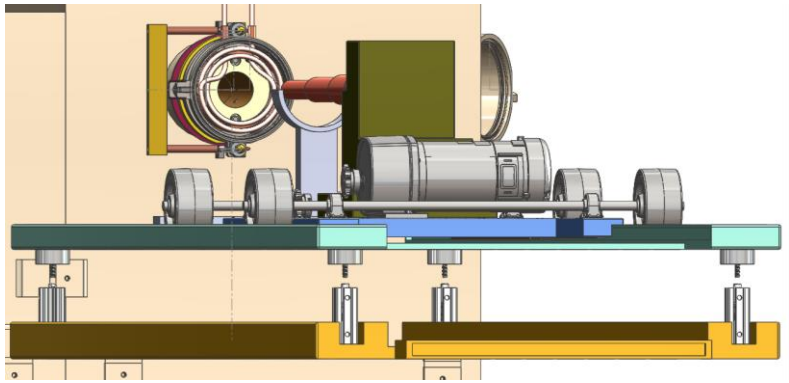
Keep capability – refurbishment to mitigate deferred maintenance

- Chief goals of the continuing refurbishment program:
  - Risk mitigation against extended down-time as guided by the Division Risk Registry
  - Improving efficiency of operation → prerequisite for the ARIEL operation era – reduced maintenance requirements, model assisted tuning, power-smart, unification of site equipment, amalgamation of control rooms
- Cyclotron: RF system, vacuum, control system (CCS), remote handling systems, injection system, BL1A
- ISAC: Target hall infrastructure, laser ion source (LIS), remote handling systems, OLIS, beam instrumentation, RF systems
- Raise efficiency: TRIUMF Control Center (TCC), new equipment to support model-based beam tuning and machine learning

