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Proton Power Upgrade Project Progress and Plans at the Spallation Neutron Source

J. Mammosser

Research Accelerator Division

Oak Ridge National Laboratory

ORNL is managed by UT-Battelle LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

Scope of the PPU Project

- Increase the beam power capability from 1.4 MW to 2.8 MW
  - This would allow for 2 MW for the First Target Station (FTS)and the remainder for a second target station (STS) in the future
- To achieve this
  - Increase linac energy from 1.0 GeV to 1.3 GeV (7 New HB Cryomodules and RF systems)
  - Increase the beam current from 25 mA to 38 mA (macro pulse avg)
  - Upgrade the ring injection are and extraction kicker power supplies
  - 2 MW Target and related supporting systems

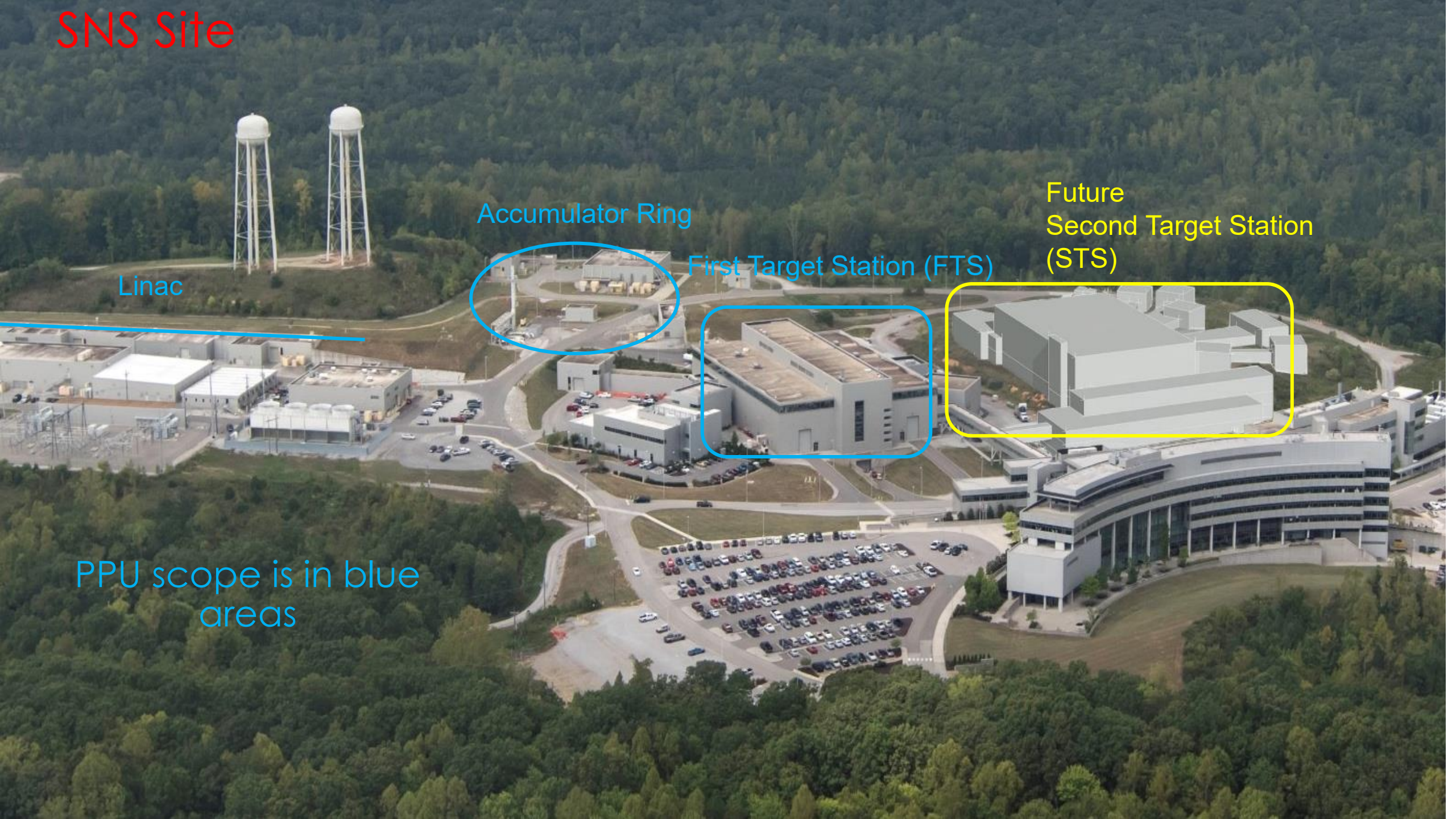
The PPU Success is Based On

- **Laboratory Partners**
  - Jefferson Lab provided engineering and fabrication 8 PPU cryomodules
  - FNAL provided engineering and fabrication of the injection magnets

- **Technical Component Vendors**
  - Which out their efforts to go beyond the normal vendor requirement during COVID period the progress on PPU would have been less

Much Thanks to Our Partner Labs and Vendors!!!

