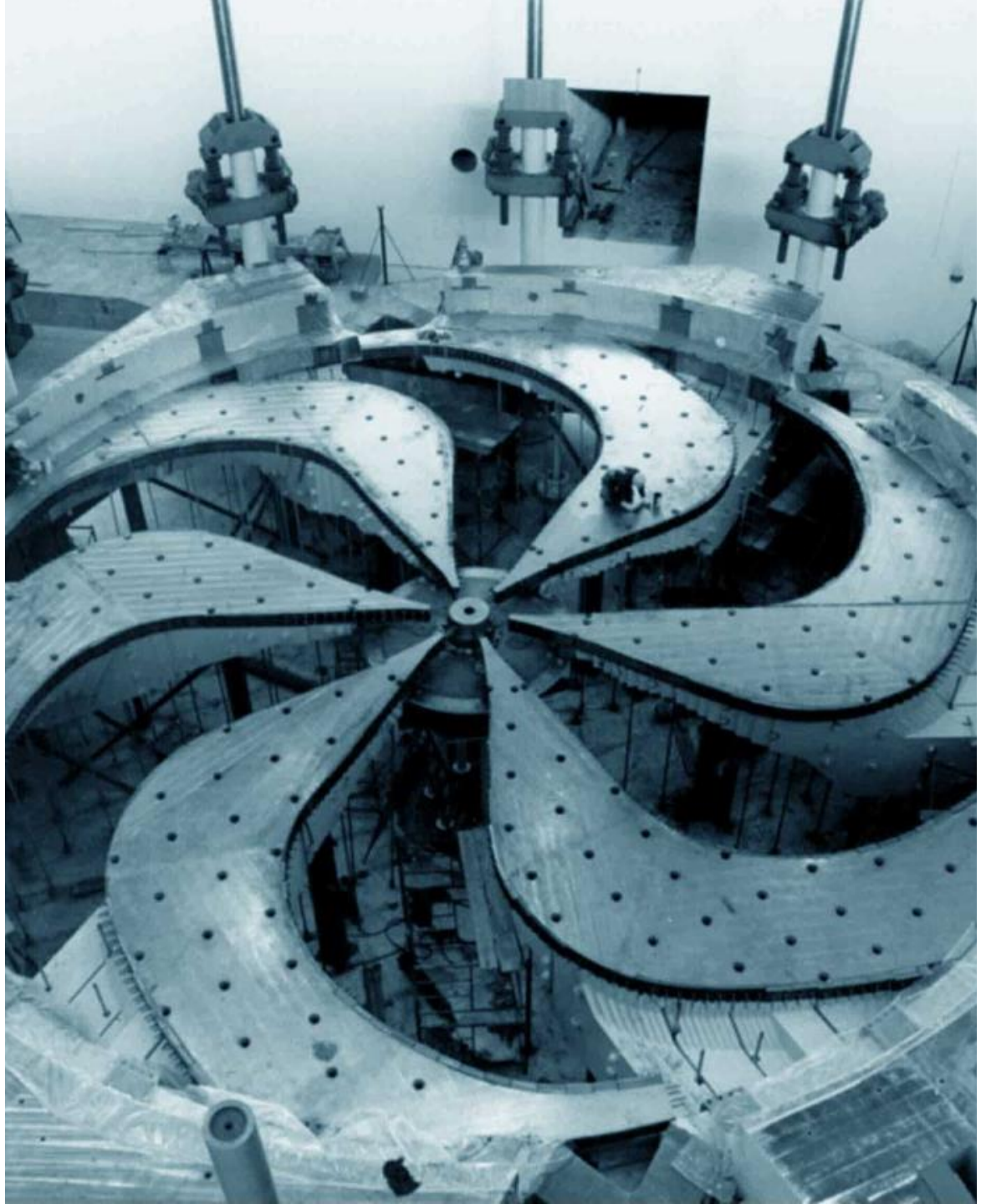
TRIUMF CYCLOTRON MAIN MAGNET POWER SUPPLY REPLACEMENT

Arthur Leung

High Power DC Systems



2018-10-05

Discovery, accelerated

TRIUMF stands for TRI University Meson Facility

Founded by University of British Columbia, Simon Fraser University, University of Victoria 43 Years Ago

Carleton University
University of Guelph
Queen's University
Simon Fraser University
University of Alberta
University of BC
University of Manitoba
Université de Montréal
University of Toronto
University of Victoria
York University
University of Calgary
McMaster University
Saint Mary's University
University of Regina
University of Northern British Columbia
McGill University
Western University
University of Winnipeg

TRIUMF is located on the campus of University of British Columbia.

