Status & Challenges @ TRIUMF ISAC Facility

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on behalf of ISAC RF/SRF team

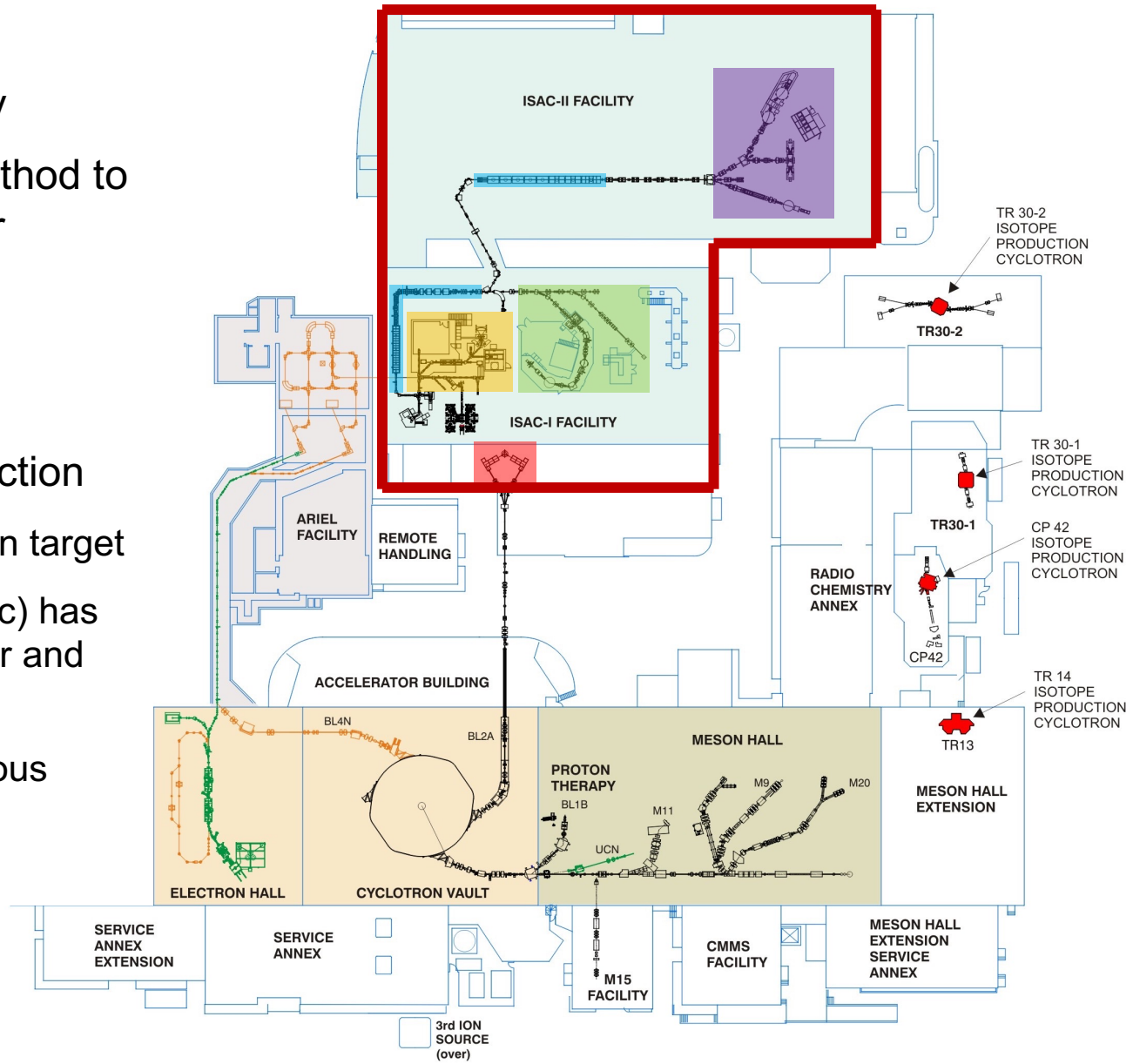
LINAC2022, Aug. 28 – Sep. 2, 2022

Discovery, accelerated


TRIUMF
Canada’s particle accelerator centre

ISAC Facility

- Isotope Separator and ACcelerator facility
  - Isotope separation on-line (ISOL) method to produce rare isotope beams (RIB) for experiments
  - Up to 50kW driver beam power from 500MeV cyclotron to ISAC target
  - ARIEL to add 2 targets for RIB production
    - 50kW proton target & 100kW electron target
    - A 1.3GHz SRF electron linac (e-Linac) has achieved 10kW average beam power and 30MeV beam energy
    - With ARIEL completion, 3 simultaneous beams for ISAC RIB programs



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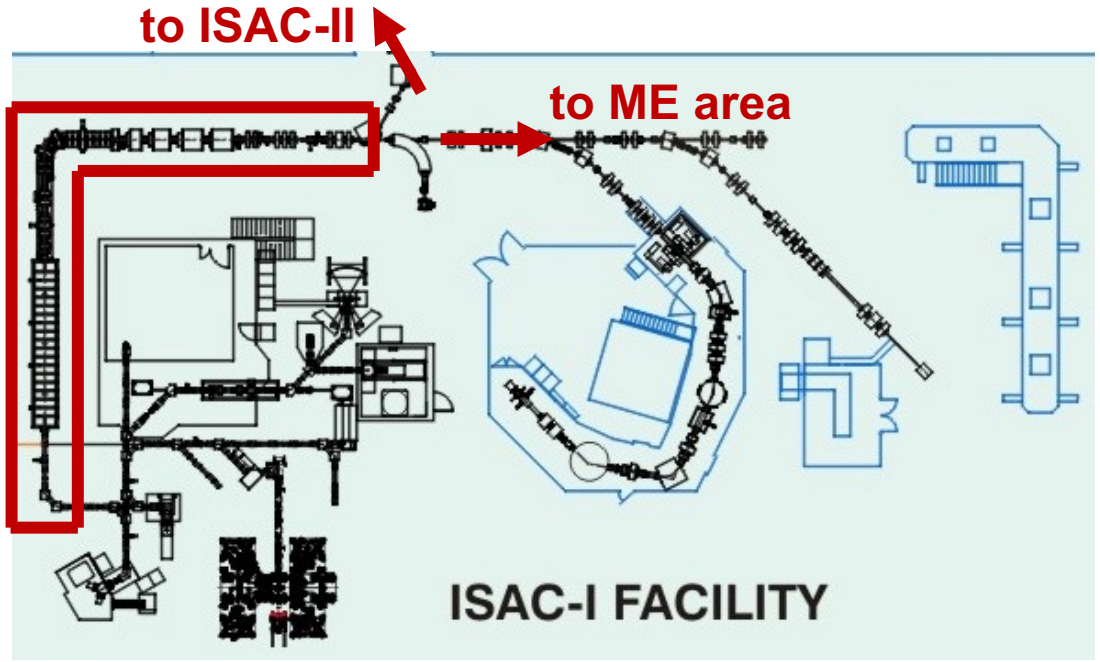
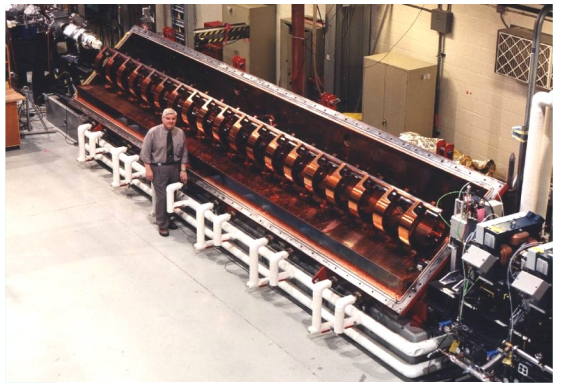
Discovery, accelerated