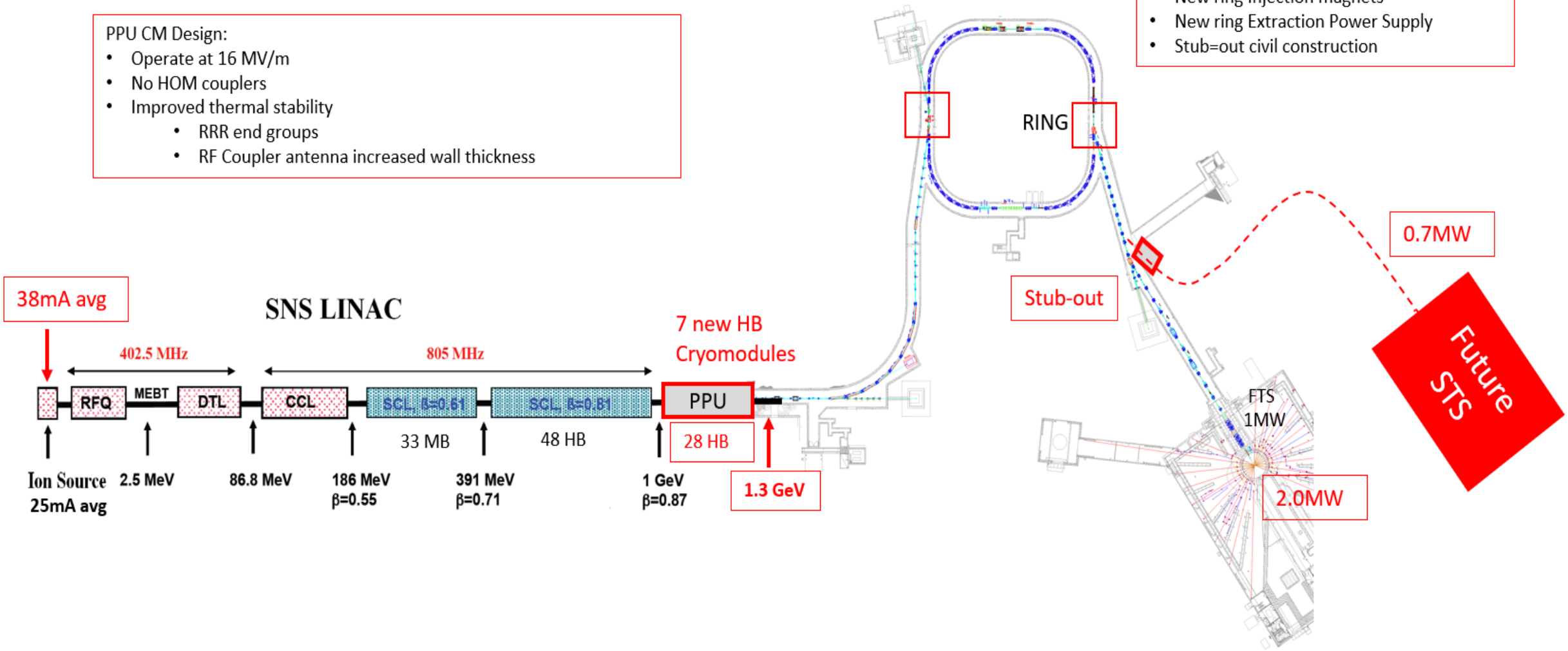
SNS Site


Linac
Accumulator Ring
First Target Station (FTS)
Future
Second Target Station
(STS)
PPU scope is in blue areas

SNS Layout

PPU CM Design:
- Operate at 16 MV/m
- No HOM couplers
- Improved thermal stability
  - RRR end groups
  - RF Coupler antenna increased wall thickness

- New ring Injection magnets
- New ring Extraction Power Supply
- Stub=out civil construction



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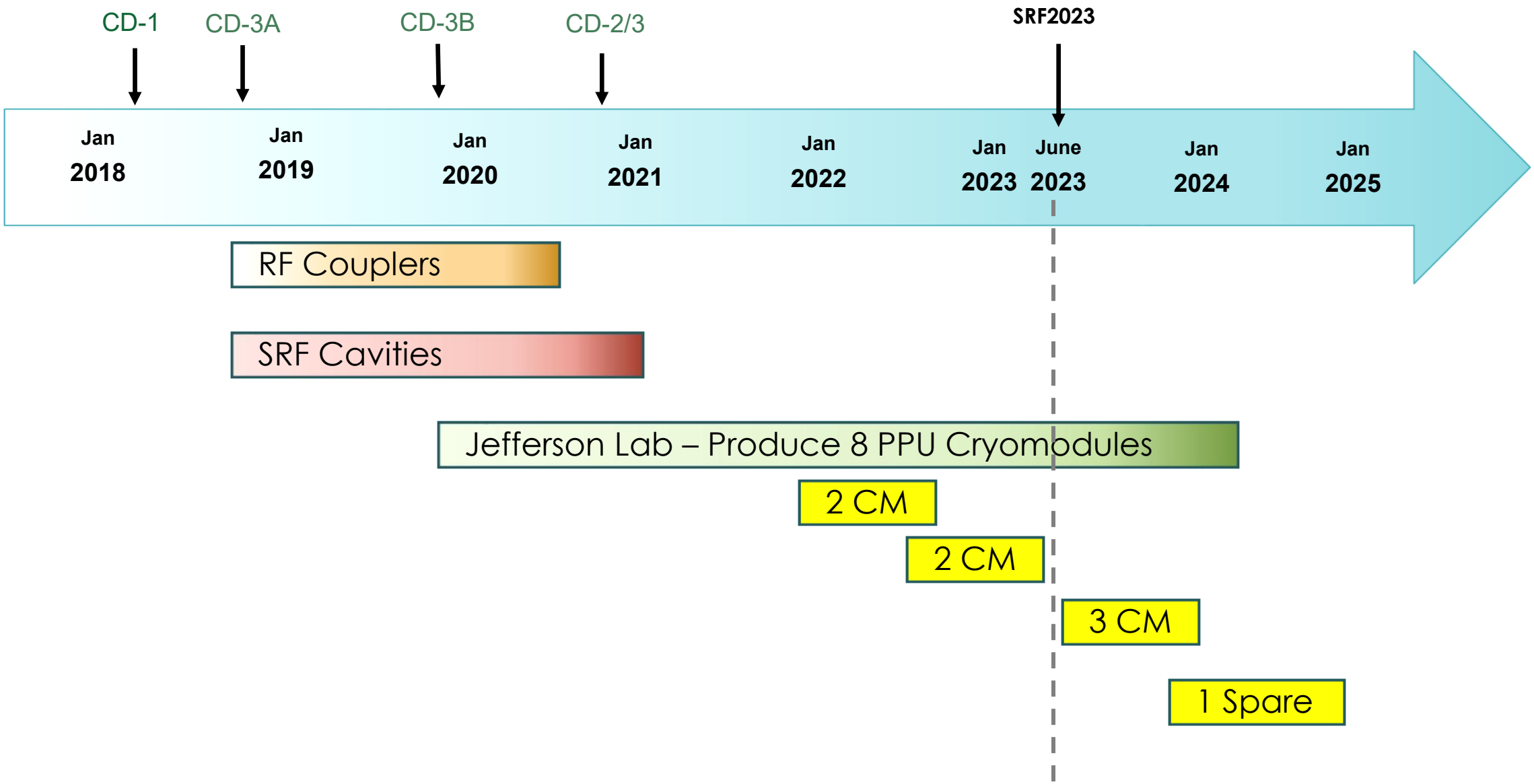
PPU specifications & KPPs

Major Specification	Current operation	PPU full capability	PPU FTS operation
Beam power (MW)	1.4	2.8	2.0
Beam energy (GeV)	1.0	1.3	1.3
Beam current, macro-pulse average (mA)	25	38	27
Macro-pulse length (ms)	1	1	1
Energy per pulse (kJ)	24	47	33
Repetition rate (Hz)	60	60	60