Locarno Beach

Whistler in winter

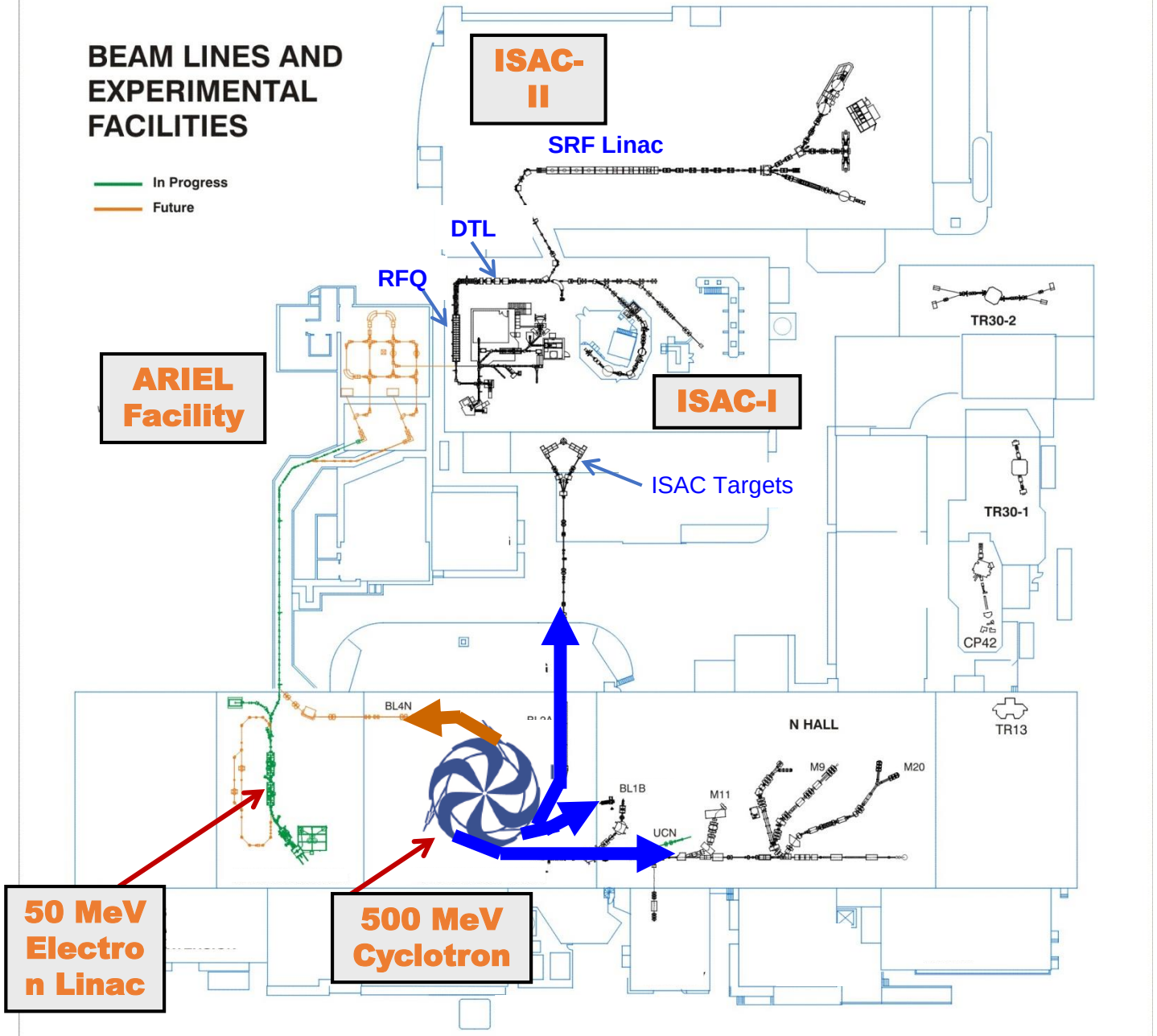
Whistler in summer

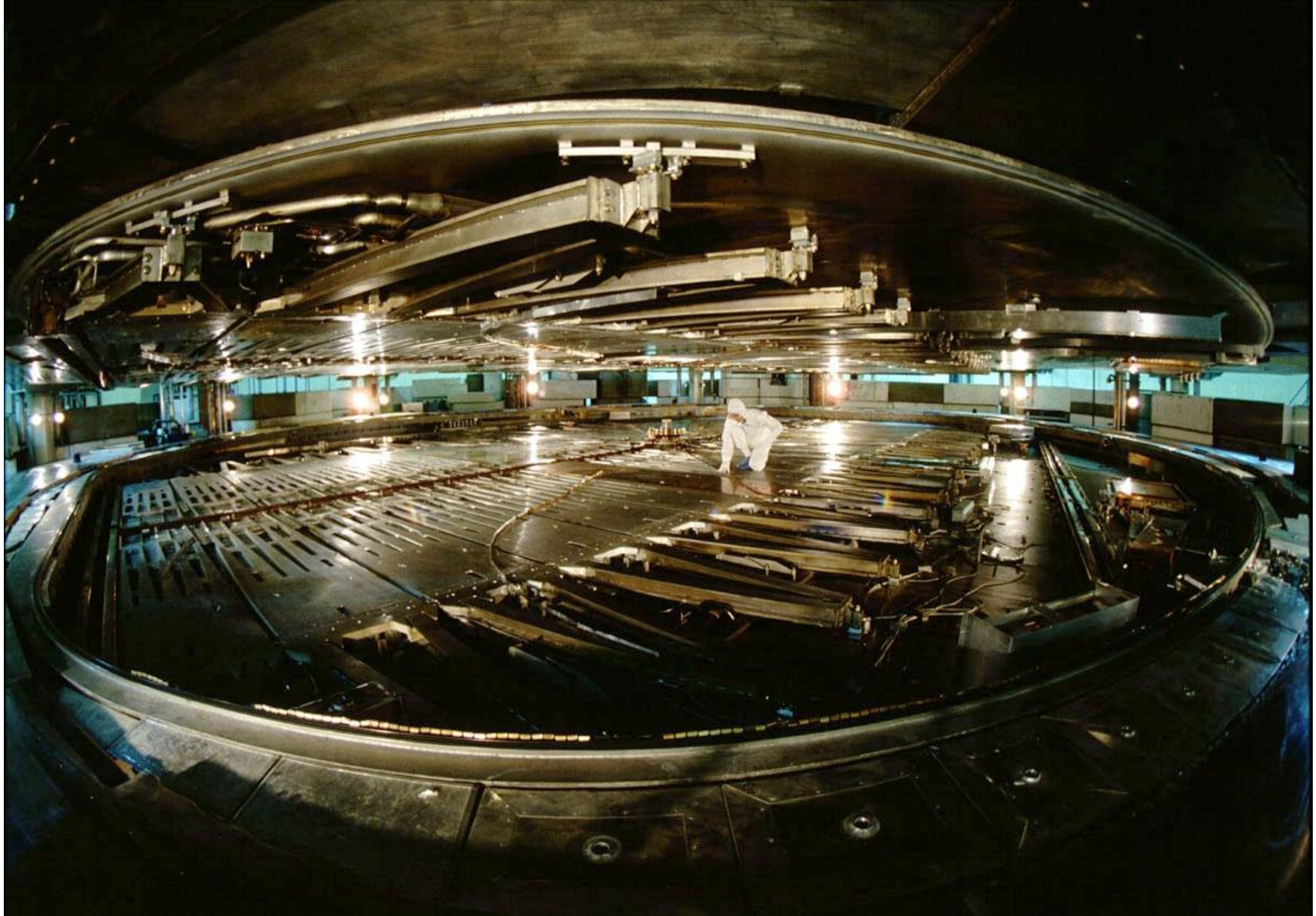
TRIUMF Accelerators

- 500MeV H^- cyclotron since 1974
- ISAC-I accelerates rare-isotopes 2001
- ISAC-II first experiment 2007
- ARIEL (e-Linac) begins 2010