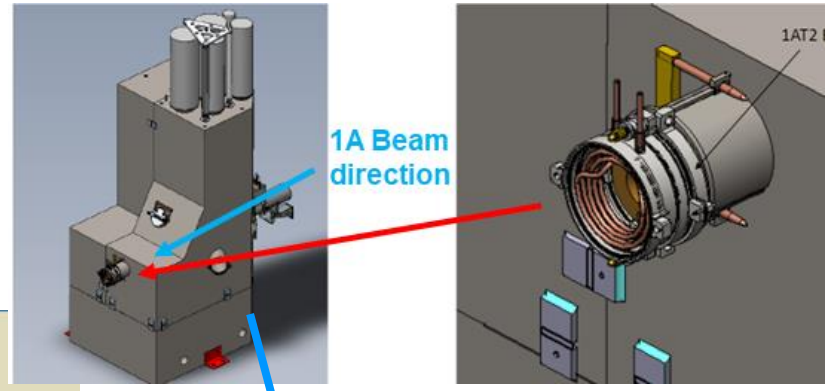


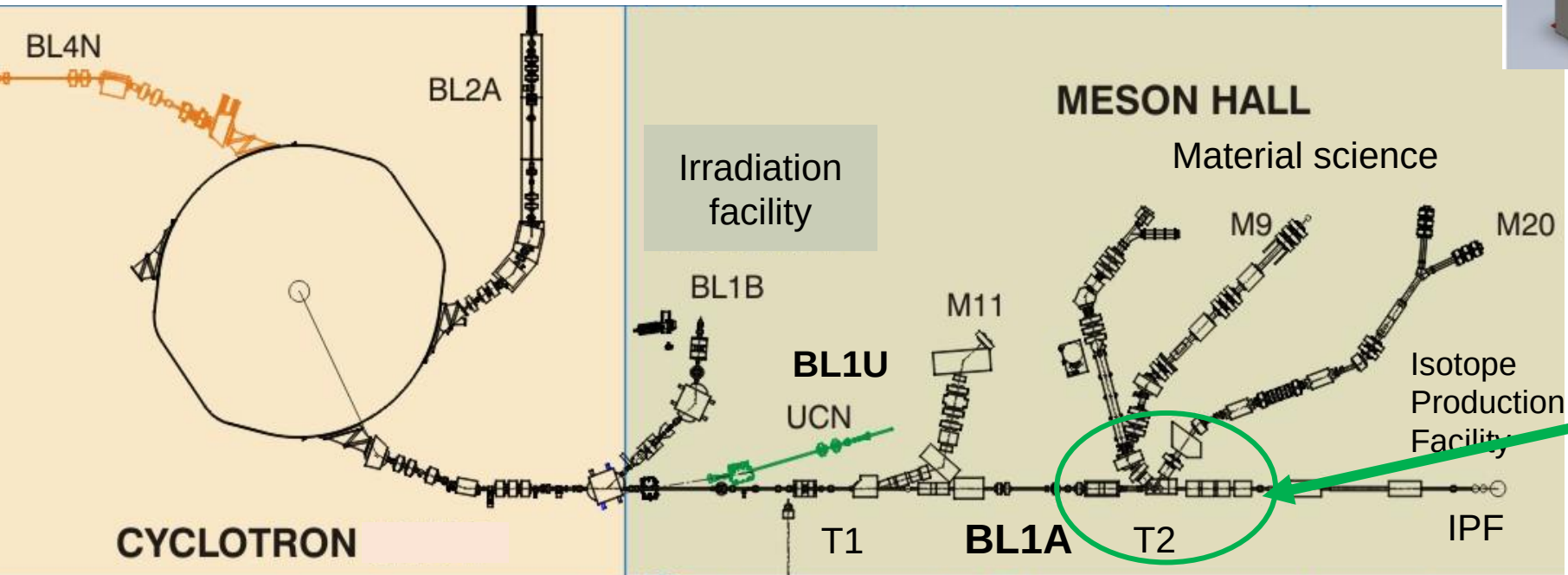
Refurbishment of BL1A

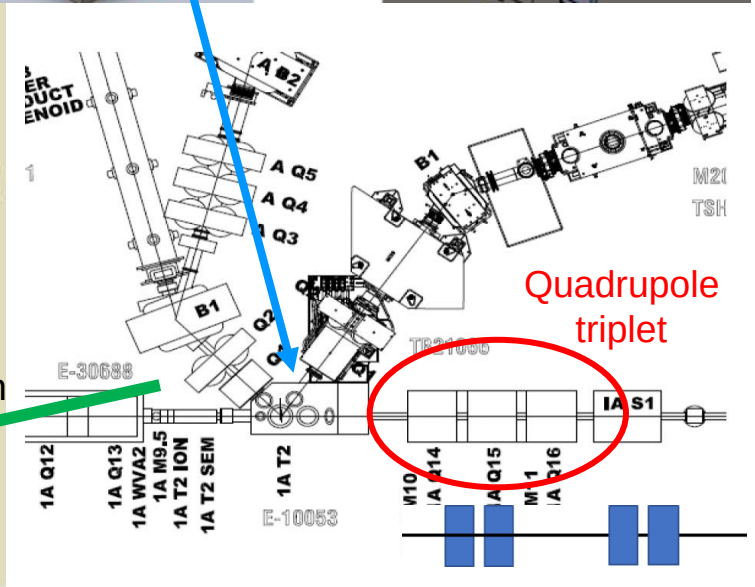
- The BL1A refurbishment project is a collection of activities to restore reliable beam operation and enhance functionality of BL1A
  → improved beam emittance, higher intensity and improved beam control.
- Revision of the beam optics is available (Document-219263)
- Two major projects are the replacement of the collimator B at T2 and the replacement of the quadrupole triplet downstream T2 with a double doublet.
  → requires remote handling systems and radioactive waste management!