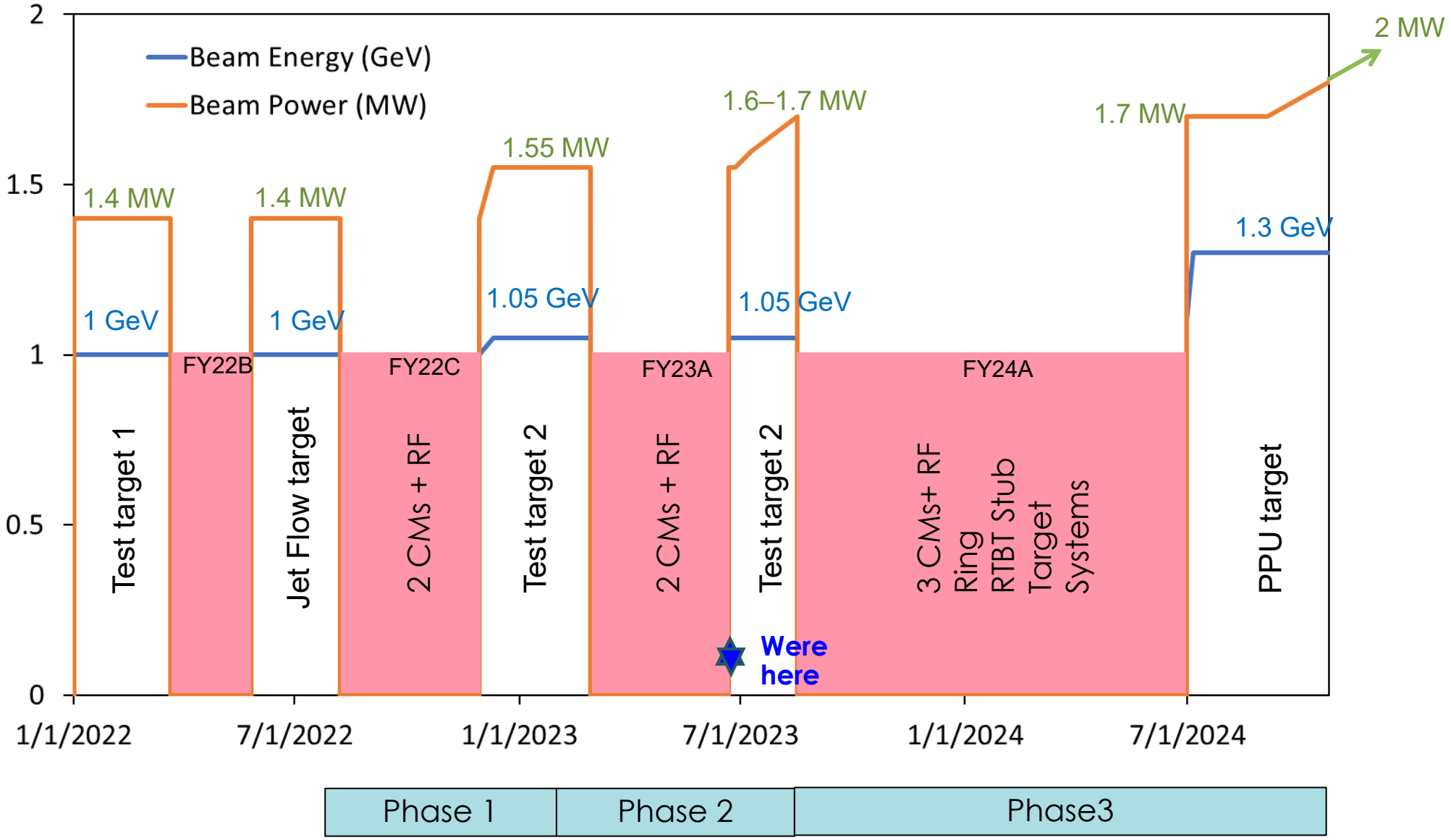
Key Performance Parameter	Threshold	Objective
Beam power on target (MW)	1.7	2.0
Beam energy (GeV)	1.25	1.3
Target operation without failure (hours)	1250 at 1.7 MW	1250 at 2.0 MW
Stored bam intensity in ring (protons per pulse, ppp)	1.60×10^{14} ppp[1]	2.24×10^{14} ppp[2]

[1] corresponds to 1.92 MW at 1.25 GeV and 60 pps
[2] corresponds to 2.80 MW at 1.30 GeV and 60 pps

Project Timeline For SCL



Power Ramp-up Plan



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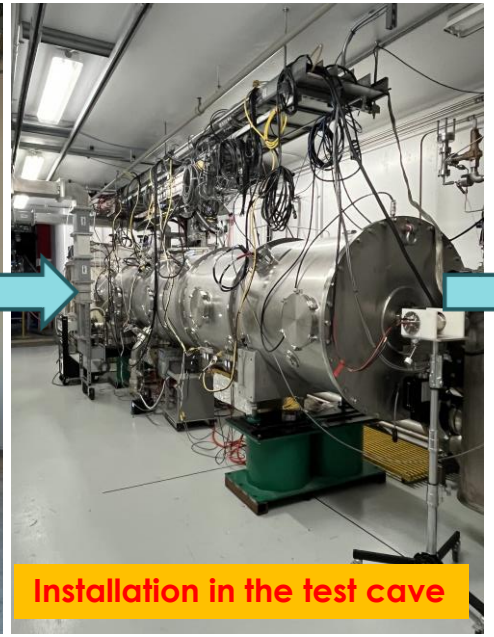
Equipment Installation

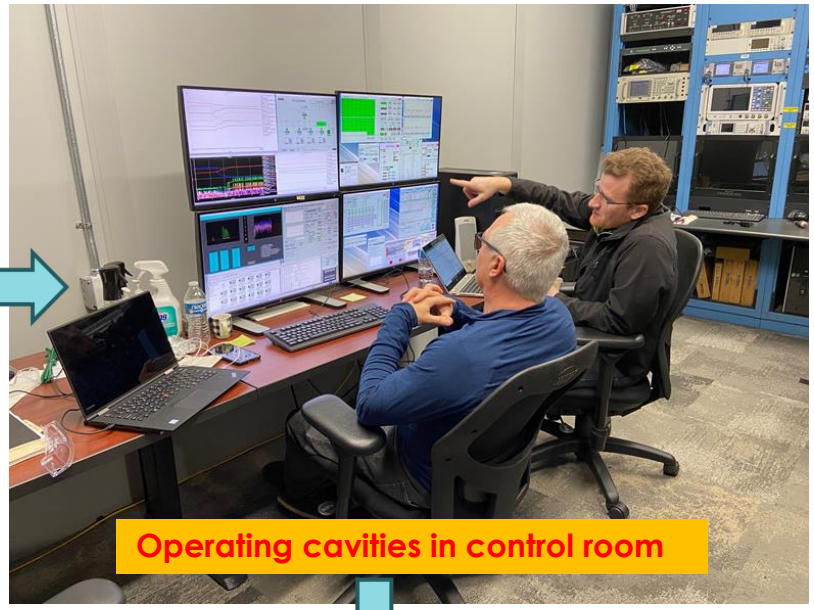
- Installation of equipment for Phase 2 has been completed:
  - Klystrons and modulators
  - PPU cryomodules
  - Instrumentation and controls racks
  - Electrical, water and support systems

Cryomodule receiving testing and installation:

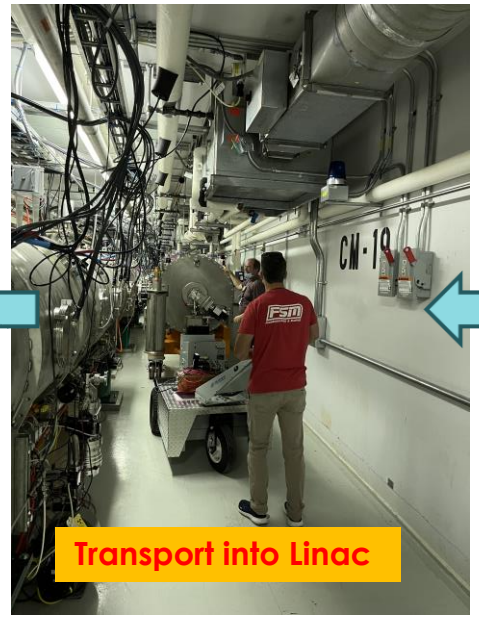

Receiving at RF Test Facility


Transfer onto carts

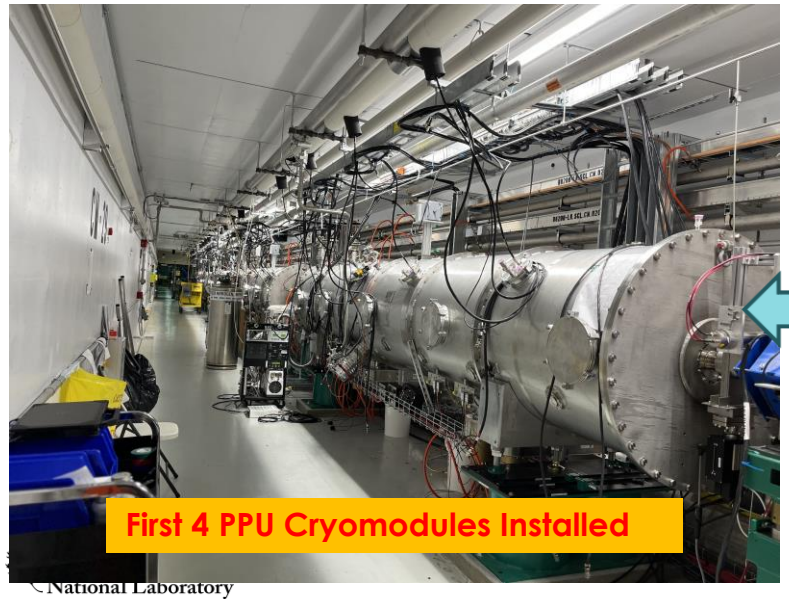

Installation in the test cave


Operating cavities in control room


Storage in front end building



Transport into Linac

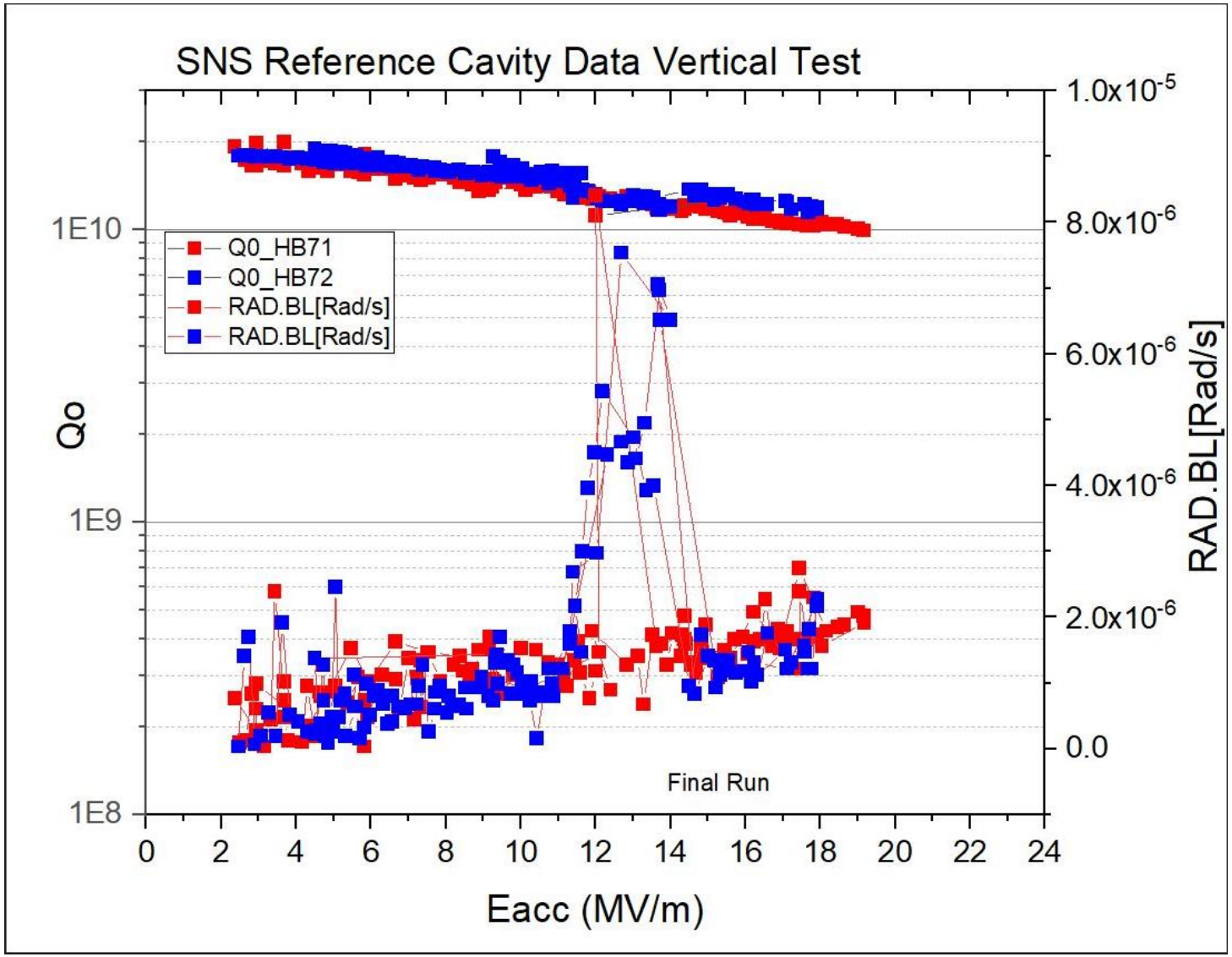

First 4 PPU Cryomodules Installed

Cavity Production at Research Instruments (RI)

- Fabricate, process, assembly and ship 32 PPU cavities
  - RRR end groups
  - No HOM couplers
- SNS provided all shipping boxes and testing hardware
- 3 Reference cavities (spares) were used develop and verify processes
  - Jefferson Lab developed electropolishing methodology and processed and qualified cavities
  - Reference cavities were shipped to RI
    - 1 was used for EP process development and the remaining two the processing and assembly cycle

Reference Cavity Tests

- Cavities were shipped to SNS and Vertical tested as received
  - Both were leak tight as received
  - Both were field emission free to administrative limit 18MV/m