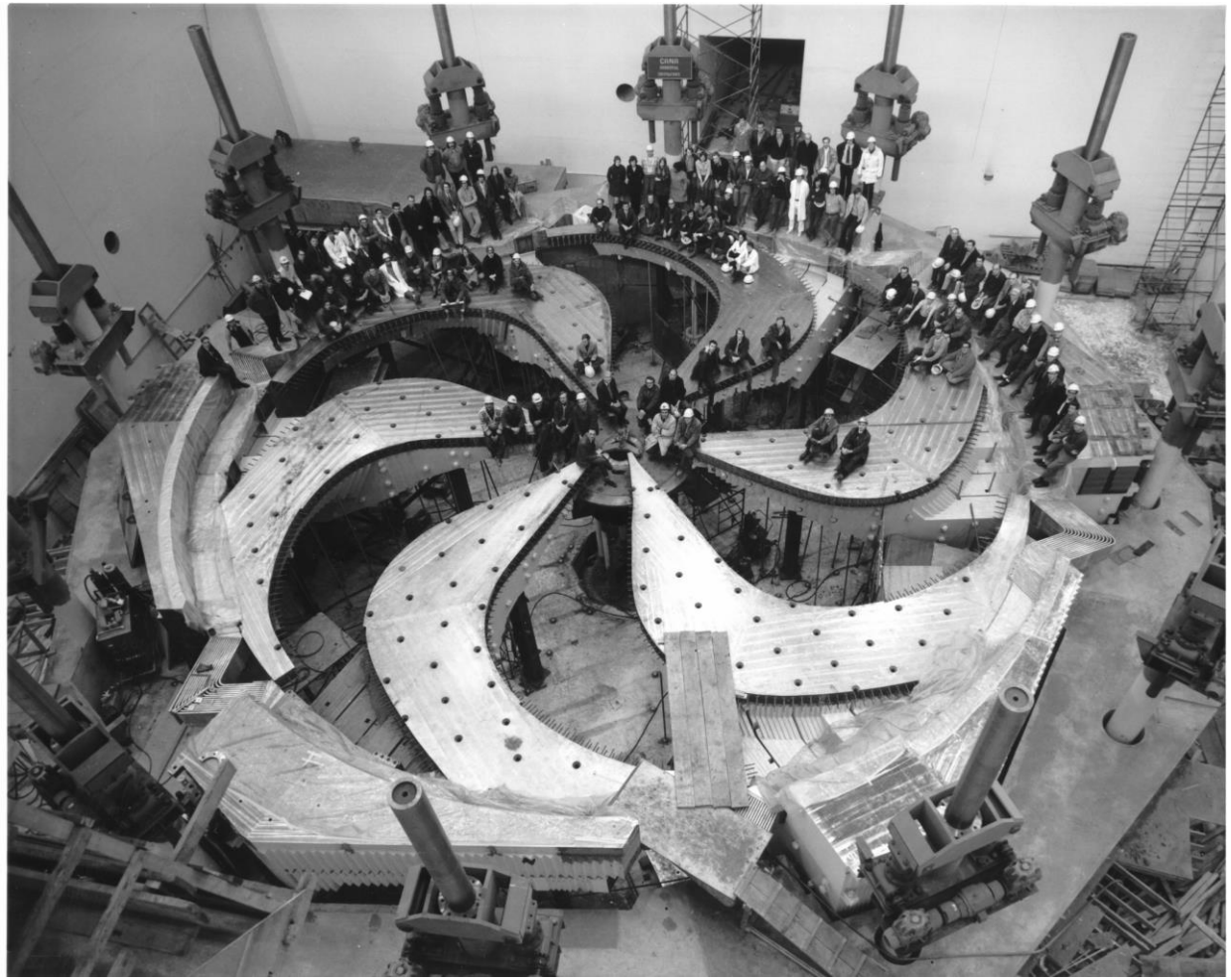
ISAC: Isotope Separator and Accelerator

ARIEL: Advanced Rare IsotopE Laboratory





Cyclotron Magnet



Bottom Half of Main Magnet Poles and Coils

Original Main Magnet Power Supply

In service for 45 years!

- Many obsolete parts

Water cooled

- Piping becoming worn

Linear Power Supply

Very stable: ~2ppm with magnetic flux feedback

Designed to operate in range 21kA – 27kA

Shunt Operation

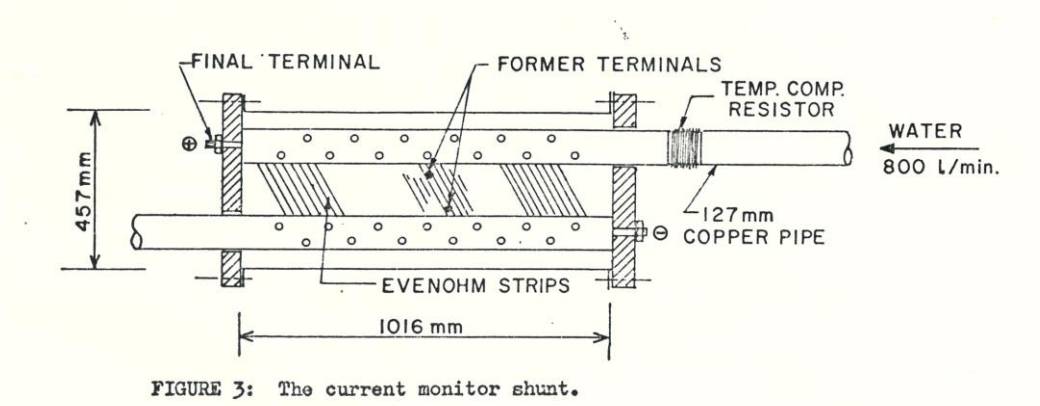
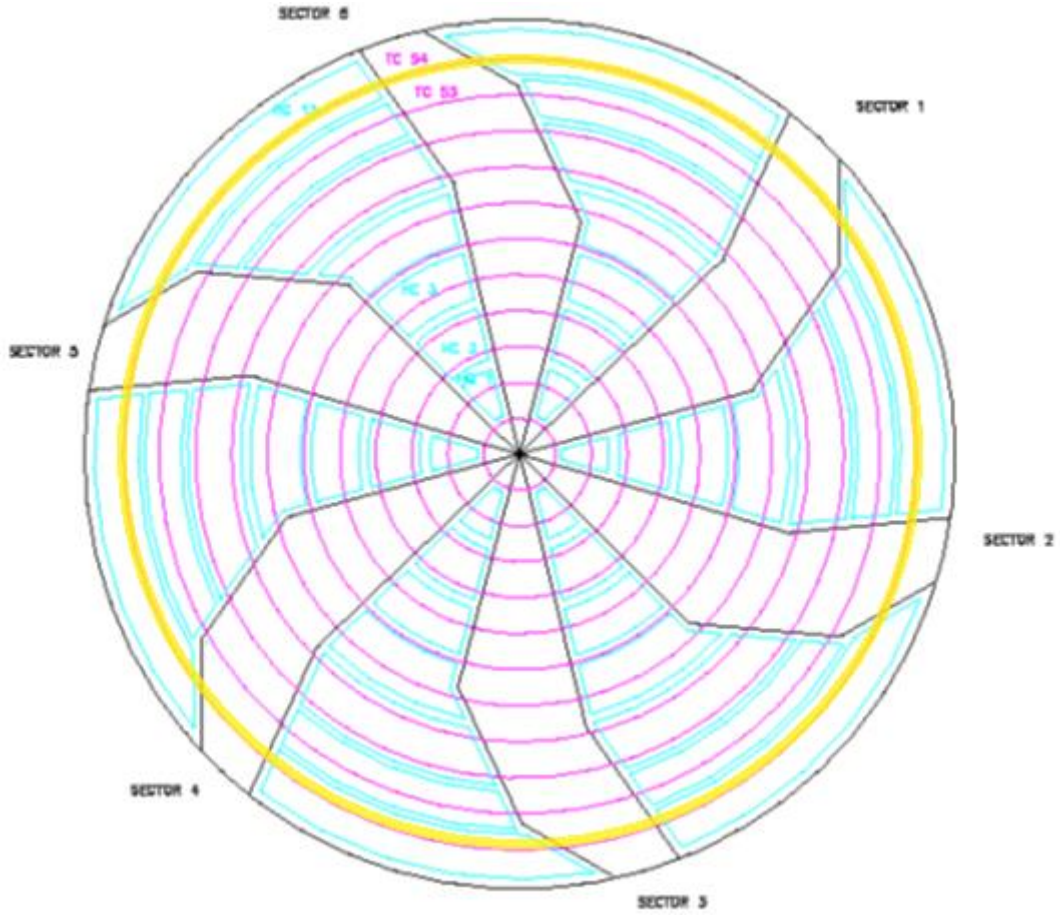
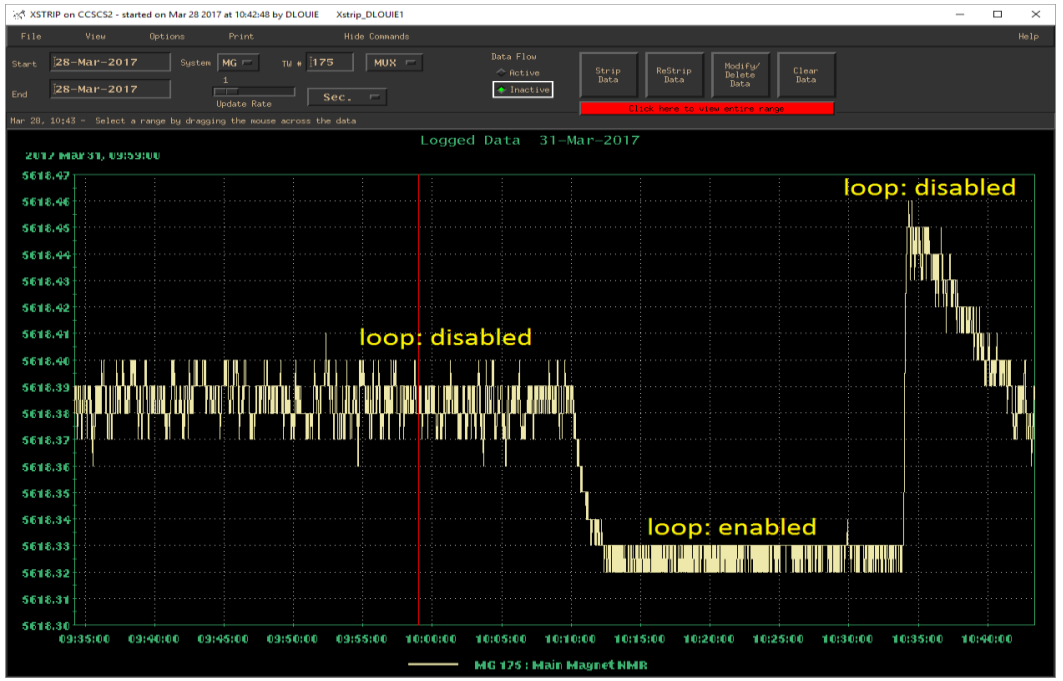