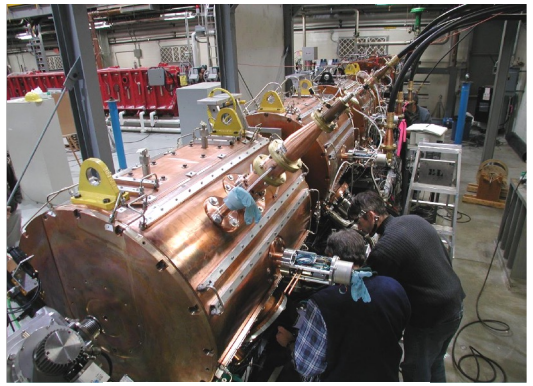
ISAC-I Linac

- Room temperature linear accelerator
  - 18 CW RF systems
  - Frequency 5MHz – 106MHz
  - Up to 220kW total RF power
  - RF Quadrupole (RFQ)
    - 2keV/u – 150keV/u for A/q≤30
  - Drift Tube Linac (DTL)
    - 150keV/u – 1.5MeV/u for A/q≤6
  - In operation since 2000





35MHz 90kW RFQ



106MHz DTL

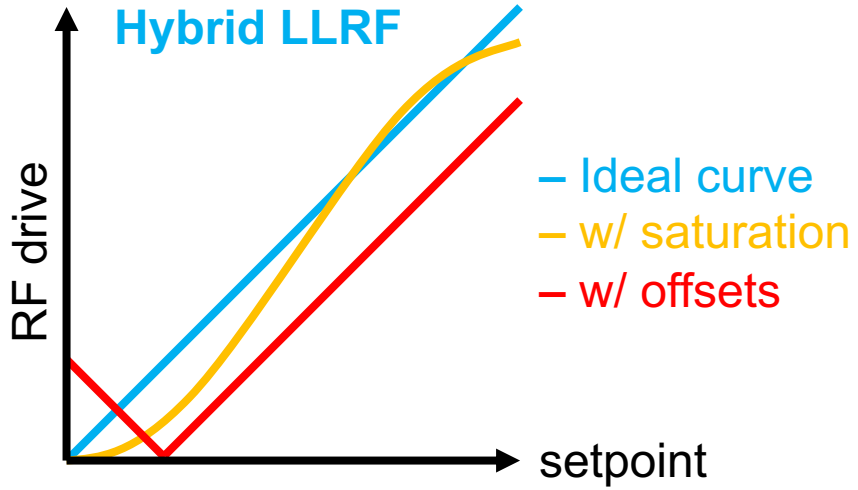
RF Challenge

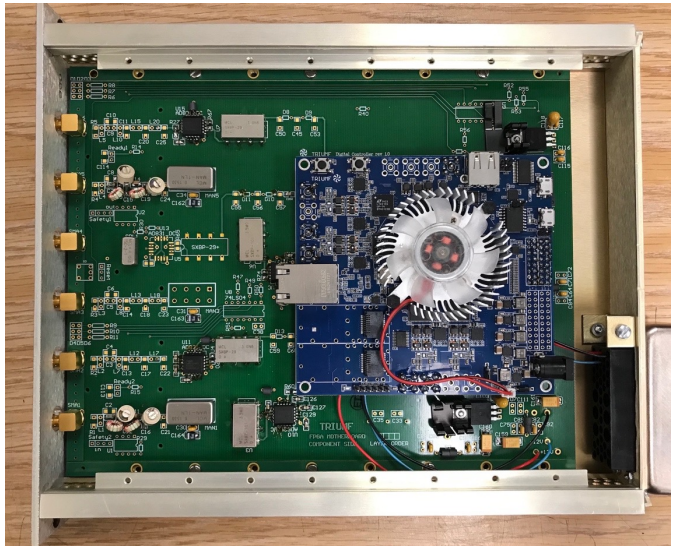
- Requirement
  - Operation requires fast system setup & stabilization while switching beam energy or A/q
- Challenge – tube RF power amplifiers
  - Over 20 years old RF systems
  - Overheating socket in aged amplifiers
  - Aged matching circuit requires longer warmup
  - Obsolete tube challenges MRO
- Solution – upgrade to solid state amplifier (SS Amp)
  - 4.8kW SS Amp installed & commissioned in 2022
  - 25kW SS Amp in production, to install in 2023
  - Long term goal to upgrade all tube amplifiers to SS amplifiers in ISAC-I

4.8kW 106MHz SS Amp in operation

RF Challenge (2)

- Requirement
  - Operation requires large RF dynamic range for various A/q RIBs
- Challenge – low level RF (LLRF)
  - Original hybrid LLRF responses are not ideal nor identical
    - Increase required beam tuning effort
    - Cause anomalous beam loss
  - VXI key component obsolete
    - Slot 0 controller discontinued increases maintenance cost
- Solution – upgrade to digital LLRF
  - FPGA based digital LLRF with high-speed ADC & DAC
  - Provide better expansion capability for various systems
  - Provide on-board communication interface
  - Pre-bunchers (ISAC & ARIEL) and booster in operation since 2019
  - Replace VXI main frame by NIM crate
  - To upgrade all ISAC-I systems in 2023