Collimator B

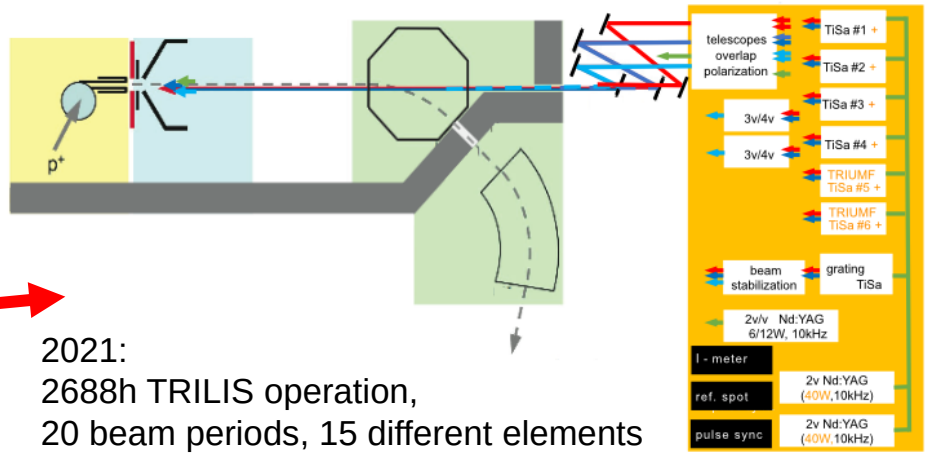




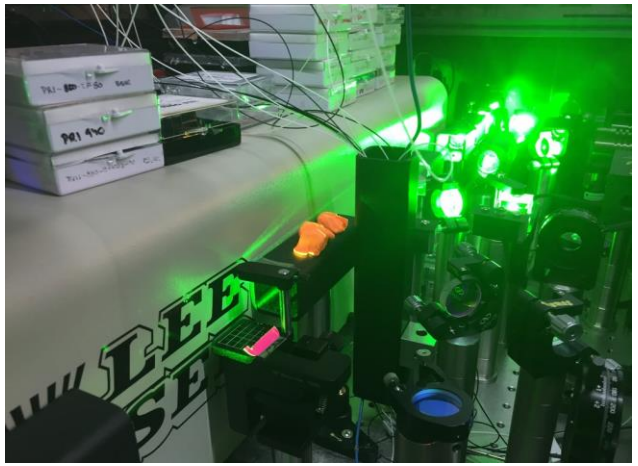


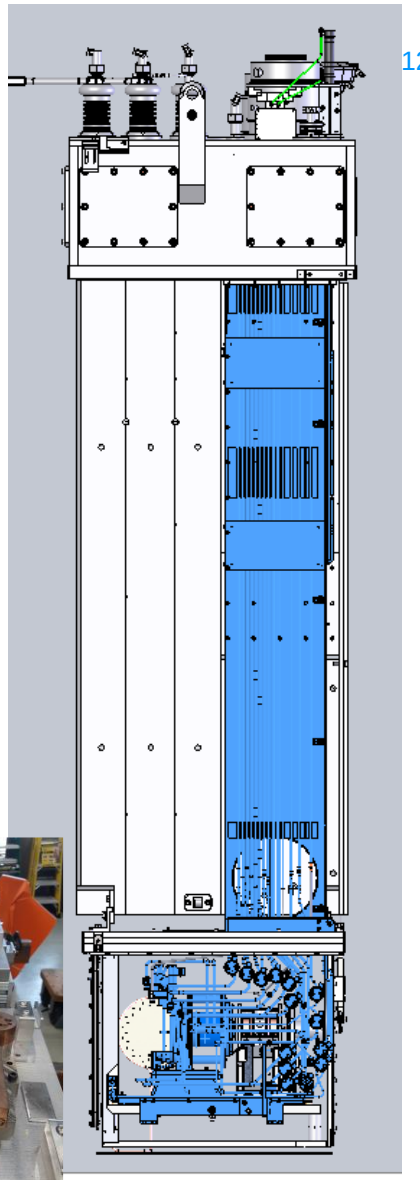
ISAC refurbishment in the next 5YP

- Full roll-out of regular target module refurbishment program (all major components except shielding). TM3 is the example for a successful module refurbishment.
- Target production and conditioning systems renewal → lab infrastructure (also for ARIEL)
- Electrical and mechanical systems refurbishment and procurement of critical spares.
- Laser Ion Source is the most demanded Target Ion Source at TRIUMF.
  → Beam development becomes increasingly difficult (2 elements/y).
  Upgrade will allow for more complex setups and ALIS (ARIEL) & TRILIS (ISAC) parallel operation!
- ISAC-I Linac RF system refurbishment:
  Replacing 25 years old tube amplifiers with solid state amplifiers (SSA).
  Replacing old low-level RF (LLRF) electronics with new digital systems.