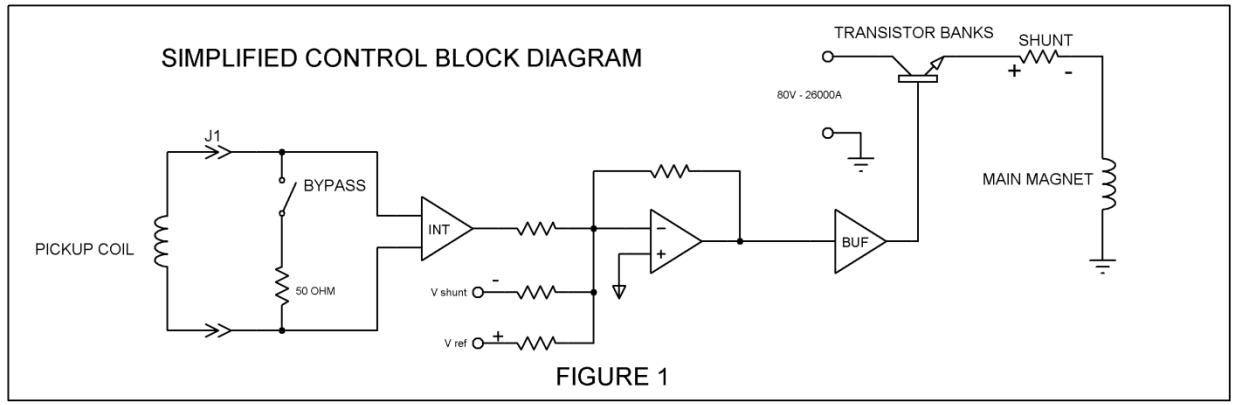
FIGURE 3: The current monitor shunt.

- Designed output is 1V at 26700A
- Evanohm material
  - 100 parallel strips
  - Low Temp. Co.: 1×10^{-5} ohm/ºC

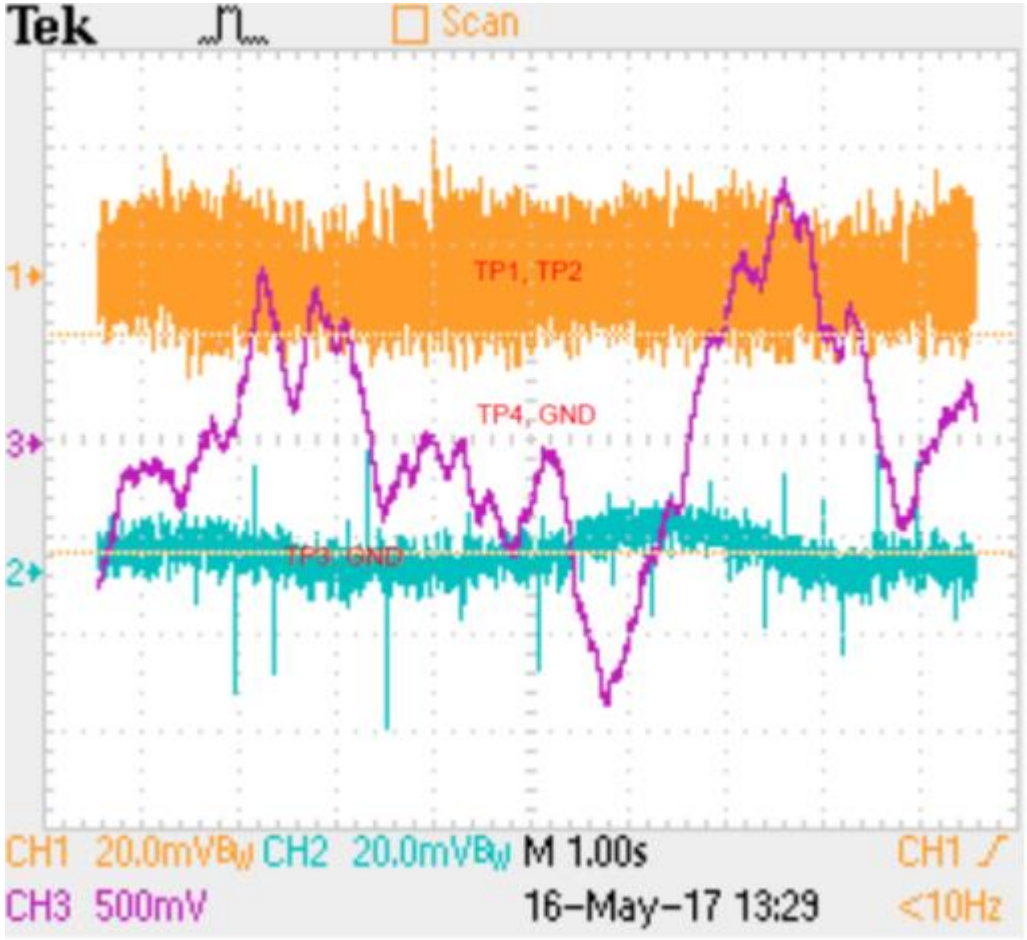
Trim Coil 54 Feedback







Trim Coil 54 Feedback



- TC54 signal in 20mV range (Orange trace)
  - Significant noise
- Integrator circuit to filter signal (Blue) then amplify (Magenta)
- Similar circuit to be designed for new power supply

