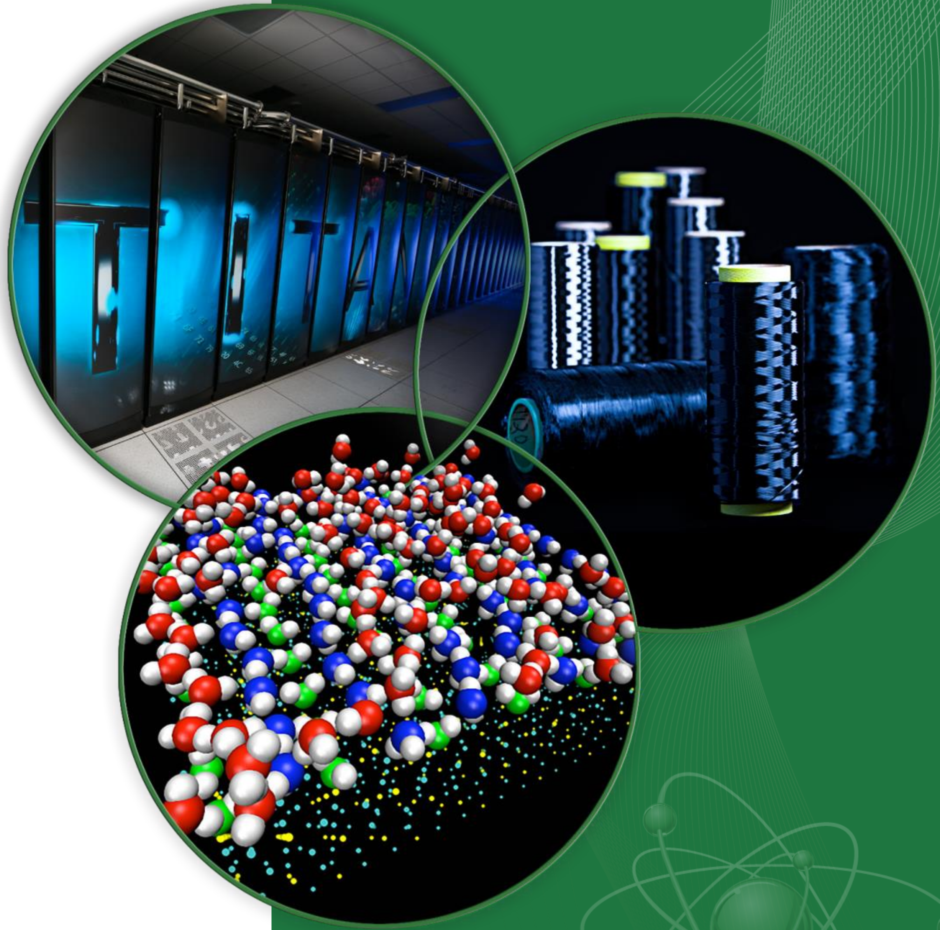
Upgrades to the SNS RF Systems to Support the Second Target Station

Presented to the

Ninth Continuous Wave and High Average Power RF Workshop

Grenoble, France
Thursday, June 23, 2016



Mark E. Middendorf

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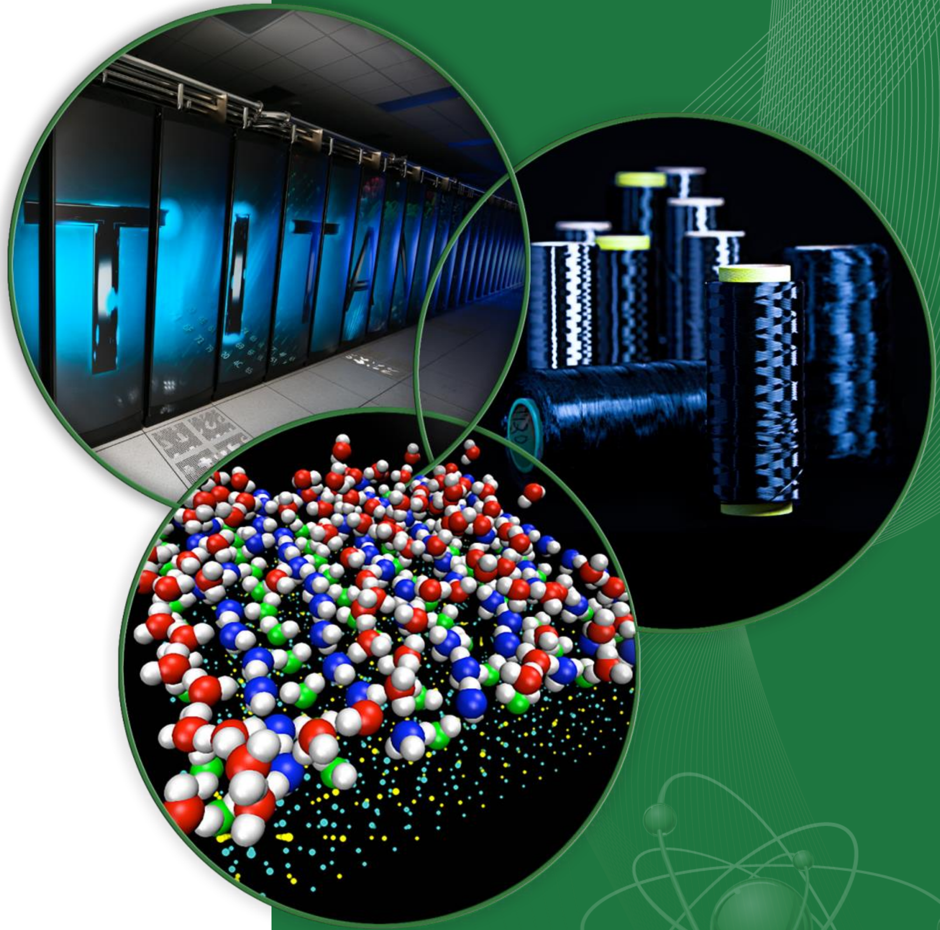