2021:
2688h TRILIS operation,
20 beam periods, 15 different elements





Raise efficiency: CCS upgrade and the TCC

Cyclotron Control System (CCS) upgrade

- Replace legacy CCS CAMAC executive crates with in-house built hardware running EPICS.
  Will allow for the removal of controls hardware from the site of the future TRIUMF Control Centre.
- Address a top-level risk:
  Failure of the executive crate could cause months of downtime due to the scarcity of replacement parts.

CCS executive crate


Driver Control Room

TRIUMF Control Centre (TCC)

- Consolidate Driver and RIB accelerator operation within a single space.
- Gain operational efficiencies in terms of staffing and enable Accelerator Operations to better manage the paradigm shift with ARIEL transitions into beam delivery.
- Will allow to deploy automatic beam tuning as a standard method to establish beam tunes and delivery.

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Increase of research capacity - ARIEL

ARIEL: ISAC×3

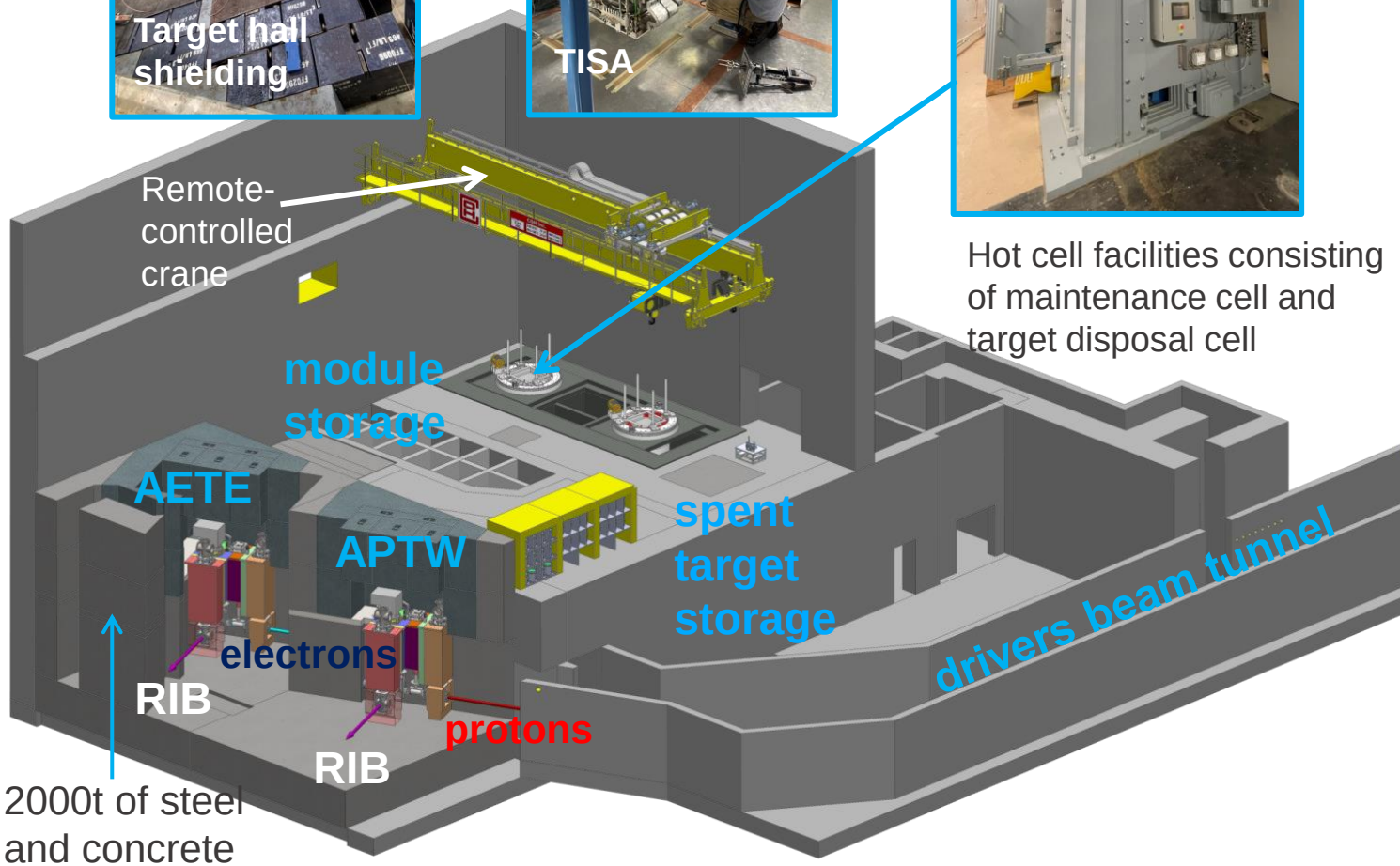
- ARIEL is the world’s most powerful isotope separation online complex.
- It will triple ISAC's present rare isotope capabilities by adding
  - a 50kW proton target station
  - a 100kW electron target station
  - Unique beam preparation and transport system (CANadian Rare isotope facility with Electron Beam ion source - CANREB)
- ARIEL is the only rare isotope facility that will provide three RIB beams simultaneously to experiments.