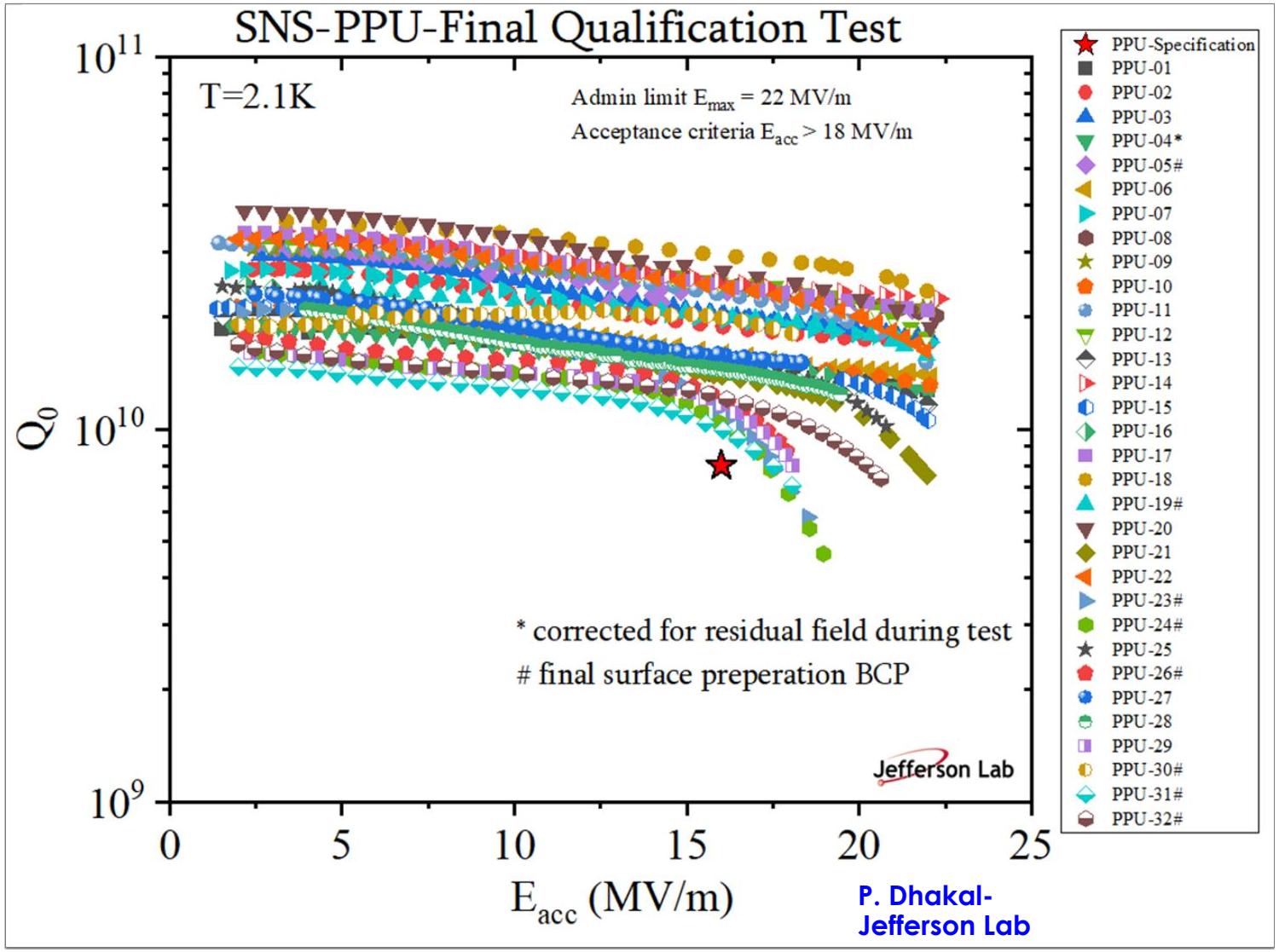


Cavity Production at RI

- Due to the small production number for cavities and the feed back time from testing, once production started there were only a few opportunities to change the process cycle
- The cavity final process steps were; 30µm EP, moved to cleanroom, water drained, solvent rinse, HPR and first assembly, final HPR and final assembly
  - Changes we did make to the process cycle
    - Starting at PPU03 –during the first assembly we omitted the Burst Disk,
    - Starting at PPU08 - FPC probe was omitted on final HPR
    - Starting at PPU11 – we added ultrasonic cleaning after final EP
  - Reasons for change
    - The burst disk and FPC feedthrough were collecting HPR water
    - The Ultrasonic step was added to attempt to increase success rate of vertical tests

Cavity Performance

- VTA Testing Criteria
  - ≥ 18MV/m gradient
  - ≤ 22MV/m administrative limit
  - <20 mrem/hr @ 16MV/m radiation at top plate
  - **All 32 cavities are in strings**
- 21/32 passed as received
- 11 passed with additional HPRs
- 22/32 reached 22MV/m limit
- 8 required 30µm BCP after Helium Vessel welding



P. Dhakal-
Jefferson Lab

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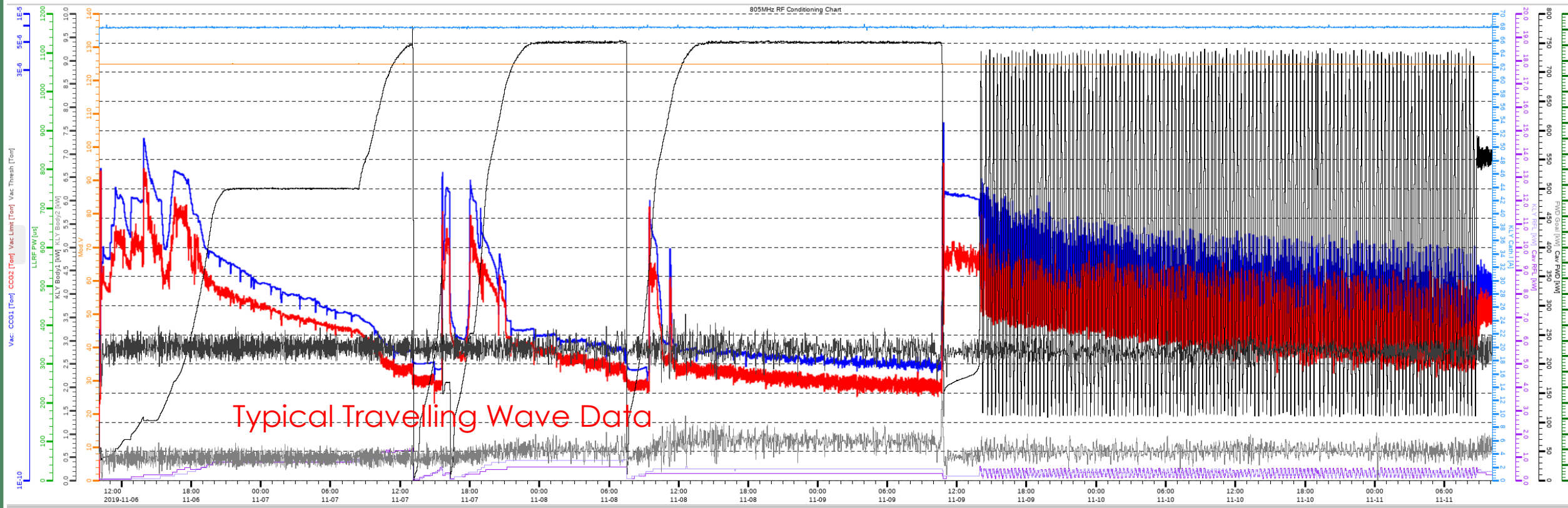
RF Coupler Conditioning