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(a.k.a. “Swims with Sharks”)

Agenda

- Introduction
- Proton Power Upgrade
  - Timeline
  - Parameters
  - Scope
    - Transmitters
    - LLRF
    - HVCM
  - Challenges
  - Schedule
- Summary

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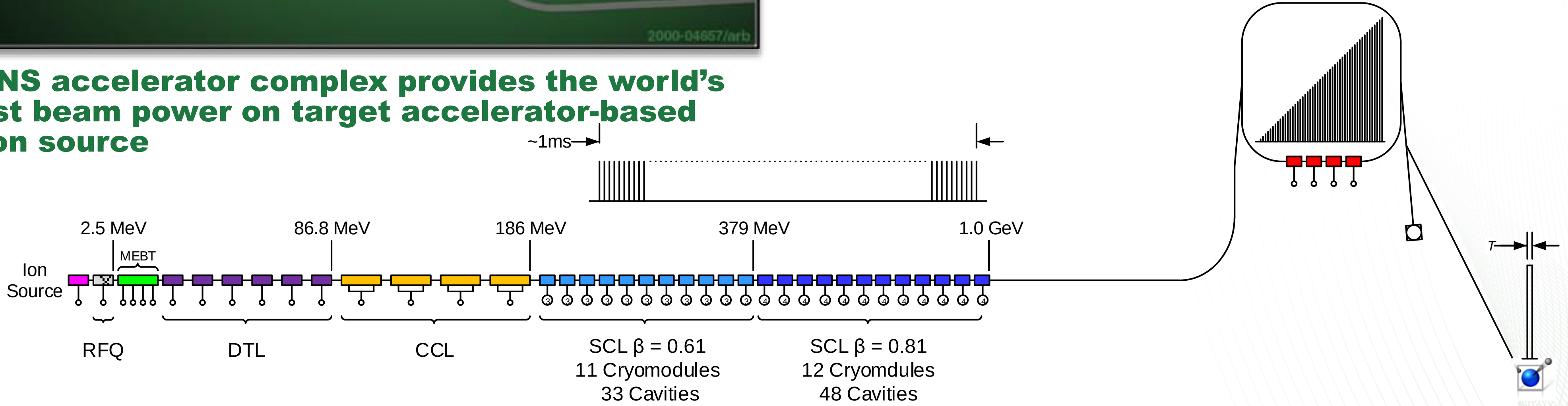
Introduction

	Design	Routine Operation
Kinetic Energy (GeV)	1.0	0.957
Beam Power (MW)	1.4	0.8-1.4
Energy per pulse (kJ)	23	13 - 23
Target Material	Hg	Hg
Repetition Rate (Hz)	60	60
RF Duty Factor (%)	8	7
Linac pulse length (msec)	1.0	0.975
Peak Linac Current (mA)	38	36
Average Linac Chopping Factor)%)	32	22
SRF Cavities	81	79-80

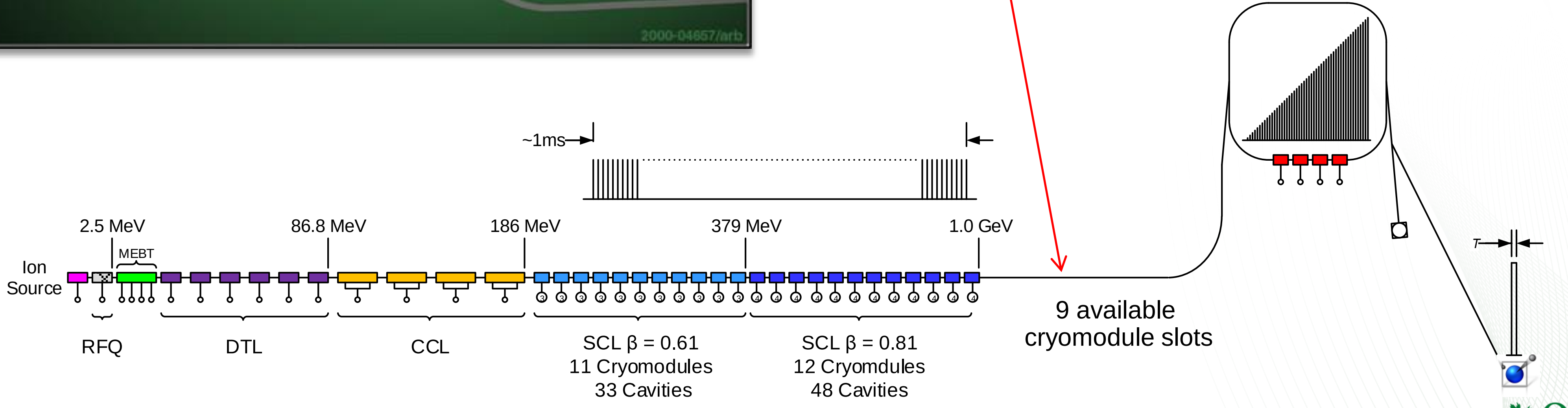
The SNS accelerator complex provides the world's highest beam power on target accelerator-based neutron source