Completion of the ARIEL CFI project

Requires the completion

- of the target hall infrastructure for both stations
  (shielding, target building infrastructure, gas handling, HV infrastructure, vacuum systems)
- of Target and RIB modules and beam dumps including the medical target and transfer system
- of beam line 4 North (BL4N) and the electron beam line
- of the integration, testing and commissioning of all systems

Hot cell facilities consisting of maintenance cell and target disposal cell



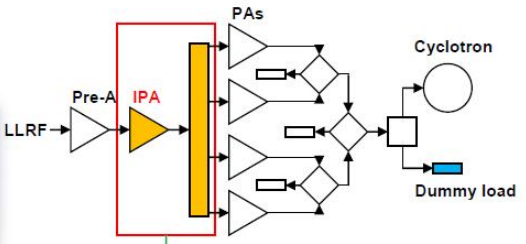
ARIEL transition into Operation

- Required for the ramp up in operation to take full advantage of ARIEL in the next 5YP:
  - Spent target decay storage vault
  - Target production infrastructure (laboratories)
  - Offline target acceptance stand – TISA completion
  - HV infrastructure for APTW
  - E-linac upgrade to full performance
- Commissioning of the electron line in the ARIEL tunnel followed by a gradual power ramp up to the electron target.
  Commissioning of BL4N followed by a gradual ramp-up of the extracted current from the cyclotron, with stable beam current in 3 high-energy beamlines.
- Roll out of the ARIEL-era operational model (Document-129655):
  TRIUMF will become a facility much more complex to operate.
  → Model-Based Tuning, TCC, integrated multi-facility maintenance.

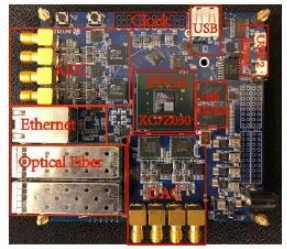
Driver accelerators for ARIEL

- E-linac towards high reliability and 100 kW beam power
- R&D on particulate contamination, Plasma cleaning
- Develop software tools to support beam ramp-up and high-power operation
- Second cryomodule, photo-gun and related optics →
  also in support of science (DarkLight, Intense THz and IR radiation, FLASH irradiation, etc.)