Traveling Wave

- 700kW, 60Hz, 1ms pulse
- Ramp to power and cycle up and down

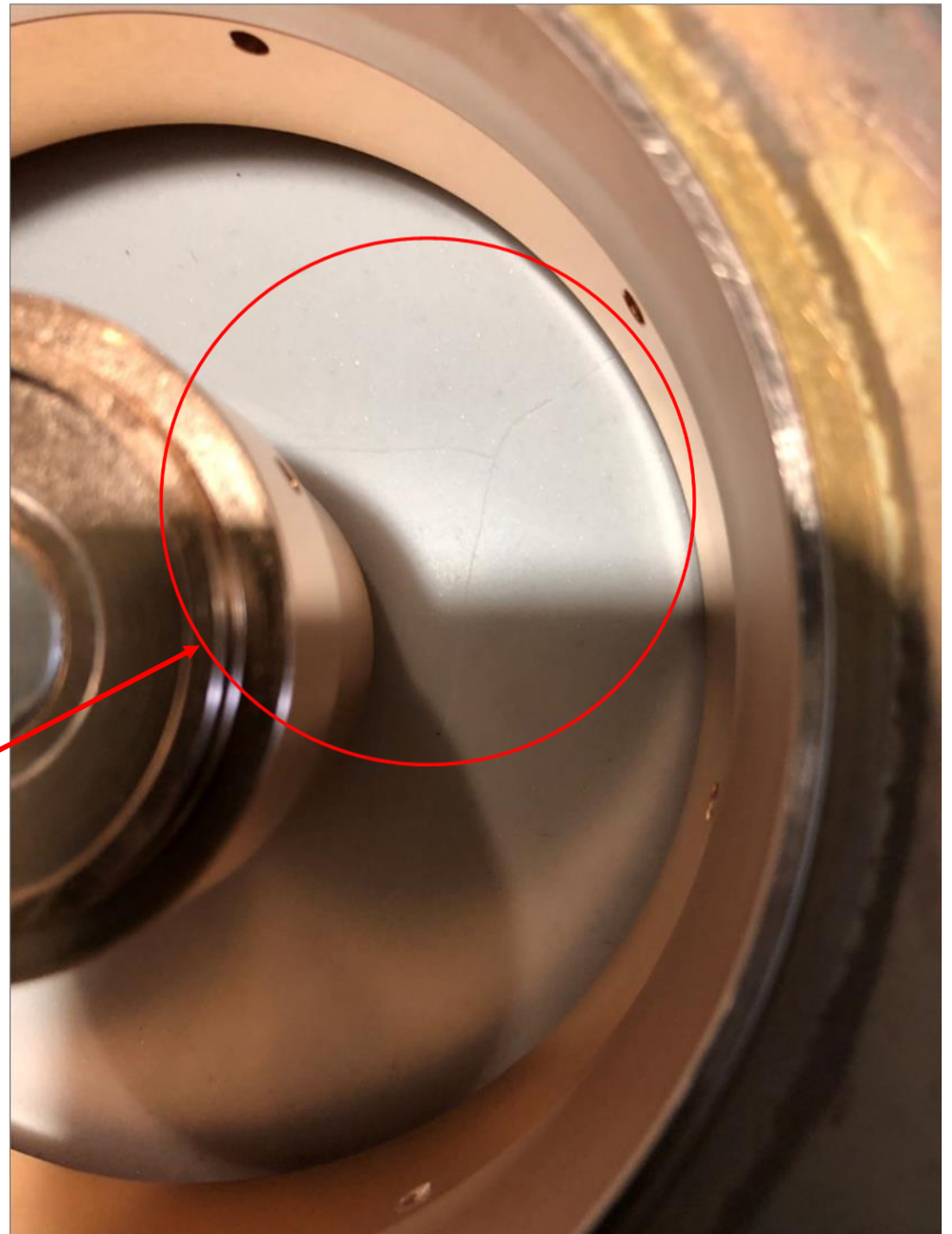
Standing Wave

- 400kW, 60Hz, 1ms pulse (7 different positions with sliding short)



Arc failure

- During testing one ceramic broke by a single arc event during standing wave testing
  - Venting the waveguide, >10-4 range leak
  - We have never seen this type failure in operations
    - 7 windows have failed during operations since 2006, all were leaks under outer conductor choke joint, with 10-7 range leaks



Cryomodule Assembly at JLab

- Production has gone very well
- All cavities were built into strings (no failures)
- Currently 6 cryomodules were shipped to SNS
- The remaining 2 are almost complete