Introduction

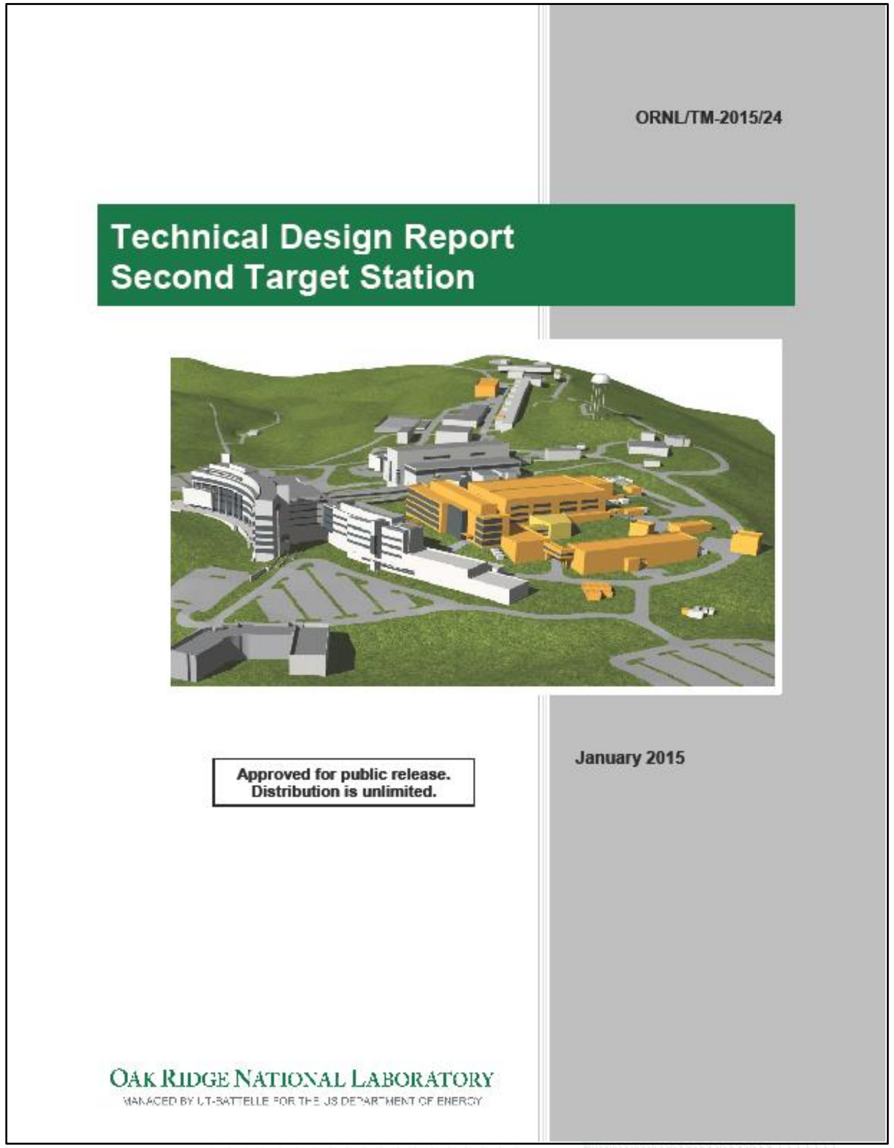
Designed from the outset to accomodate two major upgrades

- **Second target station**
- **Power upgrade**



Proton Power Upgrade - Timeline

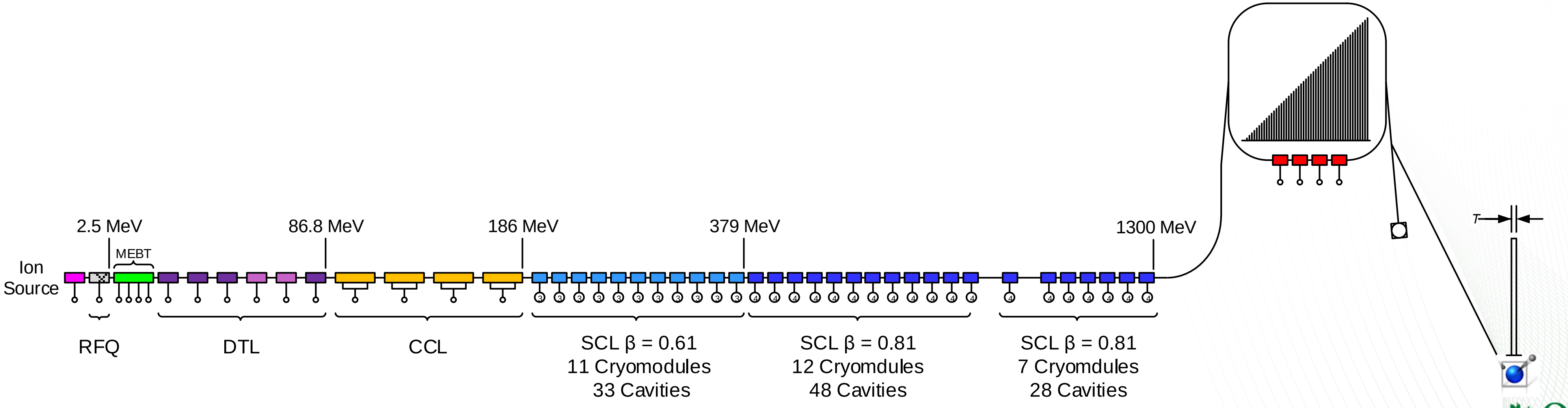
- 2004 CD-0 approved for power upgrade (energy only)
- 2009 CD-0 approved for STS
- 2011 Indefinite postponement
- 2013 Started pre-conceptual design effort for STS (included power upgrade)
- 2015 Published Technical Design Report
- 2016 PPU was split out



Proton Power Upgrade - Parameters

- Upgrades the SNS accelerator to provide 2MW beam power on target
  - Upgrades target to handle 2MW
  - Increases energy and current