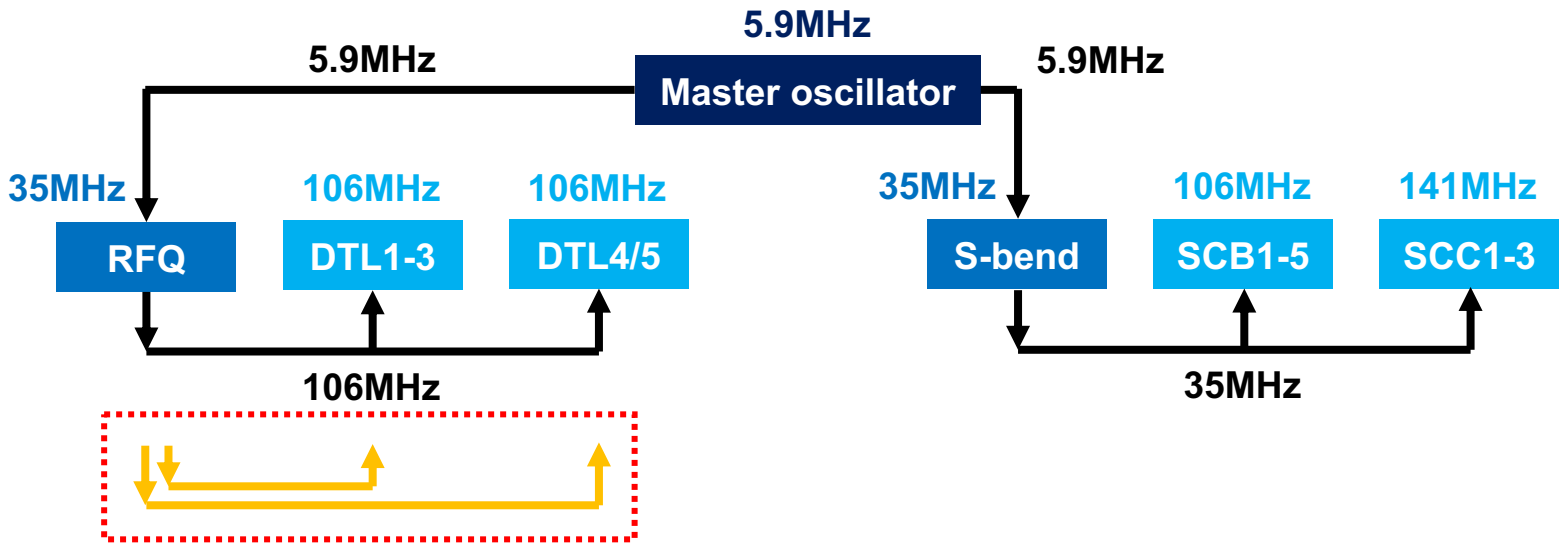




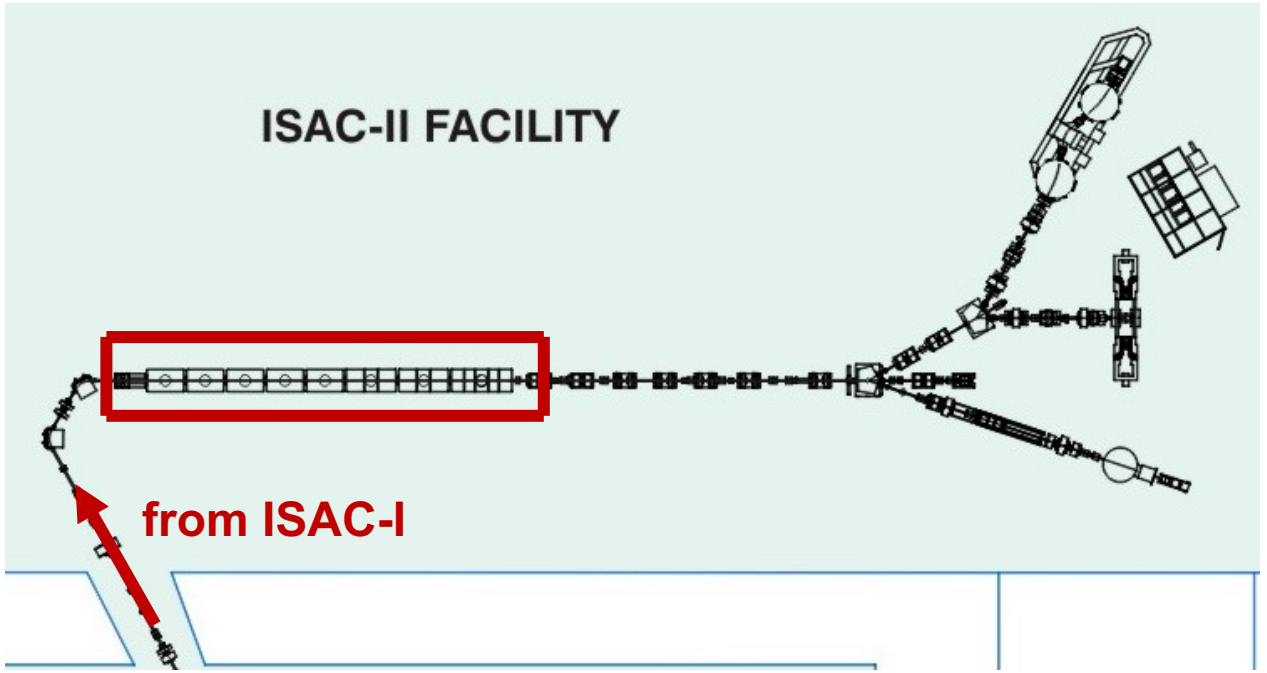
Digital LLRF board

RF Challenge (3)

- Operation issue
  - Observed DTL transmission change between day and night
  - Require few degrees phase adjustment on DTL, and variate between tanks
- Solution
  - Systematic phase measurements on RF reference signal
  - 106MHz signal path changed between RFQ and DTL
  - RF-58 & RG214 cables replaced by Andrew FSJ1-50A cables for less sensitivity to ambient temperature
  - Noises in 35MHz frequency multiplier found during phase measurements and board replaced
  - Modifications completed in 2022