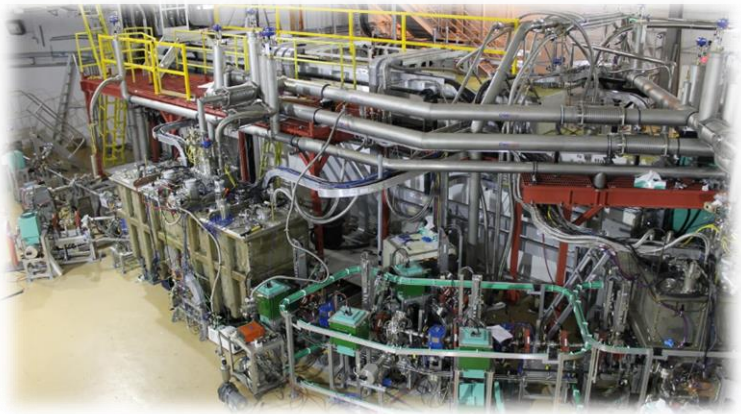
- Towards reduced cyclotron maintenance time (lid-up only every second year)
- Continue cyclotron refurbishment RF system (SSA and digital LLRF) for high current operation!

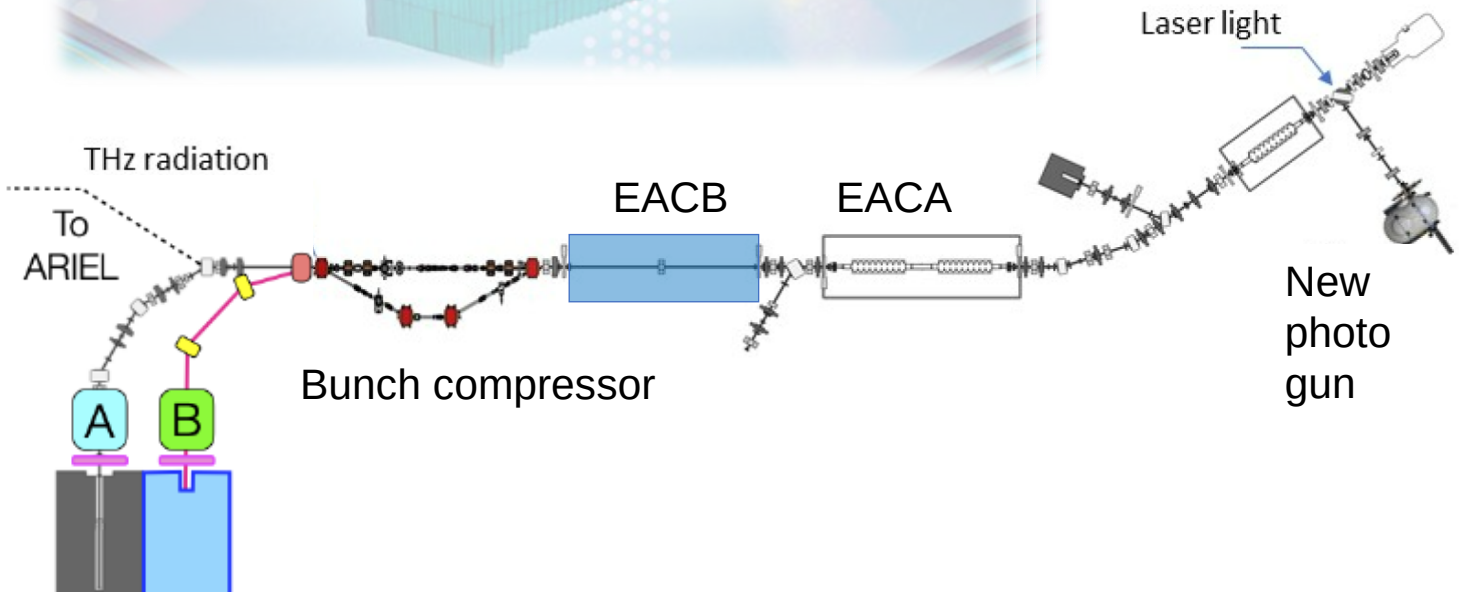


RF schematic



Digital LLRF board





Benefit of the scenario 2 – Long Shutdown (LS) in 2026

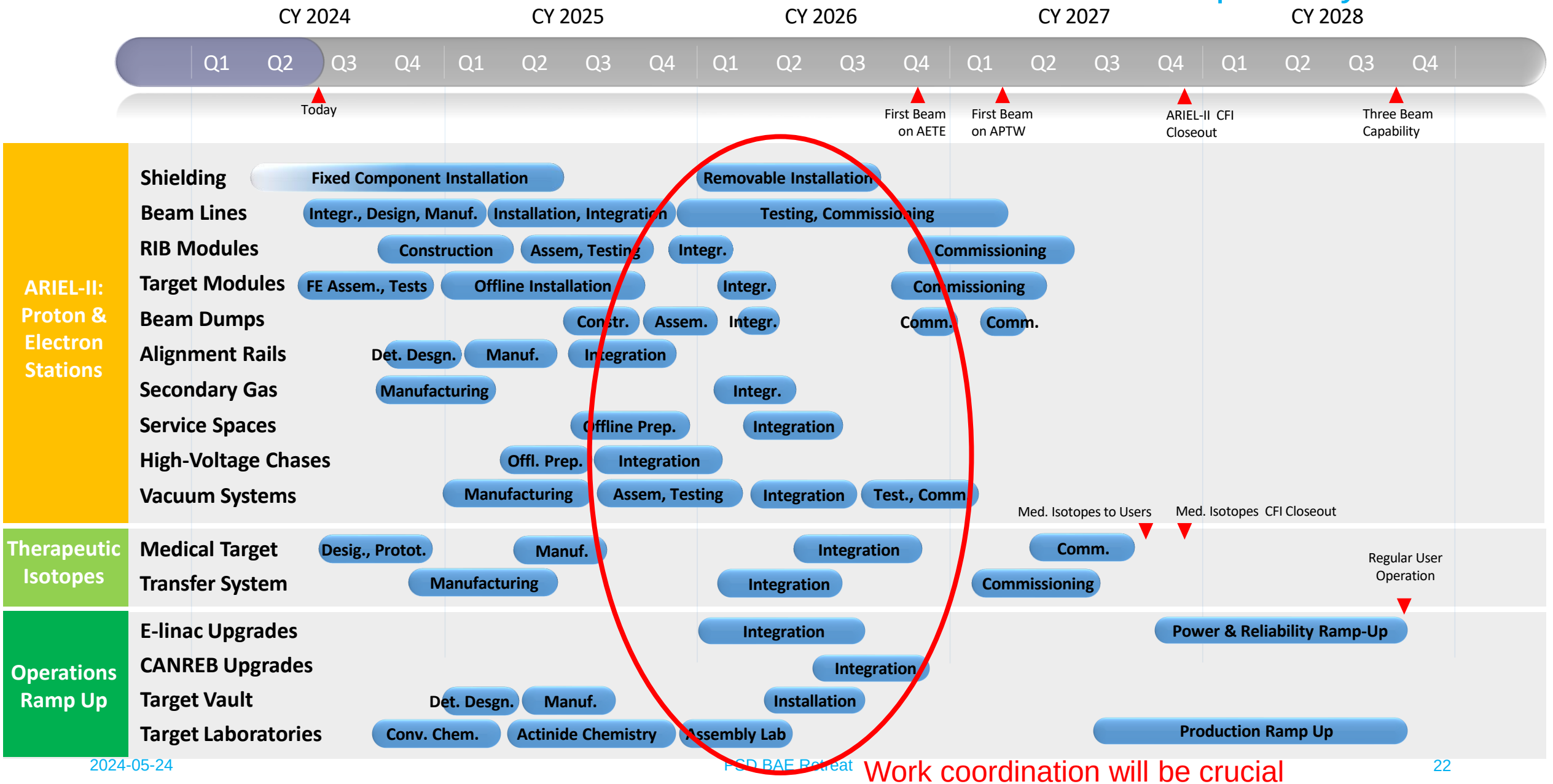
The preference for scenario 2

- The main fraction of Accelerator Division staff is occupied to safely operate the TRIUMF accelerator complex with high performance and availability.
  → regular maintenance, break fixes, exchange of obsolete systems, developments for refurbishment and upgrades
- From mid of 2025, the critical path of the ARIEL project follows the installation of systems inside of the ARIEL target building until 2028 (FTE limited) and the realization of deferred scope items (FTE and funding limited) before reaching full capabilities well within the 2030-35 era.
- Resource competition between operation of the accelerator complex and ARIEL because must be reduced for CFI project completion and completion of systems required for the ramp up of beam delivery.
  → scenario 2: Focus of division personnel on ARIEL tasks and significant reduction of accelerator operation tasks.
- A longer shutdown (6 months for instance) in the 5YP does not change the load on all expert groups from the shutdown tasks and the beam delivery preparation.

Required planning for LS2026

- Planning of the deliverables for 2025 to prepare the integration phase in 2026:
  Components for the beam line installations, the target and RIB modules as well as the vacuum and HV system must be procured prior to the labour intense integration phase.
  → requires design completion in the next 12 months
- Integration / installation work must be shifted by about two years compared to the ARIEL baseline schedule
  → departments like Targets and Ion sources, Accelerator Systems and RF/SRF must focus on these activities and identify staff for completion of the tasks.
  → Planning of the workforces (36 FTEs overall to be brought forward) and determination of the required qualification profiles.
- SMM as the tactical meeting of the lab must have the LS status as a standing agenda point to monitor progress and steer the execution
  → Support from expert group leaders is mandatory.
- QRPP will help to communicate project priorities and which projects are on-hold for the LS2026.

Preparatory Blocks



Work coordination will be crucial

Challenges of a LS in 2026

- The accelerated execution of ARIEL requires a front loading of the budget
  - need to be aligned with the expected cash flow for our 5YP
  - expenses for refurbishment must be shifted later into the 5YP.
- Boundary conditions for the scheduling and resources planning:
  - BL1A triplet replacement should be done in the long shut down to avoid additional downtime of BL1A later in the 5YP.
  - HL-LHC crab cavity cryomodules delivery follows the HL-LHC project schedule
    → but the delivery must be stretched out by another year to accommodate the LS2026.