New Main Magnet Power Supply

Selected OCEM for project

Controller provided by CERN

Maximum output of 20kA

Current Stability 2ppm

Completed in Italy Oct 2017

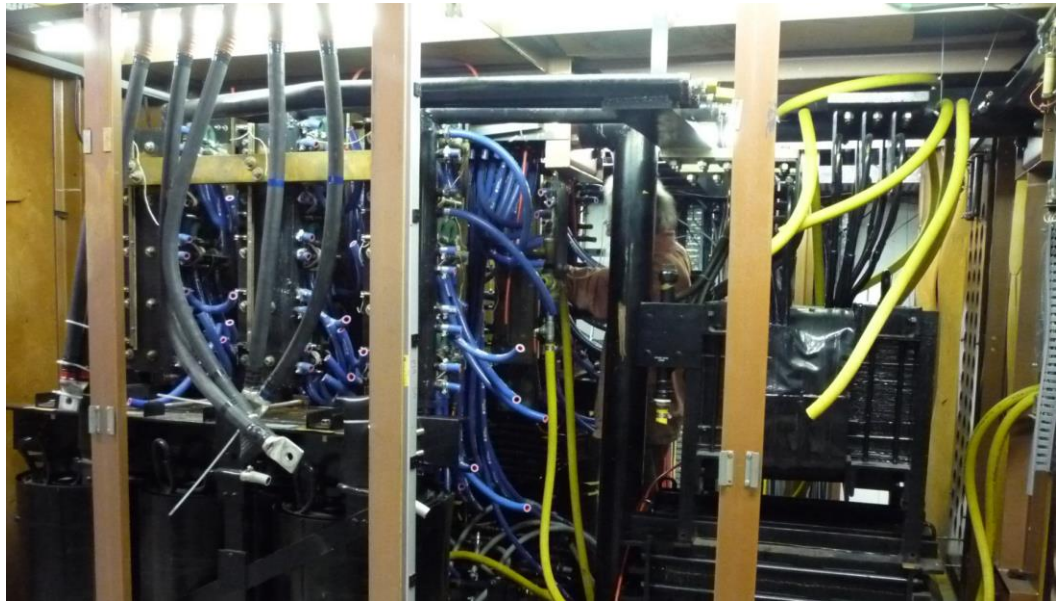
Arrived at TRIUMF Dec 2017

Re-assembled and commissioned by April 2018

Timeline

December 2017:

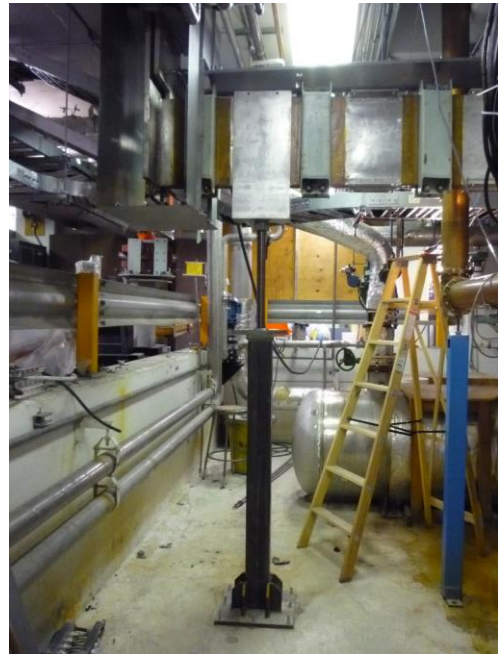
- New PS Arrival
- Old PS Final Shutdown



Timeline

January 2018:

- Shutdown begins, start disassembly
- Old Power Supply removed
- New Power Supply assembled



Timeline

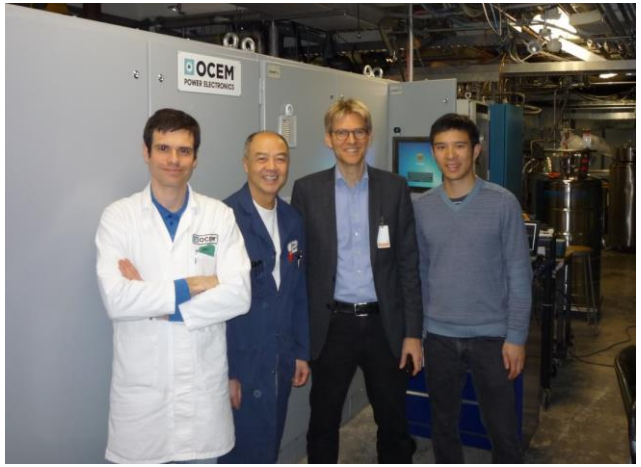
February 2018:

- Electrical connections completed
- Setup and commissioning of control system

Timeline

March:

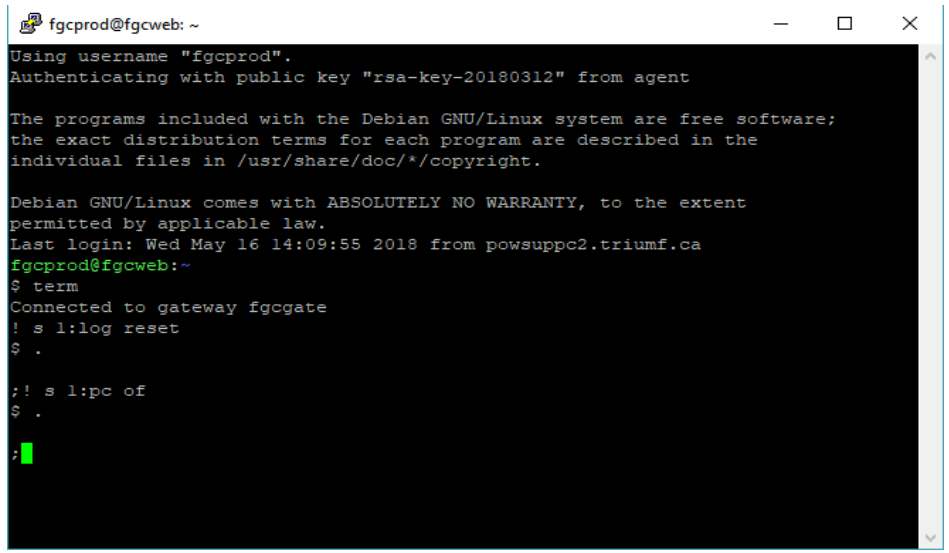
- MCB energised for first time
- Begin conditioning voltage and current loops with CERN experts
- First full load test
- 8 Hour thermal test and long term stability tests