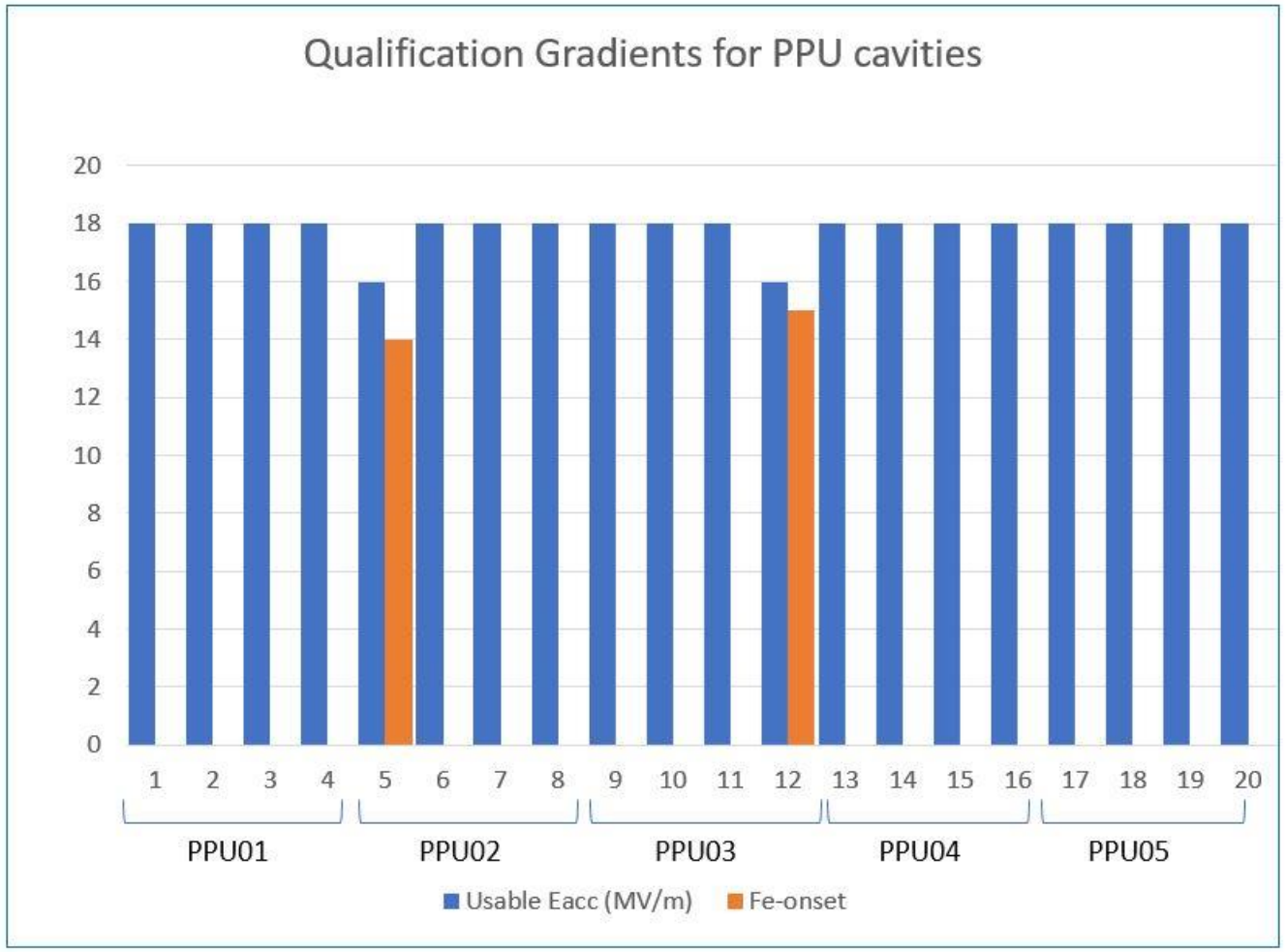

PPU08 3/30/2023


PPU05 Leaving for SNS


PPU07 3/30/2023

Cryomodule Performance

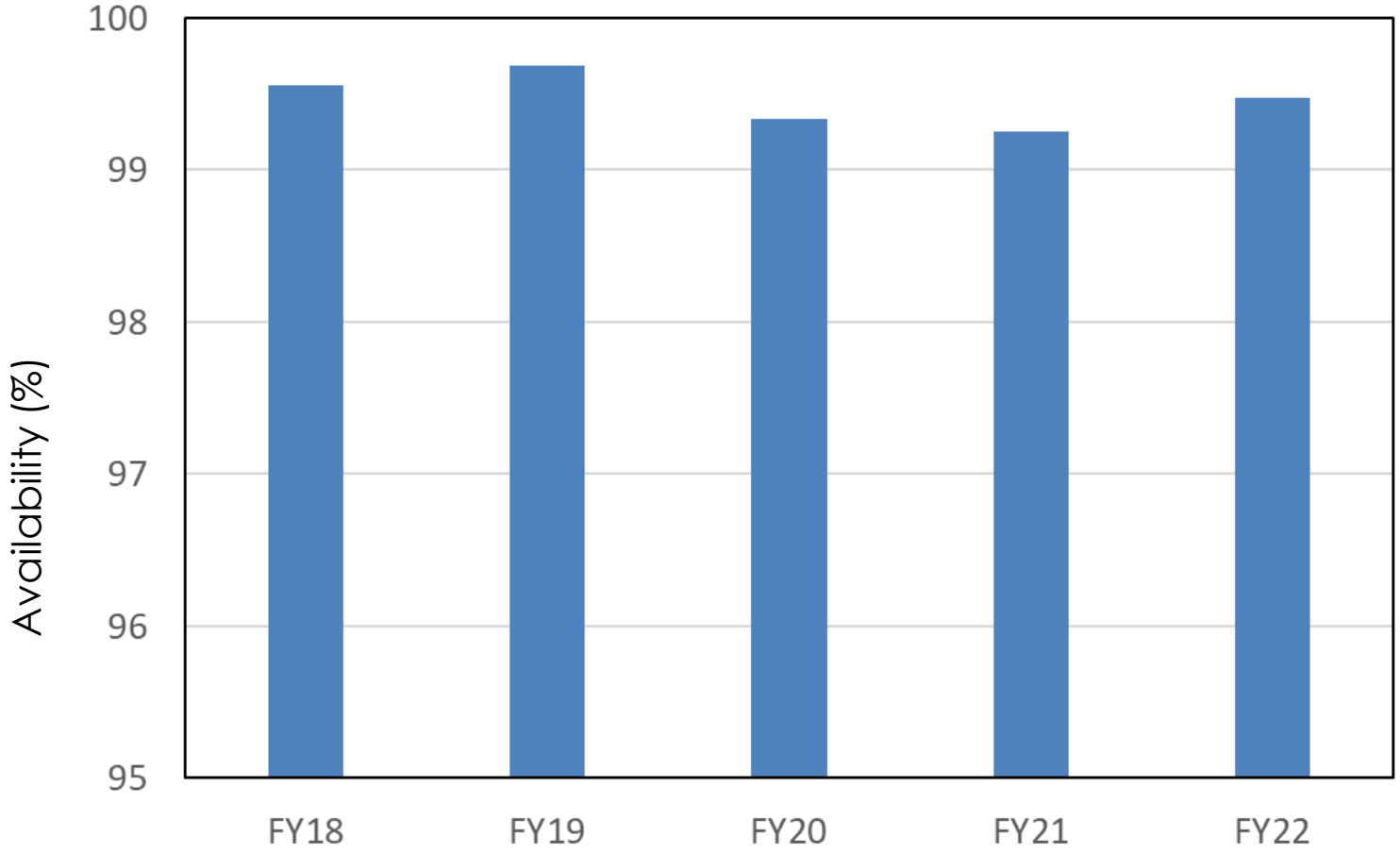
- 5 PPU cryomodule received at SNS, 4 tested, all passed
- All 16 cavities meet operational goals
- First 4 cryomodules are now installed
  - Only 2 of the 16 cavities showed mild field emission
  - All operational at 16MV/m



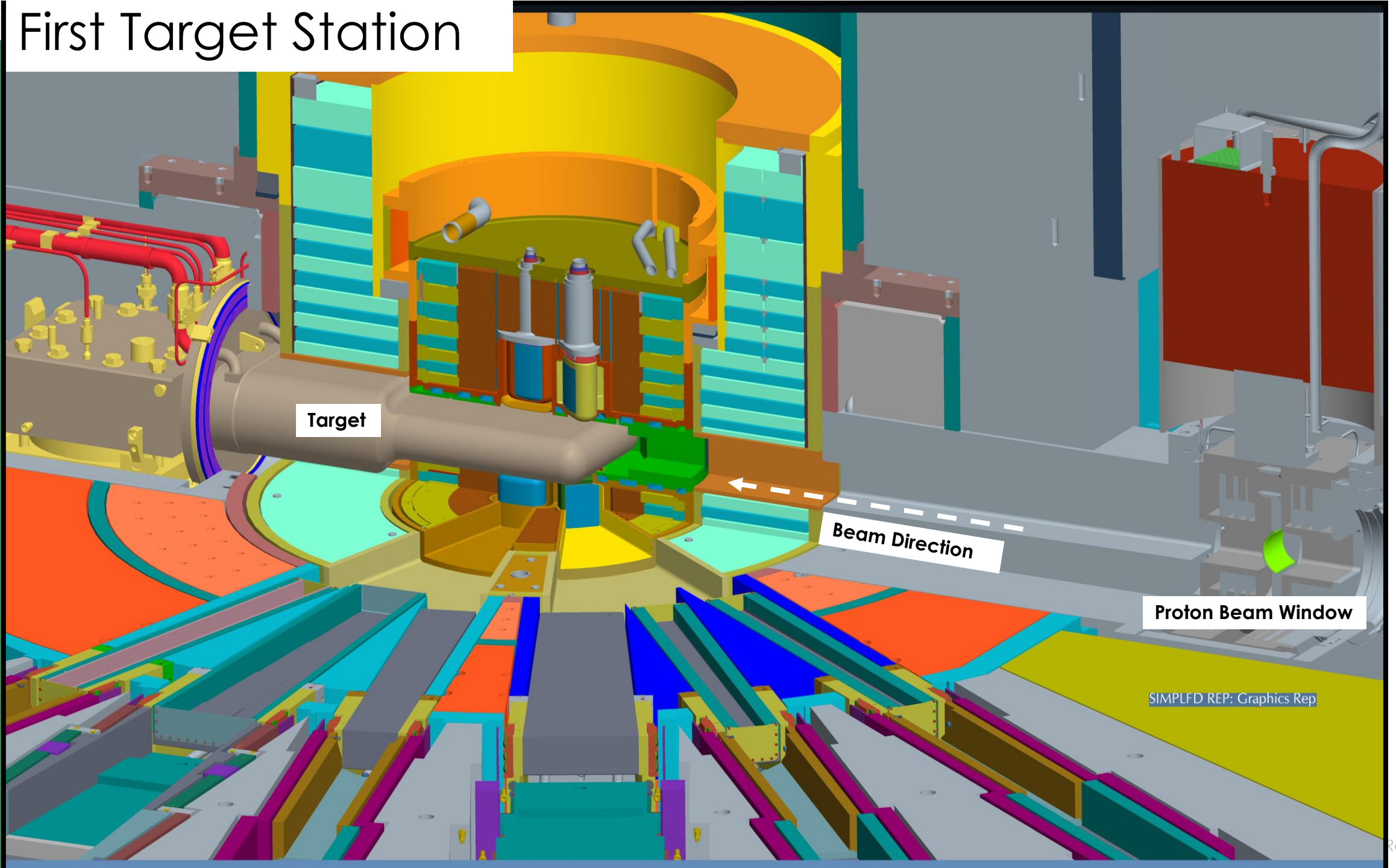
Test cave data for individual cavity tests as received from JLab