	Design	Routine Operation	PPU
Kinetic Energy (GeV)	1.0	0.957	1.3
Beam Power (MW)	1.4	0.8-1.40	2
Energy per pulse (kJ)	23	13 - 23	33
Target Material	Hg	Hg	Hg
Repetition Rate (Hz)	60	60	60
RF Duty Factor (%)	8	7	7
Linac pulse length (msec)	1.0	0.975	0.975
Peak Linac Current (mA)	38	36	46
Average Linac Chopping Factor)%)	32	22	22
SRF Cavities	81	79-80	109



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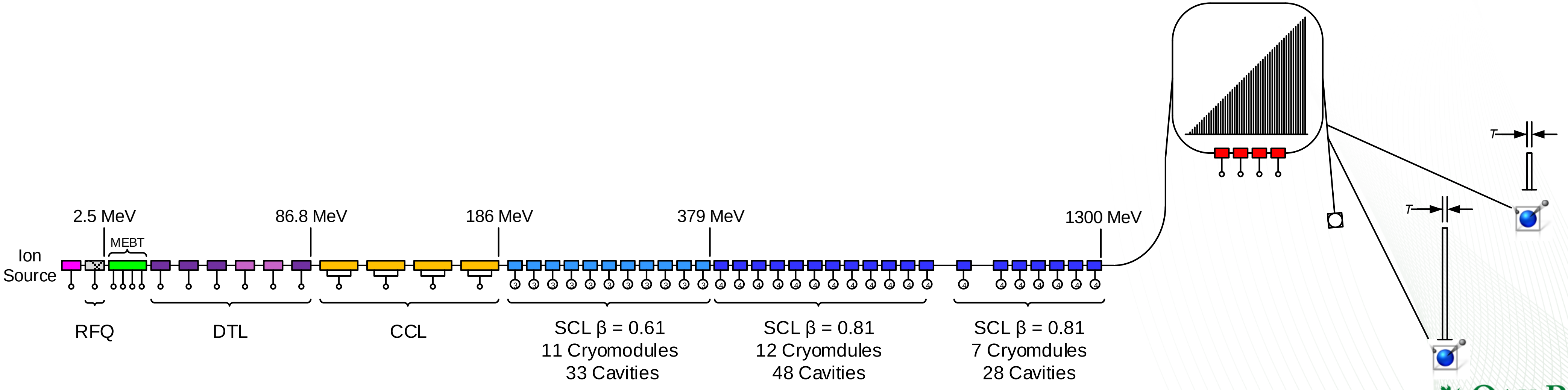
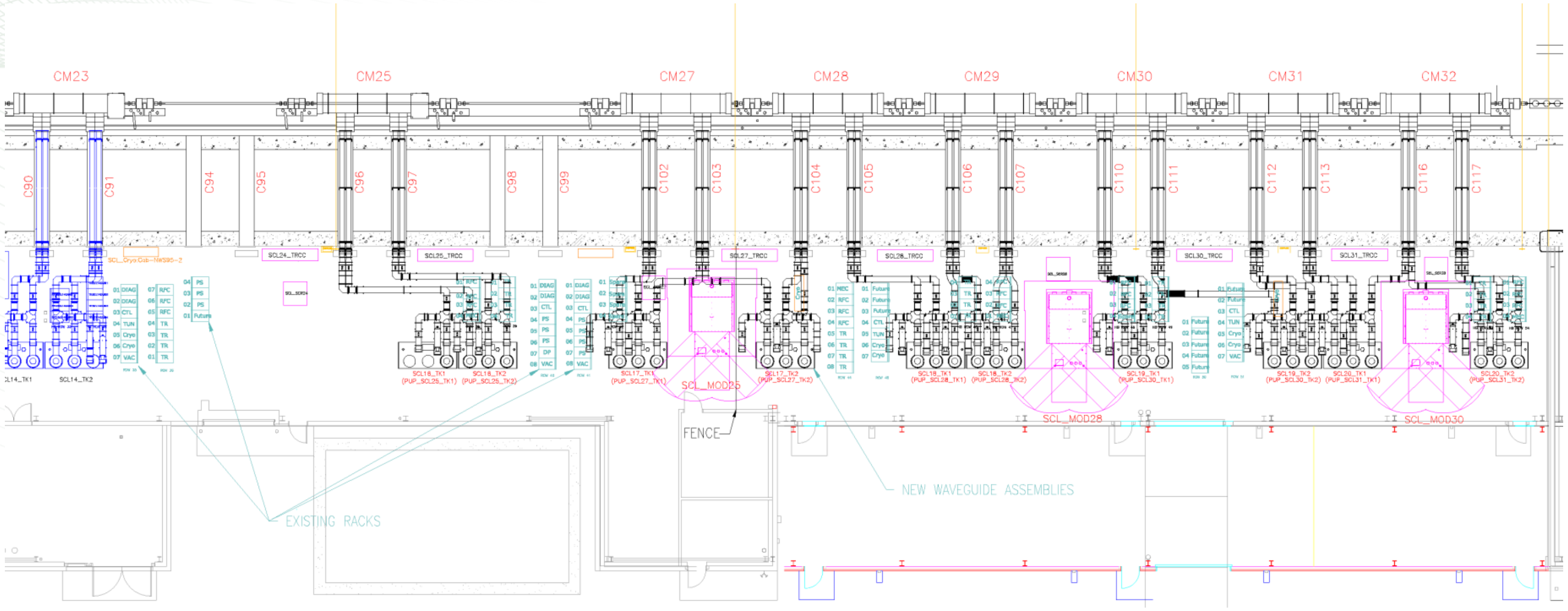
Proton Power Upgrade - Parameters