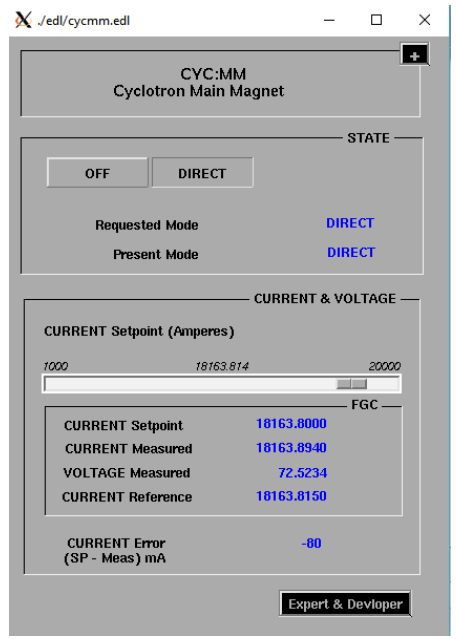


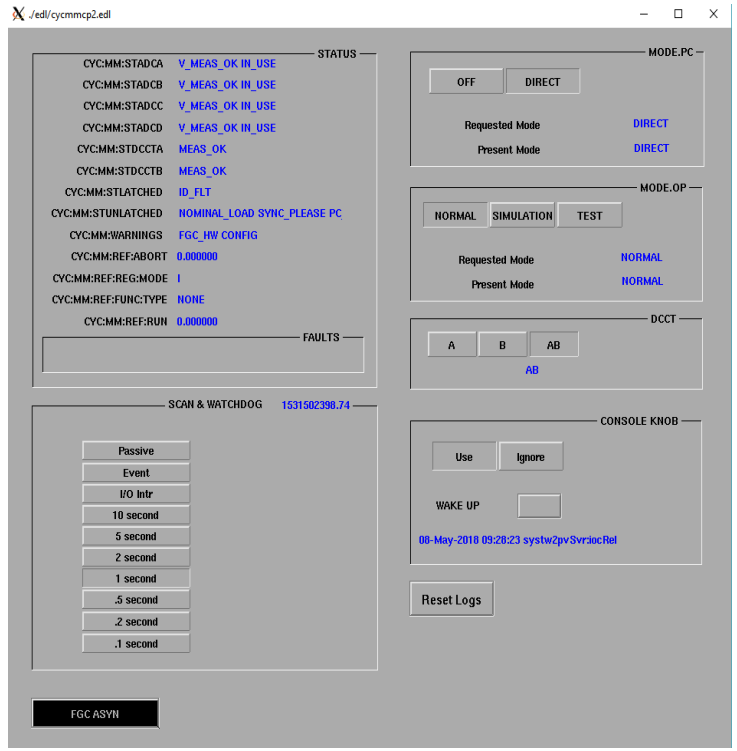
Timeline

April:

- Controls integration work
- Beam injected Apr 16





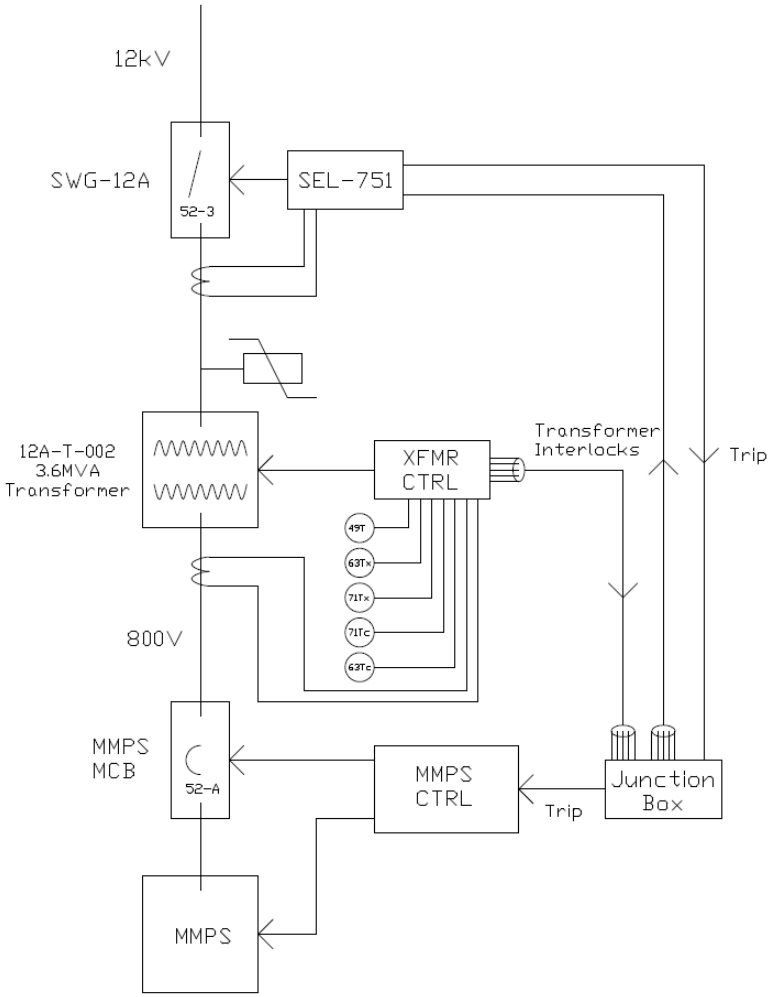


Complications

- Switch to air-cooled transformers required upgrade to AC system
  - Ventilation and fans installed for new PS
  - Make use of limited space over existing equipment
  - New AC unit needed to be installed in RF room as existing unit could not handle additional load
- AC service needed to be reviewed and ensure that it would meet new standards
  - Testing of insulation for 800VAC feed
  - Thorough inspection and test of 12kV to 800V transformer and tap changer to ensure it is still in good condition
  - Switchgear control upgrade with new protection relay system