  - To be successful with the e-linac based experiments DarkLight and high field THz radiation facility, e-linac upgrade must be timed (which is beneficial for ARIEL beam from AETE).
- Restart of systems after a long shutdown will be more challenging as older systems might not recover well or at all.
- Compensation of the loss of science output and mitigation of impact on student thesis work.

ARIEL operation ramp-up benefit

- ISAC will move back to 8 months operation, generating about 4400 RIB hours per year available to experiments compared to 3200 now and in scenario 3.
- ARIEL operation ramp-up after commissioning in 2027 will arrive at another 1000 RIB hours in 2029 (see RIB hours graphics in Nigel's talk).
- More beam will be available for ß-NMR facility to compensate some of the loss of CMMS in the long shut down.
- The ARIEL medical target will provide Th irradiation capabilities for Ac-225 production and will mitigate the risk of potential loss of irradiation time at IPF (due to failure and/or requried refurbishment activities).
  → The ARIEL hot cell will allow the handling of targets with higher activation levels.
- The ARIEL e-linac upgrade and ramp-up to full performance will also benefit experiments like DarkLight, high field THz radiation facility and FLASH irradiation.
- ARIEL completion will also mitigate project fatigue → ARIEL project would move towards 20 years project runtime by the end of the next 5YP.

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Thank you

science week 24
July 22 - 26

Discovery, accelerated