- Upgrades the SNS accelerator to provide 2MW beam power on target
  - Upgrades target to handle 2MW
  - Increases energy and current
- Installs all HPRF required for Second Target Station

	Routine Operation	PPU	FTS	STS
Kinetic Energy (GeV)	0.957	1.3	1.3	1.3
Beam Power (MW)	0.8-1.40	2	2	0.47
Energy per pulse (kJ)	13 - 23	33	40	47
Target Material	Hg	Hg	Hg	Tungsten
Repetition Rate (Hz)	60	60	50	10
RF Duty Factor (%)	7	7	7	7
Linac pulse length (msec)	0.975	0.975	0.975	0.975
Peak Linac Current (mA)	36	46	46	46
Average Linac Chopping Factor(%)	22	22	33	18
SRF Cavities	79-80	109	109	109

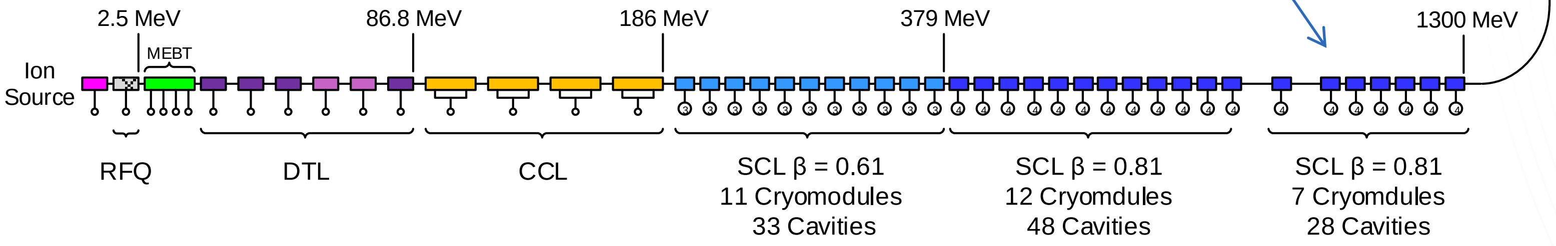


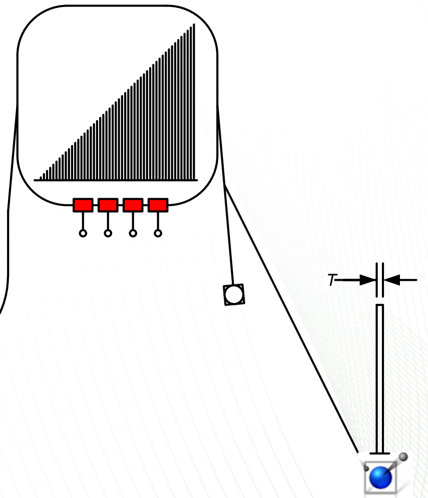
Proton Power Upgrade - Scope



- Energy upgrade
  - 28 high-β cavities in 7 cryomodules
  - 28 HPRF systems
    - 5 transmitters
  - 28 LLRF systems
  - 3 HVCMs
- Current upgrade
  - Increasing peak current
  - Reducing chopped beam fraction
- Upgrade DTL klystrons due to additional beam loading

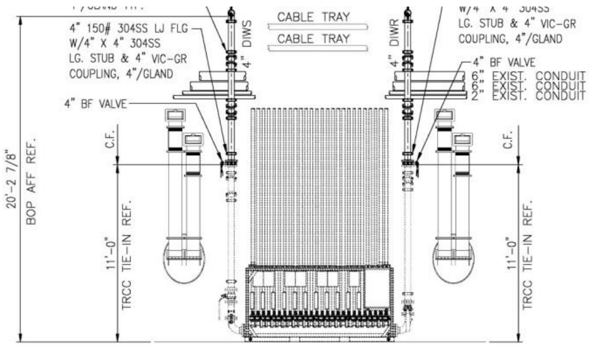
- With the exception of the LLRF, systems will be identical to installed base with noted enhancements

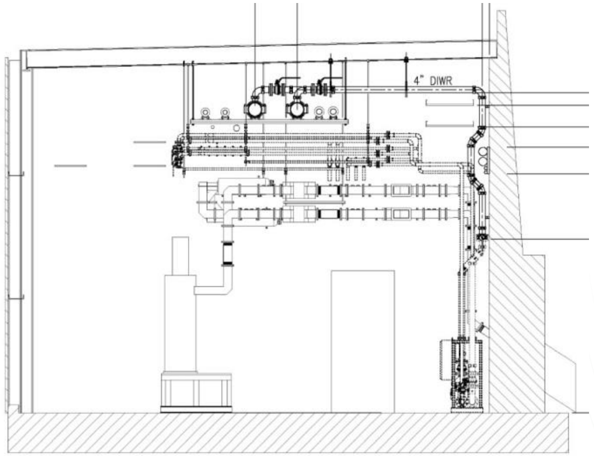




Proton Power Upgrade - Transmitters

- Transmitters
  - CPI VKP-8291B, 700kW klystrons
  - Single magnet power supplies
  - Internal chassis temperature measurement
  - RHV fiber optic fan-out
  - Compact cooling cart
    - Ultrasonic flow transducers
  - Waveguide support structure





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Proton Power Upgrade - LLRF

- The current LLRF systems for the Linac is obsolete.
- There are adequate spares of the Linac LLRF systems to support PPU but the current system cannot meet Second Target Station (STS) requirements.
  - No support for more than one style of beam loading
  - No pulse-to-pulse AFF correction
  - Current system is bus bandwidth limited to 20 Hz
- Utilizing the current Linac LLRF system for PPU is undesirable due to the requirement to replace it for STS.