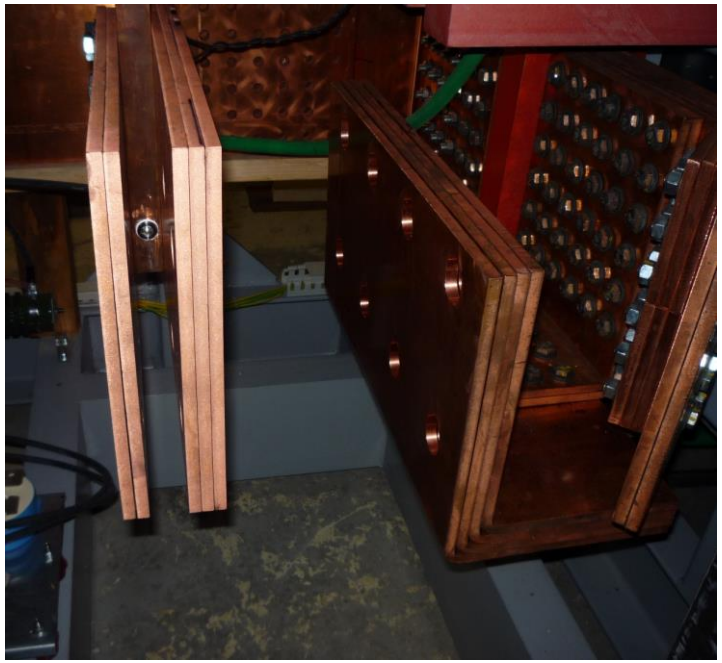
Switchgear Control Upgrade

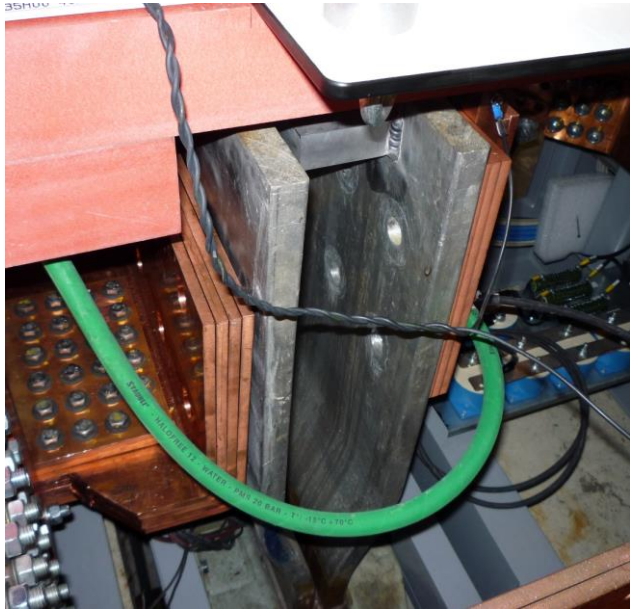
- Original Power Supply used 12kV switchgear as MCB
  - Transformer protection was part of power supply interlock system
- New Power Supply has independent 800V MCB
  - Transformer protection needed to be redesigned
  - Interlocked through SEL751 protection relay
  - SEL751 to send trip signal to PS as well for machine protect



Input Bus Bar Alignment

- Vertical aluminum bus did not align with DC bus
  - Mounting holes did not have sufficient allowance
  - Mounting required bolts to screw into threaded copper plates
- Negative plate mounting holes were machined into slots
- Mounting mechanism for Positive plate redesigned
  - Machined threaded steel inserts
  - Cutaways machined into copper plates to install inserts



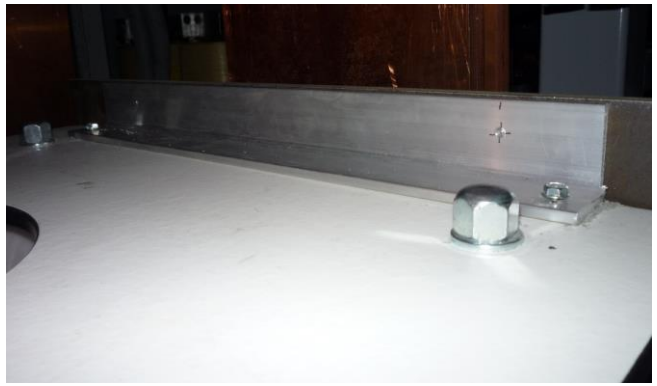


EMF noise

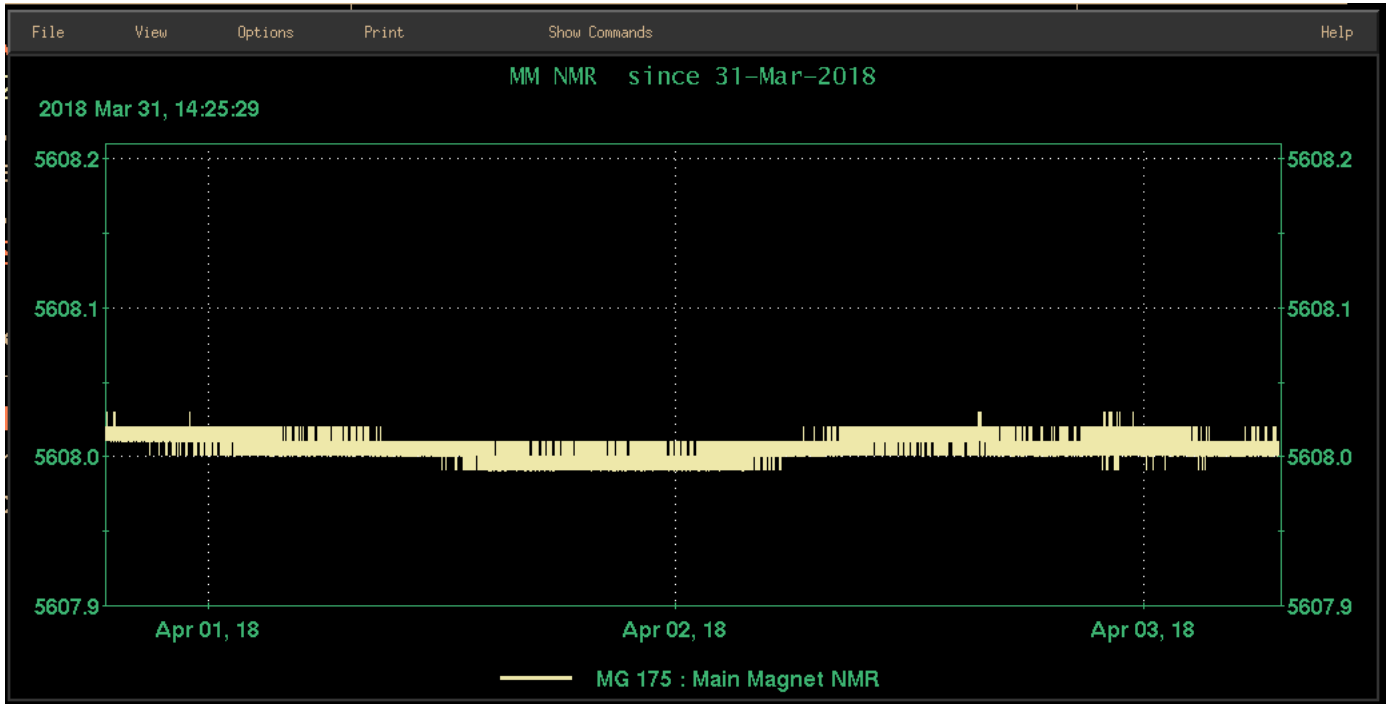
- EMF interference with Extraction Probe readback
  - Significant noise picked up when new PS ran at >10000A
- Attempt to reduce EMF generated by power supply
  - Investigate circulating ground current between PS cabinets
- Discovered that noise was picked up along Extraction Probe signal cable, which ran near input transformers
  - Re-routed signal cable, noise issue was solved
- So far no other devices have had similar issues

DCCT Noise

- OCEM originally consulted CERN for design of output bus and DCCT mounting structure
  - Design to suppress interference between bus and DCCTs
  - Build did not match approved design
- During commissioning, significant noise on DCCT readback
- Mitigation plan: Attempt shielding
  - Noise was significantly reduced
  - Final shielding - 10mm steel plate
- With shielding, output stability met specification