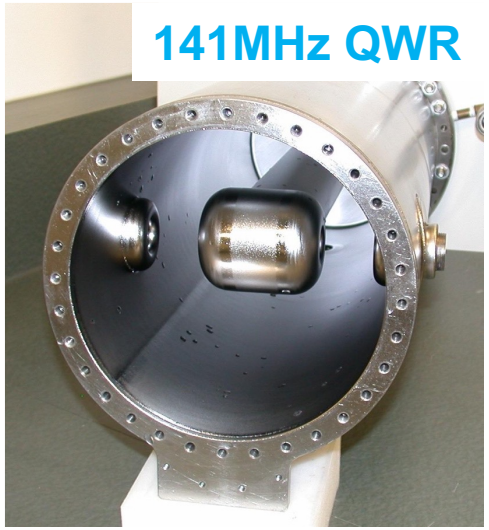
ISAC-II Linac



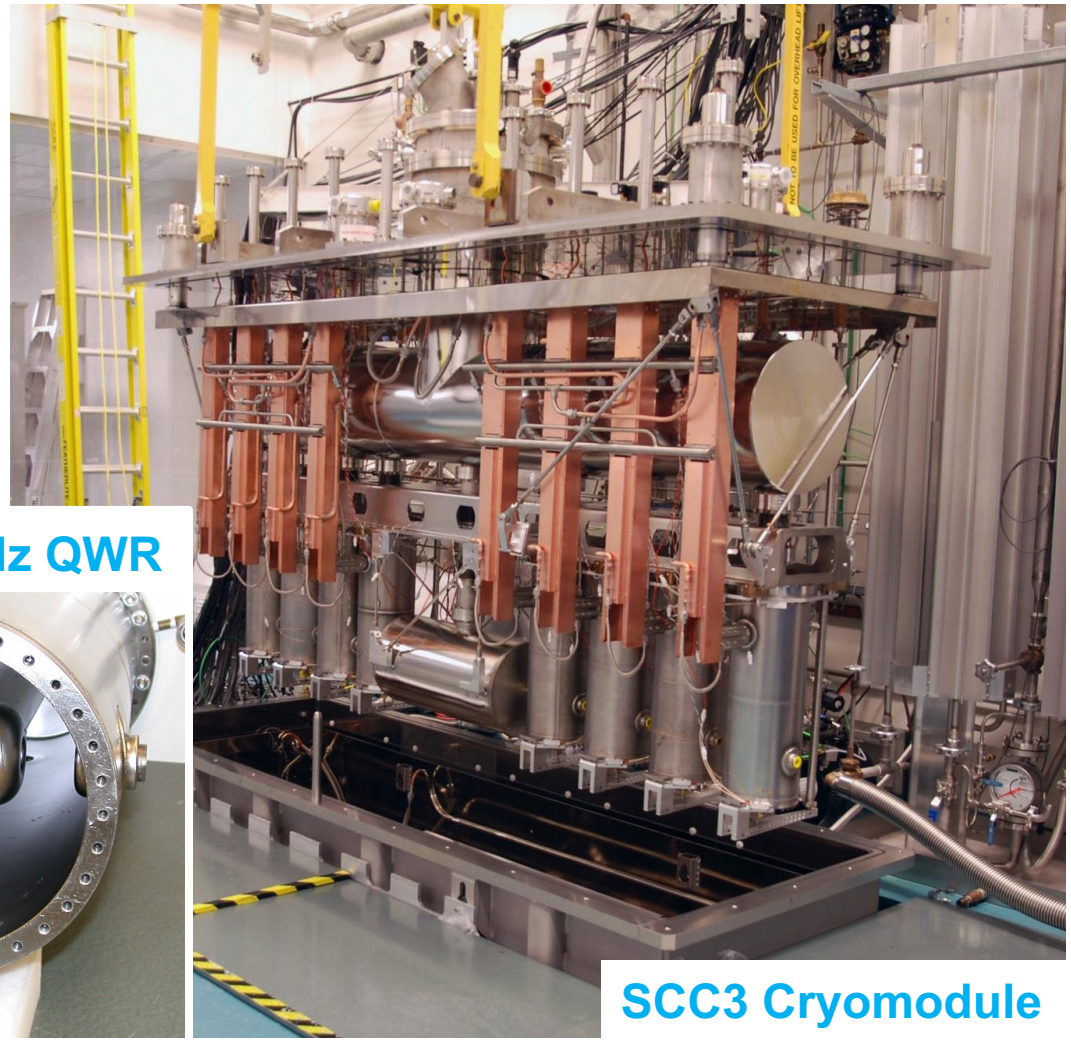
- 40MV superconducting linear accelerator
- Accelerate to 6.5–16MeV/u for 2≤A/q≤6 RIBs
- In operation since 2006

ISAC-II Cryomodules

- 40 quarter-wave resonators (QWR)
  - Phase-I (SCB) 106MHz & β 5.7%, 7.1%
  - Phase-II (SCC) 141MHz & β 11%
  - Operating @ 6MV/m gradient & 7W cavity dissipation w/ 200W RF drive
- One 9T SC solenoid per CM
- Operating temperature @ 4K
- Top load CM design
- Single vacuum system
- 80K thermal shield
- Warm μ-metal shield
- Nb jacket as cold magnetic shield