SCL Operational statistics has been stable last 15 years

- Providing 1 GeV beam after completion of plasma processing on high beta cryomodules since FY2019

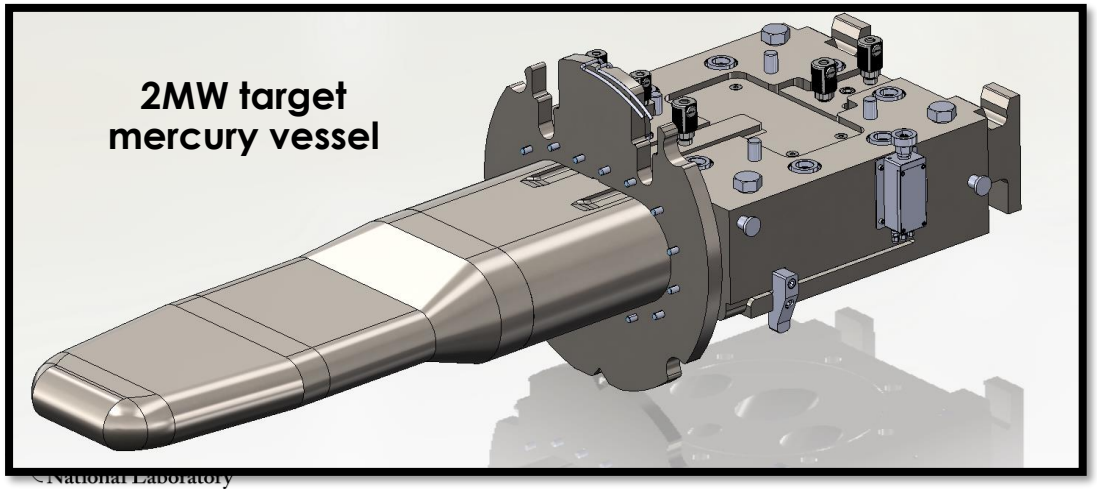


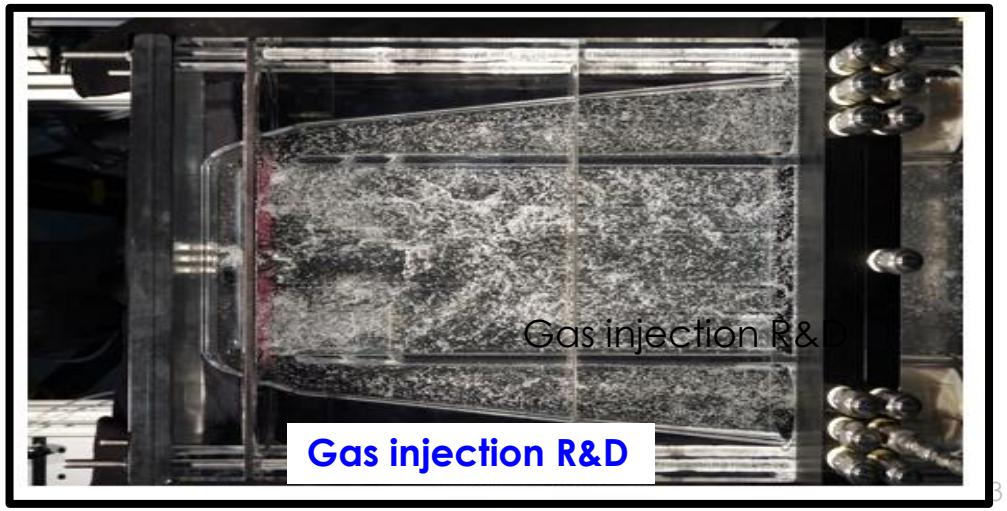
First Target Station



PPU approach for First Target Station

- 2-MW target
  - All available means of leverage are sought (gas injection, years of operational experience, post irradiation exam, strain measurement, fabrication, collaboration, modeling/simulation, etc.)
  - 10 + 10 slpm gas injection capability
- Successful R&D for high-rate gas injection





Target R&D

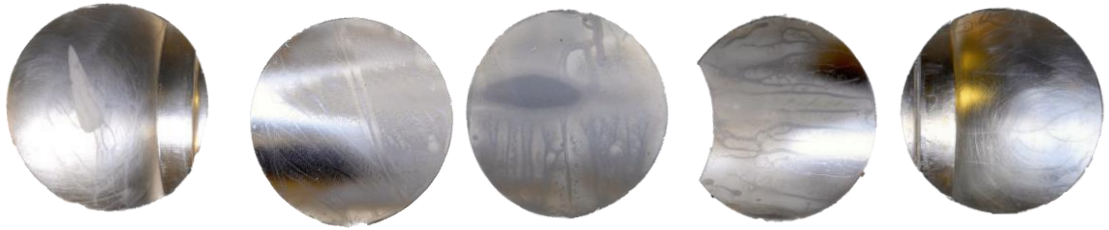
- **Main focus of R&D has been the mitigation of cavitation damage and reduction of fatigue**
  - The inner walls of the target vessel becomes damaged due to the beam interaction with the mercury flow causing cavitation
  - This limits the lifetime of the target

Target 16

- **Jet-flow w/no gas Injection**
- P_{avg} = 968 kW
- E_{total} = 1780 MWh

Target 28

- **Jet-flow w/orifice bubbler**
- Q_{avg} = 1.58 SLPM
- P_{avg} = 1330 kW
- E_{total} = 3186 MWh



Target 29

- **PPU-test target #1 Swirl bubbler**
- Q_{avg} = 3.79 SLPM
- P_{avg} = 1324 kW
- E_{total} = 1931 MWh

Post Irradiation Examination (PIE)

Conclusion

- PPU Project is now 80% complete going extremely well with only one remaining down for installation of equipment and remaining civil construction
- The PPU cryomodules, ring magnets and target system upgrades are underway with good progress
  - **Installed equipment is functioning at design specifications**
- Thanks to our Partner Labs and Industrial Vendors, PPU is on track due to the excellent collaborations