Performance



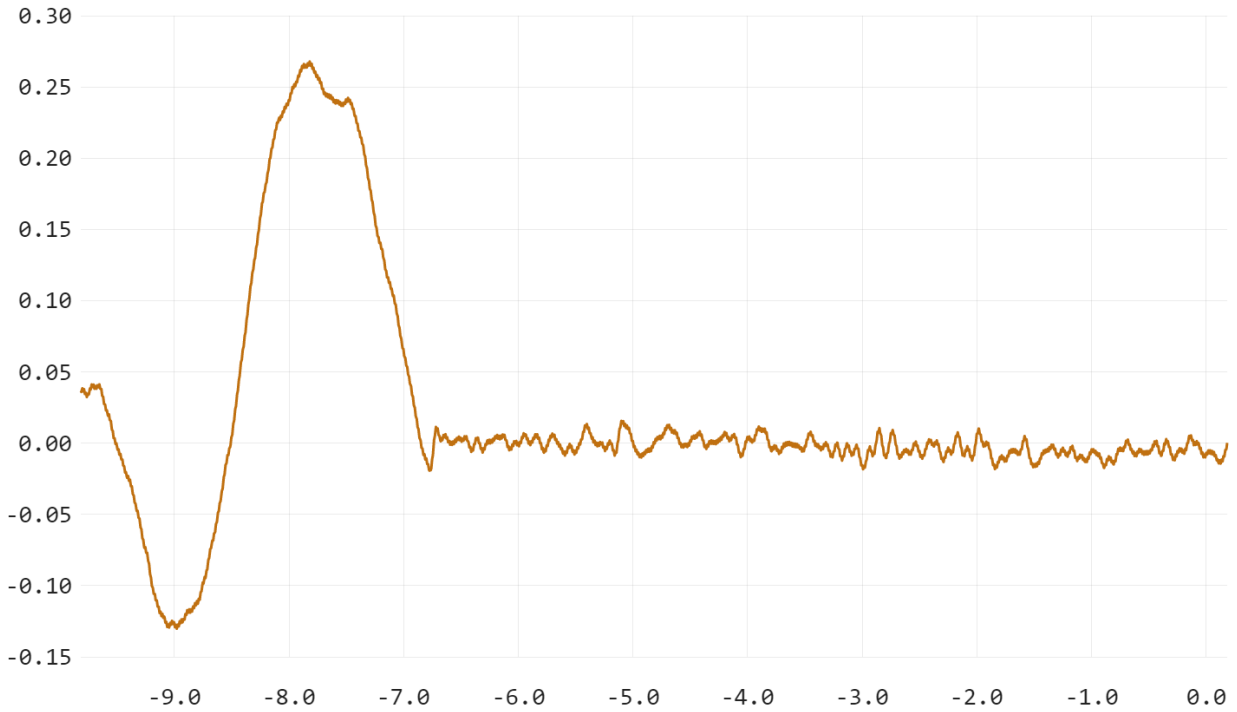
- Confirmed 2ppm performance
- Flux feedback loop to be further characterized
- 92% efficiency – old PS 80% efficiency
- Savings of ~$70,000 CAD per year on electrical bill
  - Receiving $330,000 CAD incentive from BC Hydro Power Smart program

Achieving Required Field Stability

- CERN FGC3 Controller
  - Temperature regulated cabinet
- High precision DCCTs
- I-loop supports external reference
  - Ability to implement flux loop compensation

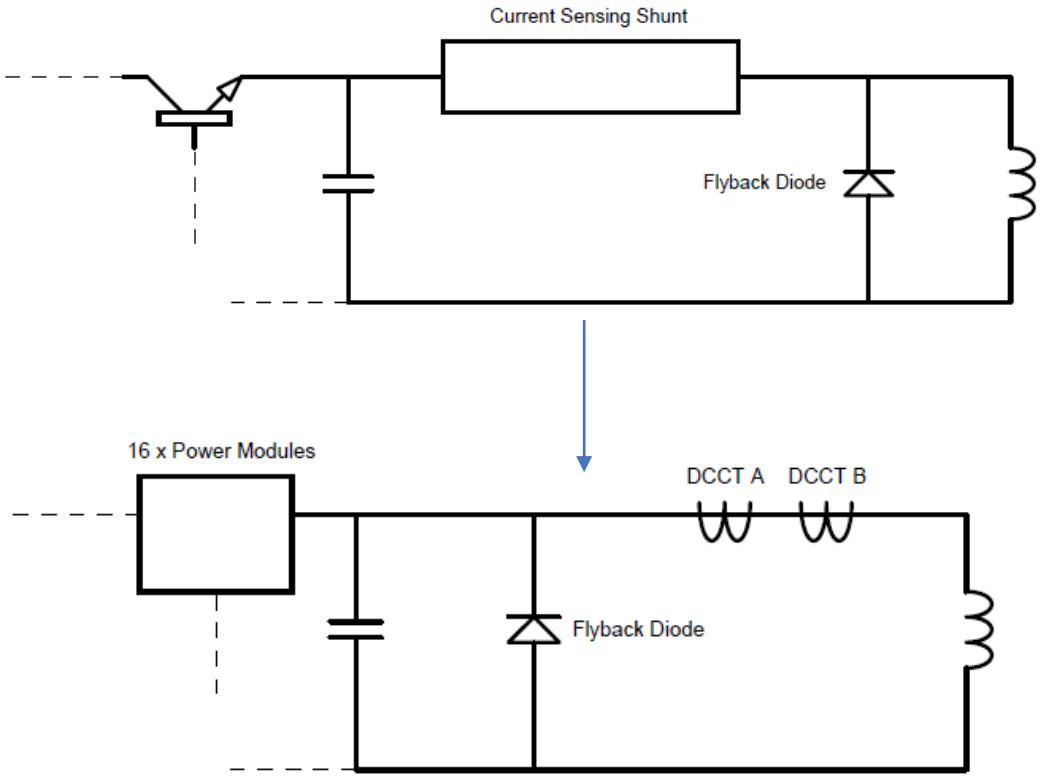
Flux Loop Compensation Board

- Circuit design based on trim coil 54 signal integrator
- Tested with modified time constant, amplification (10V range)
- Demonstrated improvement to short term low frequency noise through flux loop readback
- Does not appear to be necessary for beam operation



Fly-back Diode Modification

- Changes to installation may have removed need for flux loop compensation
- Original Fly-back diodes installed along DC Bus Bar, after Shunt
  - Leakage Current not measured by Shunt
- New Fly-back diodes installed before DCCTs, internal to PS



Ongoing Commissioning and Troubleshooting

- RF issues during Cyclotron Start-up
  - RF on same 12kV network as new power supply
  - Found new supply will trip when RF crowbars due to current regulation error
  - Major effort to retune after each trip
  - Limit was increased but trips continued as power module output high faults
- Troubleshooting continues with CERN’s assistance, but tuning time has improved and RF trips decreased
- Integration of post-mortem logs with TRIUMF network

Thank You!

- CERN: Jean-Paul Burnet, Miguel Bastos, Gilles Lo Godec, Quentin King, Olivier Michels
- DESY: Joerg Eckoldt
- OCEM: Luca Bondesan, Saverino Carrozza, Roberto Donato, Oreste Gamerini, Alessandro Morato, Renato Lo Verso