Standard LLRF Configuration
- **VXI based**
- **2 LLRF systems per rack (IOC)**

Proton Power Upgrade - LLRF

- Replacement LLRF system developed on µTCA.4 platform
  - Baseline plan currently under investigation
  - Allows for use of commercial of the shelf (COTS) hardware where possible
    - lowers development effort
  - Removes VXI backplane data throughput limitations to allow for full 60 Hz updates
    - current system limited to 20 Hz
  - Controls Group is adopting µTCA platform for their next generation systems
    - ensures support in the future
  - Considerable development work will be necessary

Proton Power Upgrade - LLRF

- The installed arc detector system will be reused
- RF reference line is in place and will reuse the current LO distribution scheme

AFT Arc Detector System

Reference Line in Tunnel

Master Oscillator Rack

Proton Power Upgrade - HVCM

1.5MVA Transformer
13.8kV/2.1kV 3Φ

High-Voltage Converter Modulator
(Alternate Topology)

SCR Cabinet

- To accommodate the modest power increase, an alternate modulator topology is under consideration
  - Outputs of the three interleaved full bridge converters are in placed in series, not parallel
    - Results in voltage reduction across secondary components
  - Boost capacitor across transformer secondary is eliminated
    - Eliminates a failure prone device
    - The IGBTs turn off losses are minimized
  - Topology is load tolerant; can supply one to ten klystrons with minimal output deviation

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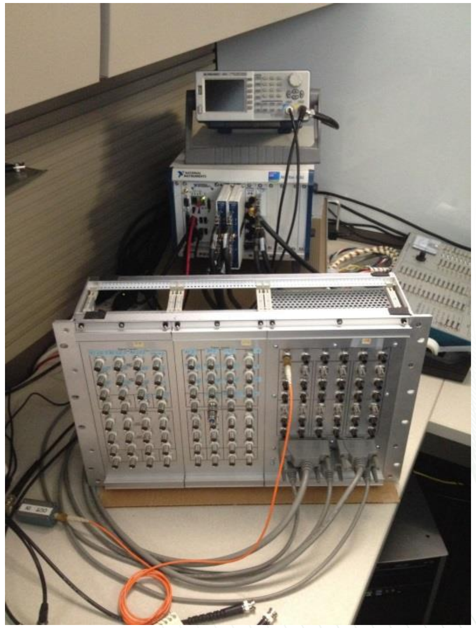
Proton Power Upgrade - HVCM

- Next Generation Controller
  - Replaces several pieces of obsolete and unreliable equipment
  - NI PXI platform with embedded controller using LabView
  - 32-channel synchronous high speed analog input channels
    - Provides synchronized full speed continuous monitoring and data capture
  - Multiple digital and low-speed analog channels to monitor and control IGBT gate drivers, interlocks and protection systems
- Provides new capabilities
  - Ability to perform pulse-flattening
  - Phase-shifted pulse width modulation
  - Frequency modulation
  - Flux compensation
  - First fault identification
  - Data logging including high speed waveforms
  - Faster troubleshooting

Next Generation Controller



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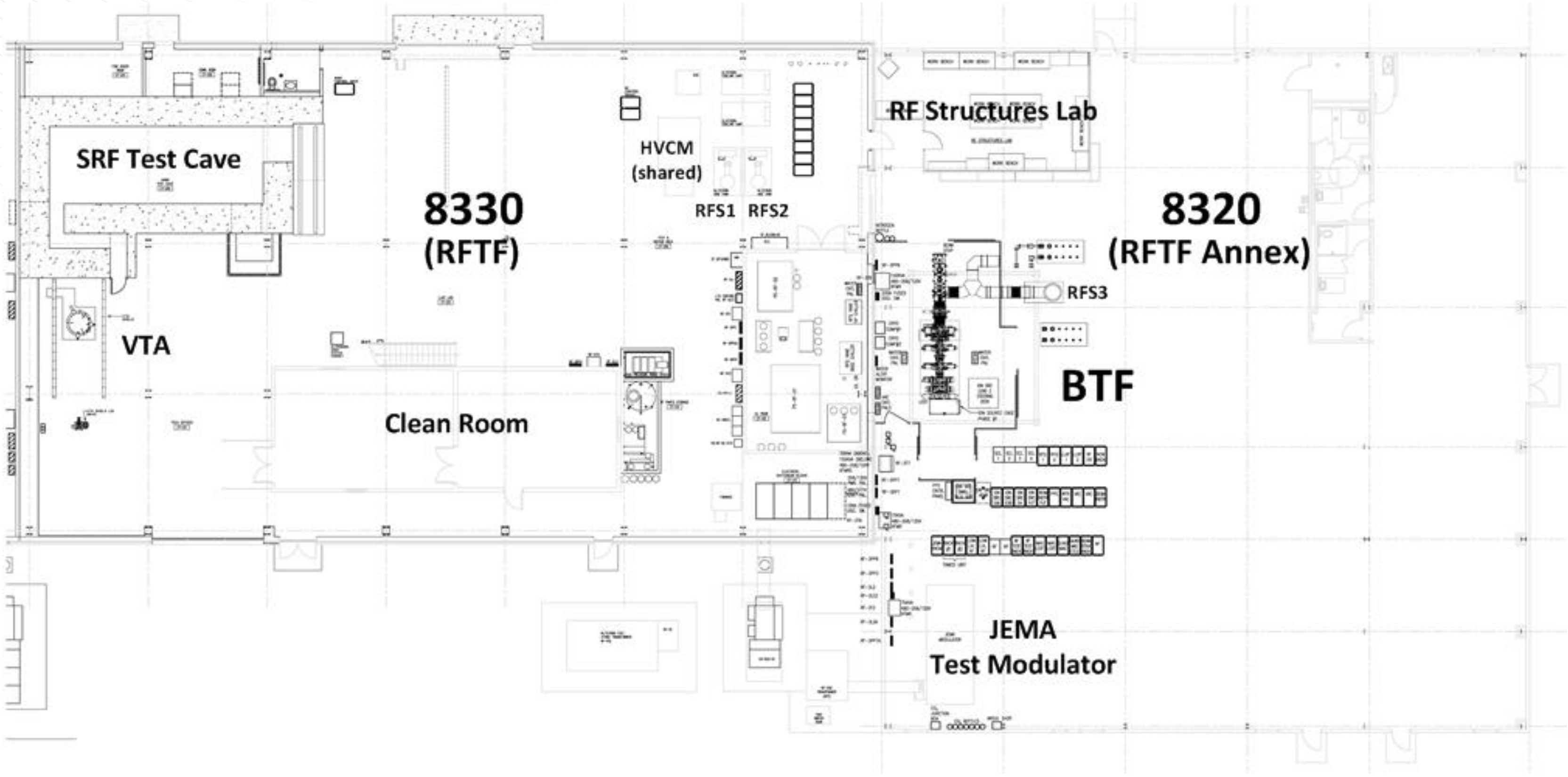
Proton Power Upgrade - Challenges