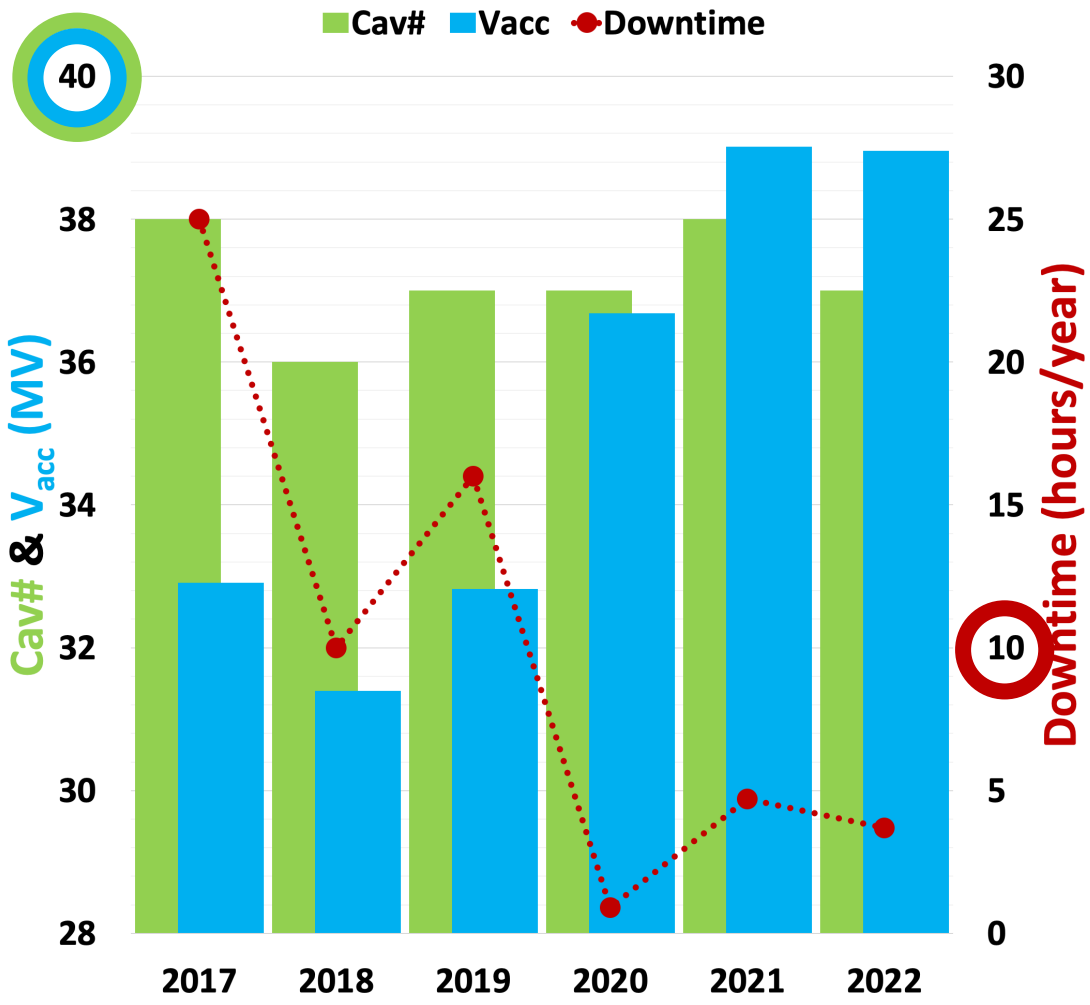
141MHz QWR



SCC3 Cryomodule

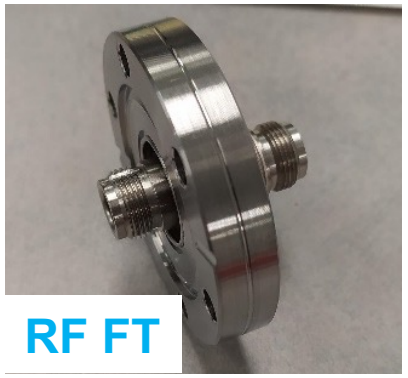
ISAC-II Performance

- Past 5 years performance
  - ~37/40 cavities available for operation
  - Total accelerating voltage increased gradually to 39MV
  - RF downtime reduced below 10 hours/year since 2020
- Goal is to provide 40 cavities and >40MV for operation while maintaining low RF downtime
  - Lessons learned from MRO
  - Improve system reliability
  - Optimize RF procedures



Cavity Ancillaries Upgrades

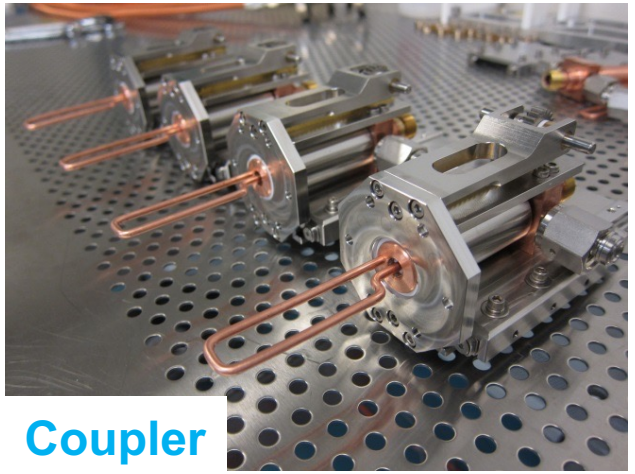
- Reduce opportunity of cavity failures and maintain cavity availability for operation
  - Internal RF drive cable
    - Replace Heliax super flexible cable by hermetic rigid cable
  - RF feedthrough
    - Upgrade to higher rated power option
  - RF coupler
    - Upgrade for better mechanical alignment and reliability
  - Frequency tuner
    - Improved reliability of the mechanical links to tuning plate