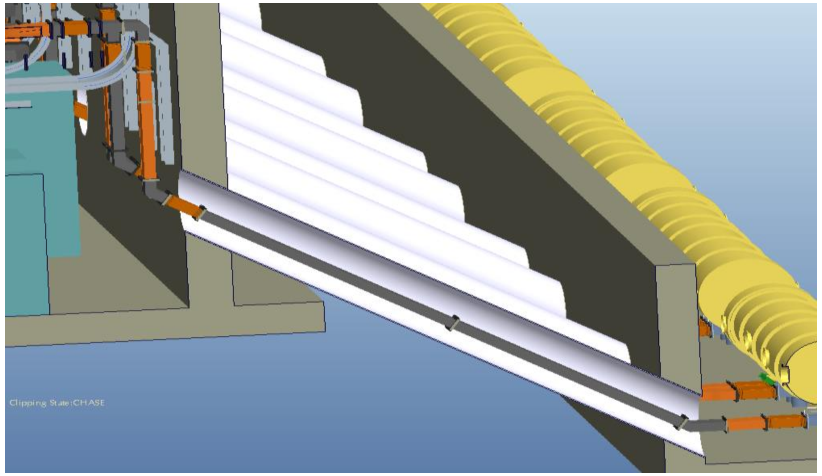
- Space
  - East end of klystron gallery currently used for storage and shop space
  - RF Annex is being re-designated a technical development space

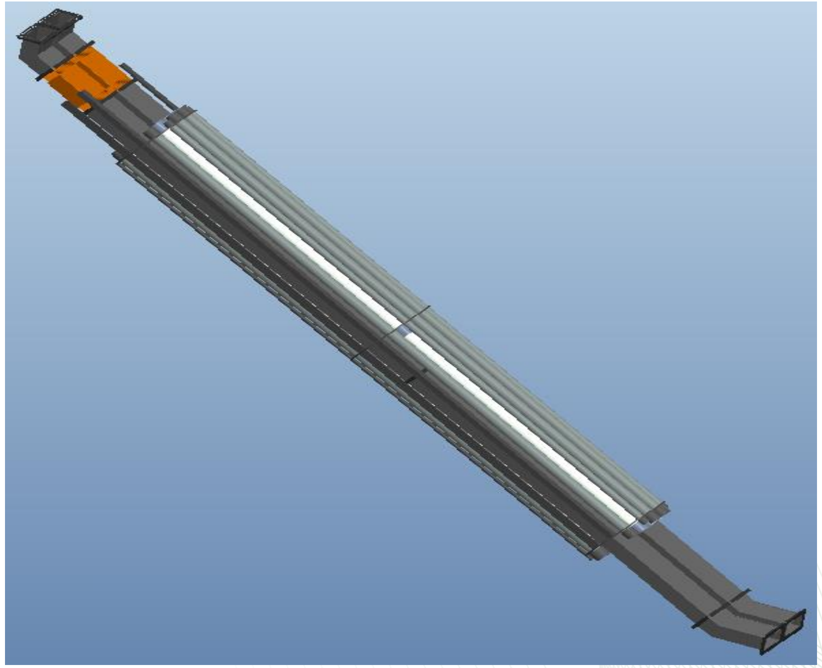


- Solution?
  - Better use of existing spaces
    - Chestnut Ridge Maintenance Facility
    - RATS2
    - Mezzanines
  - Out source construction
    - Cryomodules
    - HVCMs
  - Rent temporary off-site technical space

Proton Power Upgrade - Challenges

- The penetrations from the klystron gallery to the tunnel have in insert that integrates waveguide and conduit
- The inserts were originally installed before the klystron gallery building was constructed.