RF FT

RF cable

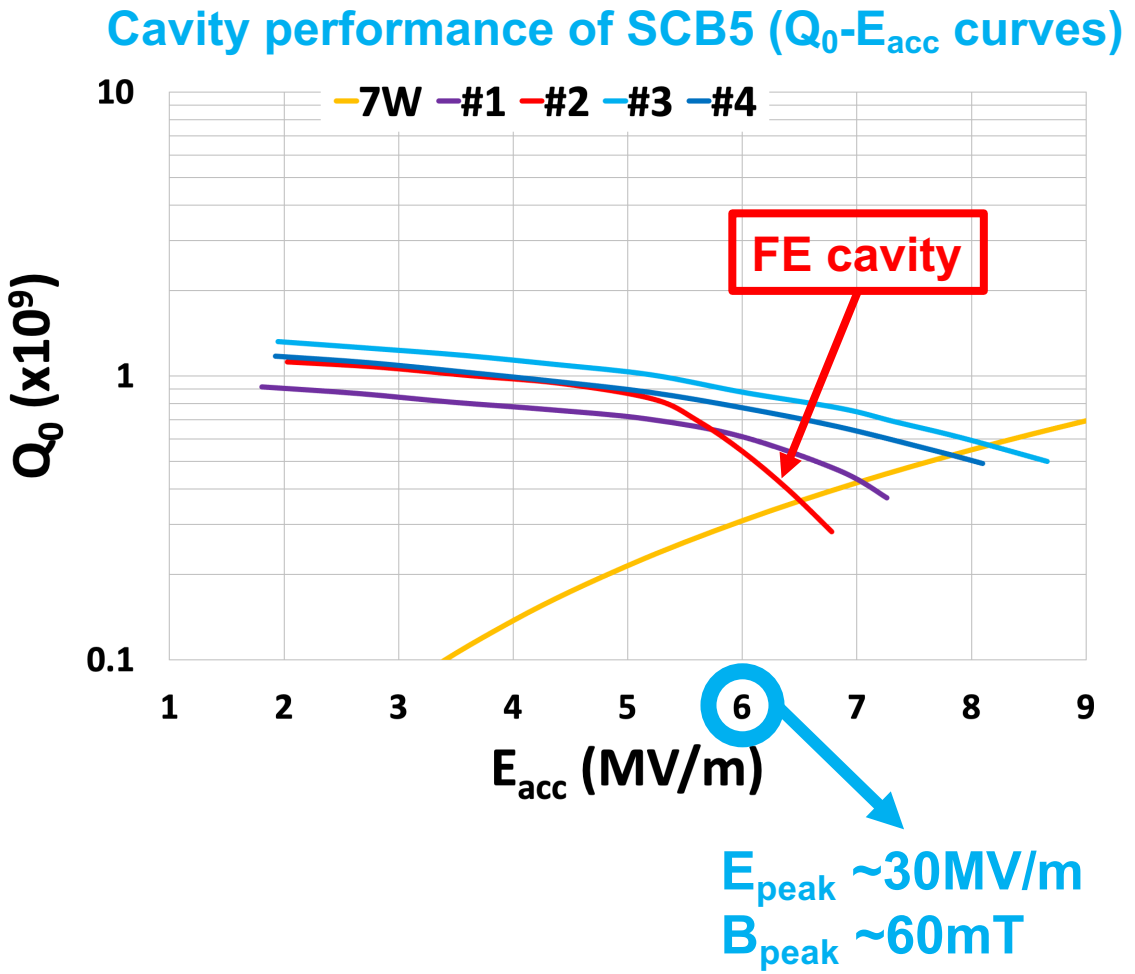
Tuner plate



Coupler

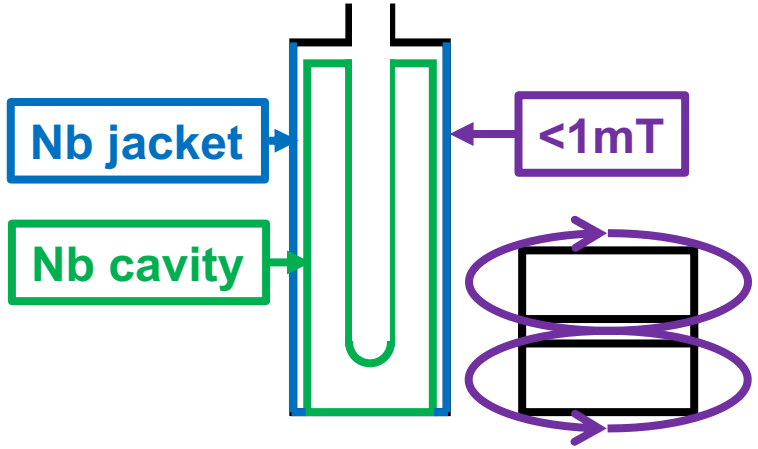
Cavity Challenge

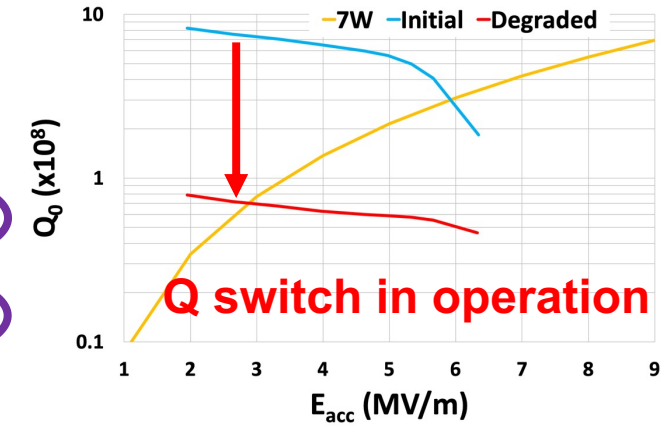
- Issue – field emission (FE)
  - Caused by particulates on RF surface with high e-field
  - Reduce cavity performance
  - Increase RF instability
  - Cause cavity trips and operation downtime
  - Severe cavity degradation (next slide)
- Mitigation solution
  - Optimize operating setpoints
    - Run FE cavities below FE onset
    - Push FE free cavities to compensate total voltage
  - Monitor cavity performance and apply RF conditioning as required

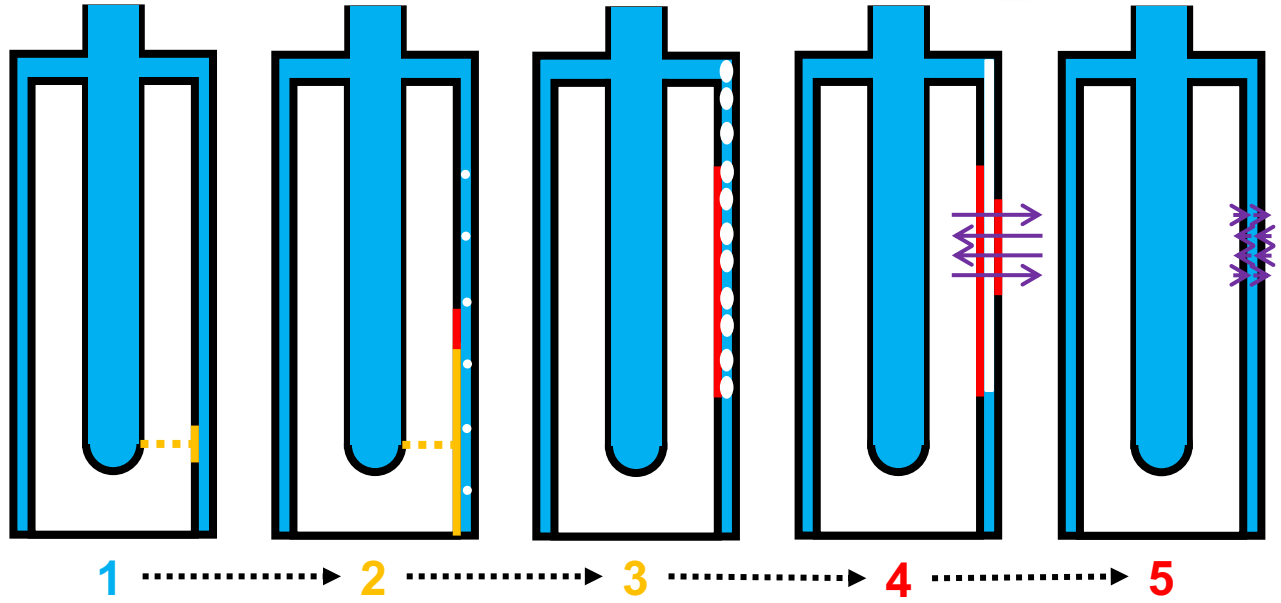


Cavity Challenge (2)

- Issue – magnetic poisoning from solenoid fringe field
  - A ‘hole’ opened in the Meissner shield and flux trapped in FE cavities cause severe Q degradations
- Recovery procedure
  - 15K cavity thermal cycle in zero magnetic background (~4hours)
- Avoidance solution
  - Run cavity below FE onset
  - Quench detection & interlock





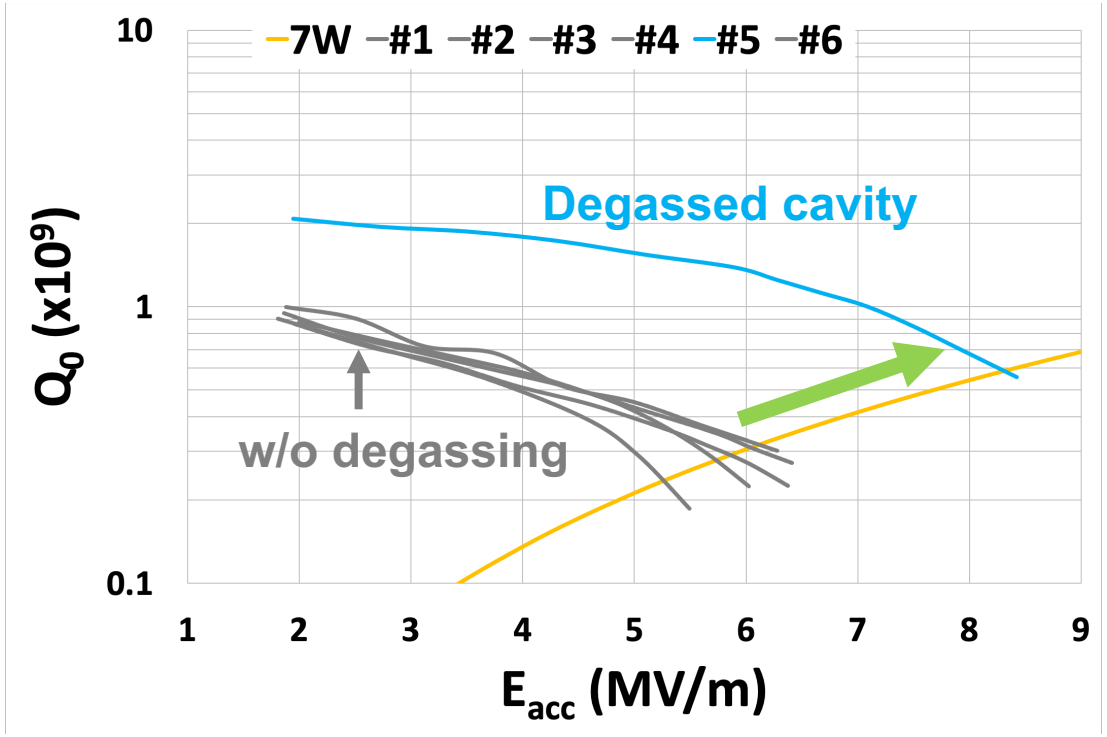


Cavity Challenge (3)

- Issue – higher hydrogen content in SCC cavities
  - Show stronger Q-slope in the medium field regime and limited cavity operating gradient at 7W
  - Back trace to cavities manufacture
  - SCB tolerated up to 10 hours in 50-150K, while SCC degraded in Q after 1 hour soaking
- Solution – employ UHV furnace for hydrogen degassing
  - Potential ~30% improvement on SCC based on test date
  - Should also improve SCB performance

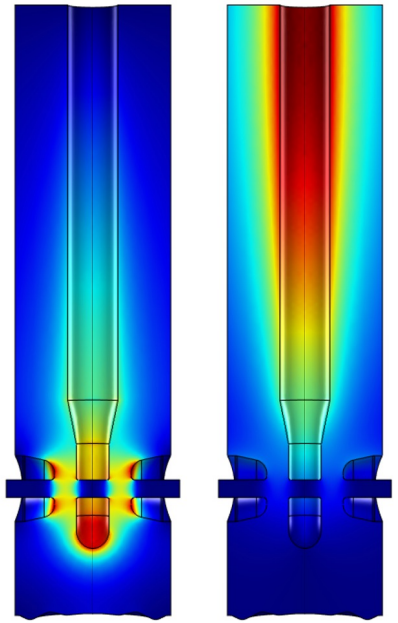
Average operating gradient in 2022

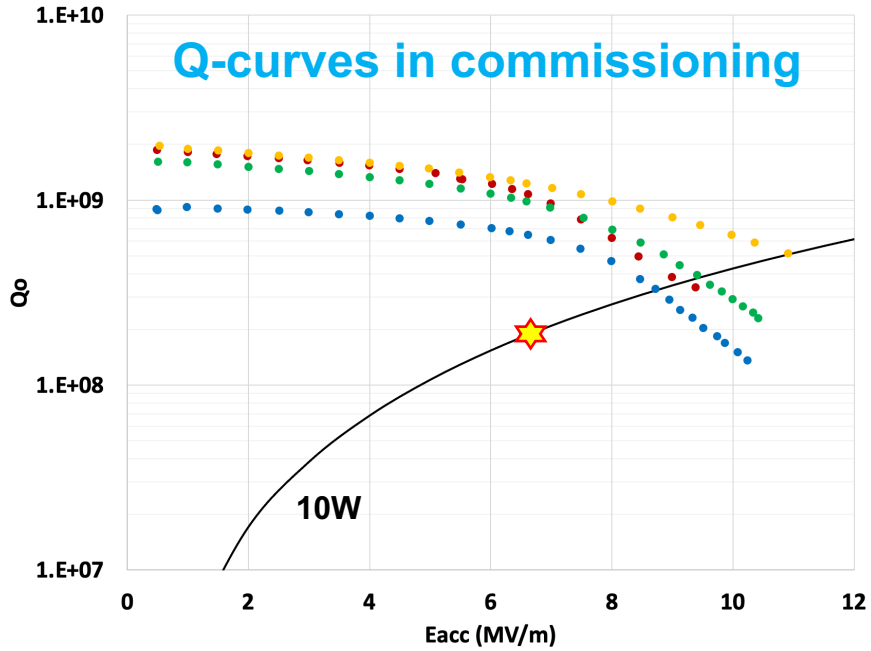
SCB 6.3MV/m v.s. SCC 5.4MV/m



Cryomodule Development – VECC CM

- ISAC-II style cryomodule w/ separated vacuum design
- New design of cavity (RF & vacuum), coupler, frequency tuner, bottom assembly, WCT/ICT and internal/external fixtures for shipping
- Cryogenic and RF commissioned in 2022
- Solidify expertise for future upgrades in ISAC





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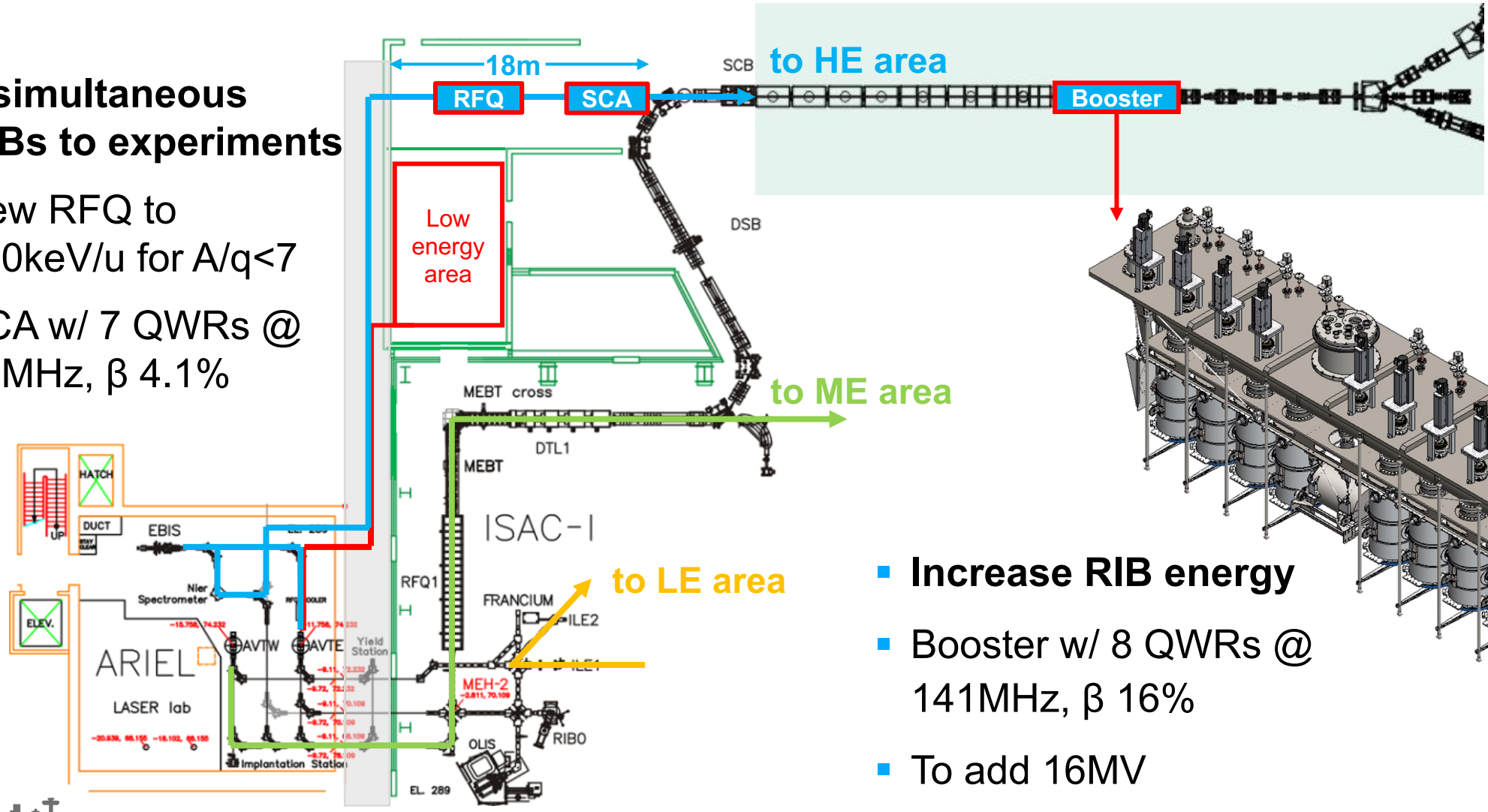
Future of ISAC Facility

- **3 simultaneous RIBs to experiments**
- New RFQ to 400keV/u for A/q<7
- SCA w/ 7 QWRs @ 71MHz, β 4.1%



- **Increase RIB energy**
- Booster w/ 8 QWRs @ 141MHz, β 16%
- To add 16MV

Summary

- ISAC Linac has been accelerating RIBs for experiments since 2000.
- RF systems have met operation challenges, such as aged critical components and obsolete equipment.
- On-going refurbishment programs were based on systematic analysis and lessons-learned from 2 decades of operation.
- The system's availability, reliability and capability have been improved by attacking the most vulnerable parts in the RF chain.
- Development programs and collaborations enhance and augment TRIUMF expertise in Linac technologies for the future.

ISAC RF/SRF Team

- Z. Ang, T. Au, K. Fong, X. Fu, J.J. Keir, P. Kolb, D. Lang, R.E. Laxdal, R. Leewe, Y. Ma, B. Matheson, R.S. Sekhon, B.S. Waraich, Z. Yao, Q. Zheng, V. Zvyagintsev

Thank you
Merci

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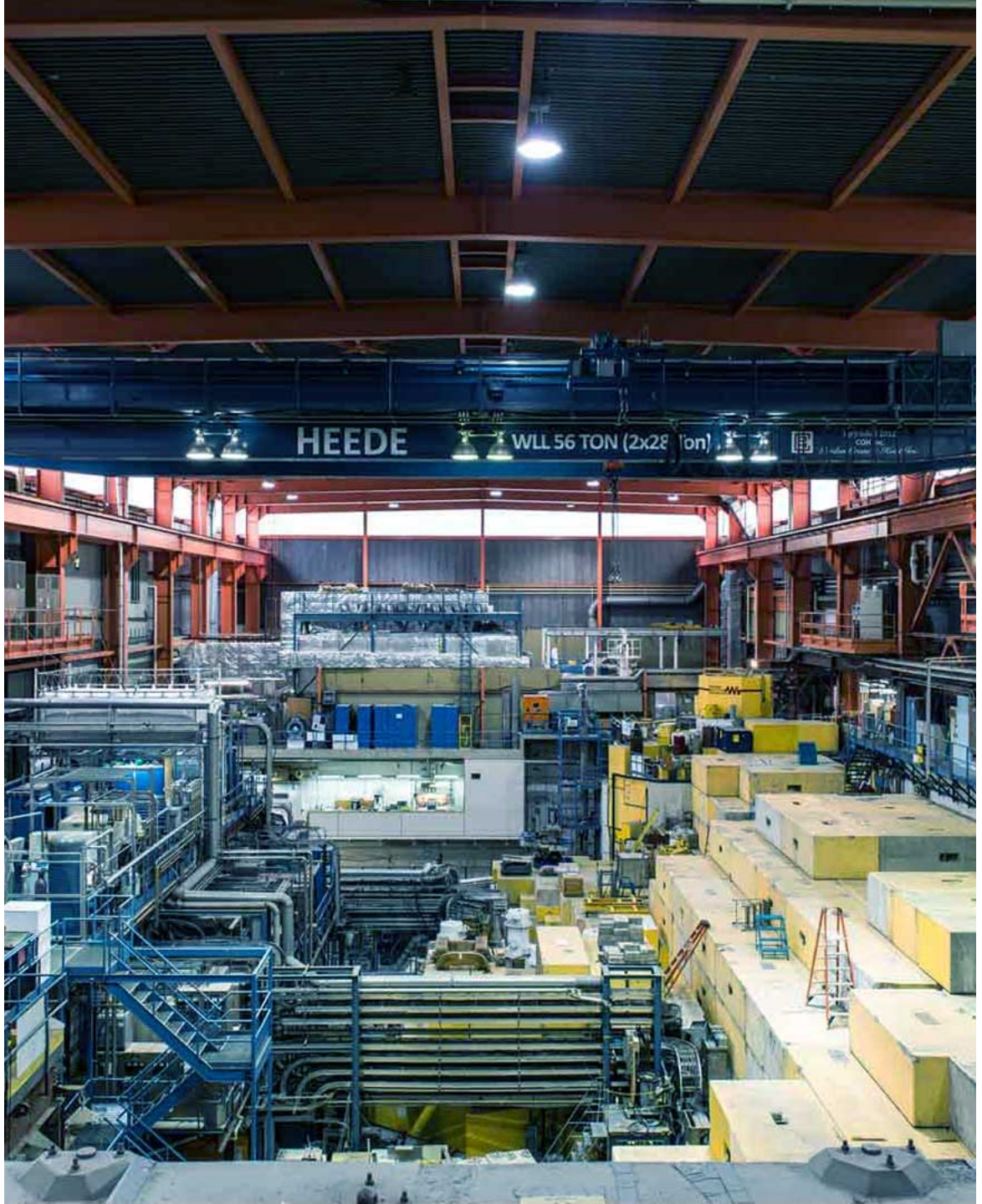

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