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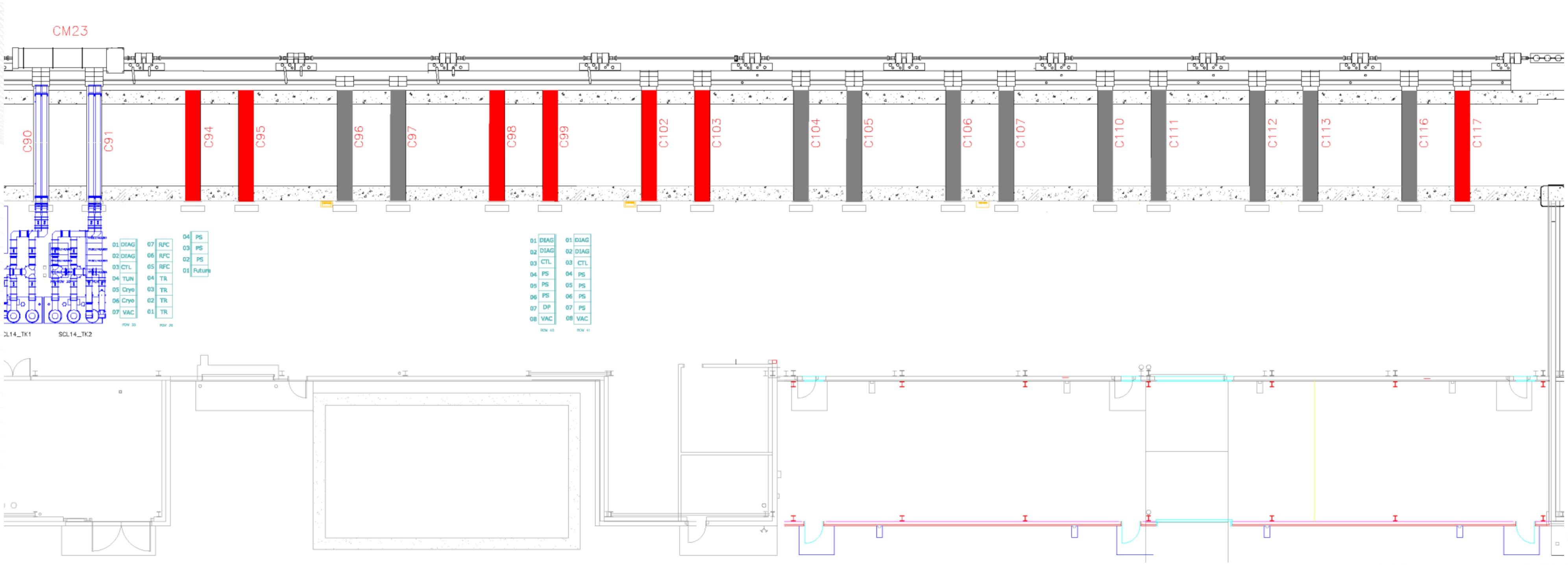
Proton Power Upgrade - Challenges



- During construction, the decision was made to reduce the size of the klystron gallery to save money
  - Klystron gallery ended around chase 103
  - Required cables for equipment downstream from CM23 were pulled through chases 94, 95, 98, 99, 102, 103, and 117
  - Equipment racks were installed in the klystron gallery blocking clear access to chase 94 and 99

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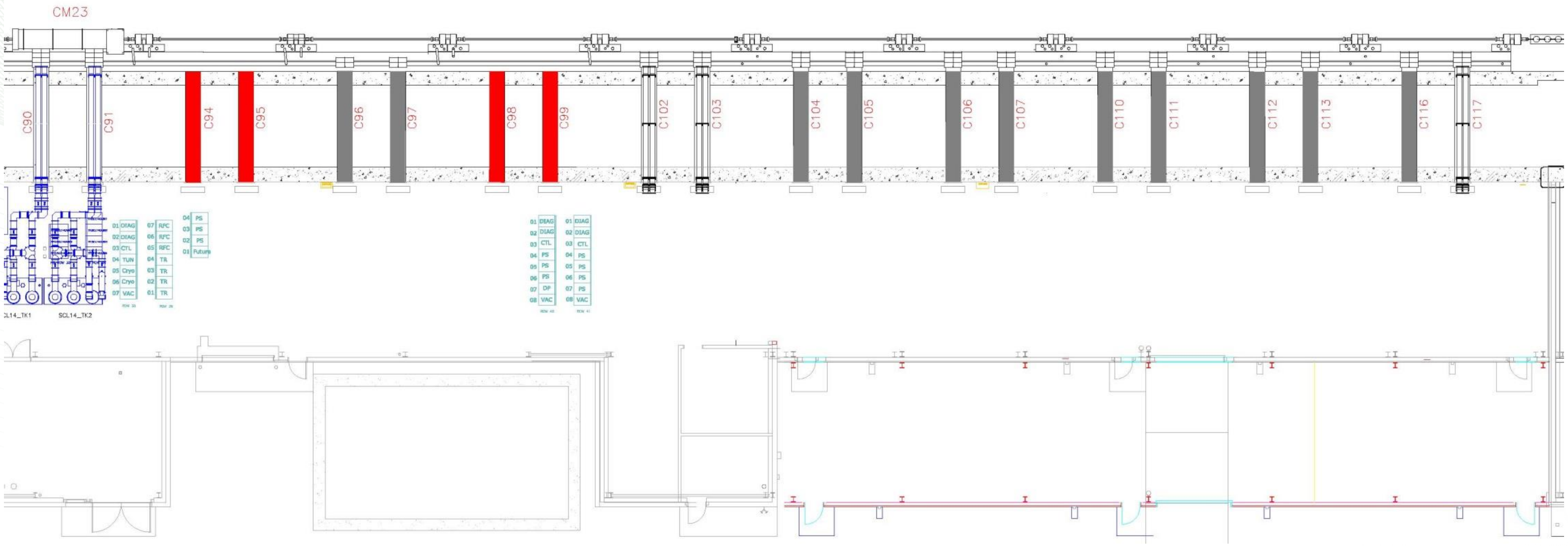
Proton Power Upgrade - Challenges

Chases with cables

Proton Power Upgrade - Challenges



- Clear cables from chases 102 and 103
- Re-cable, bringing cables up through chase 99
- Install chase inserts and backfill with poly beads

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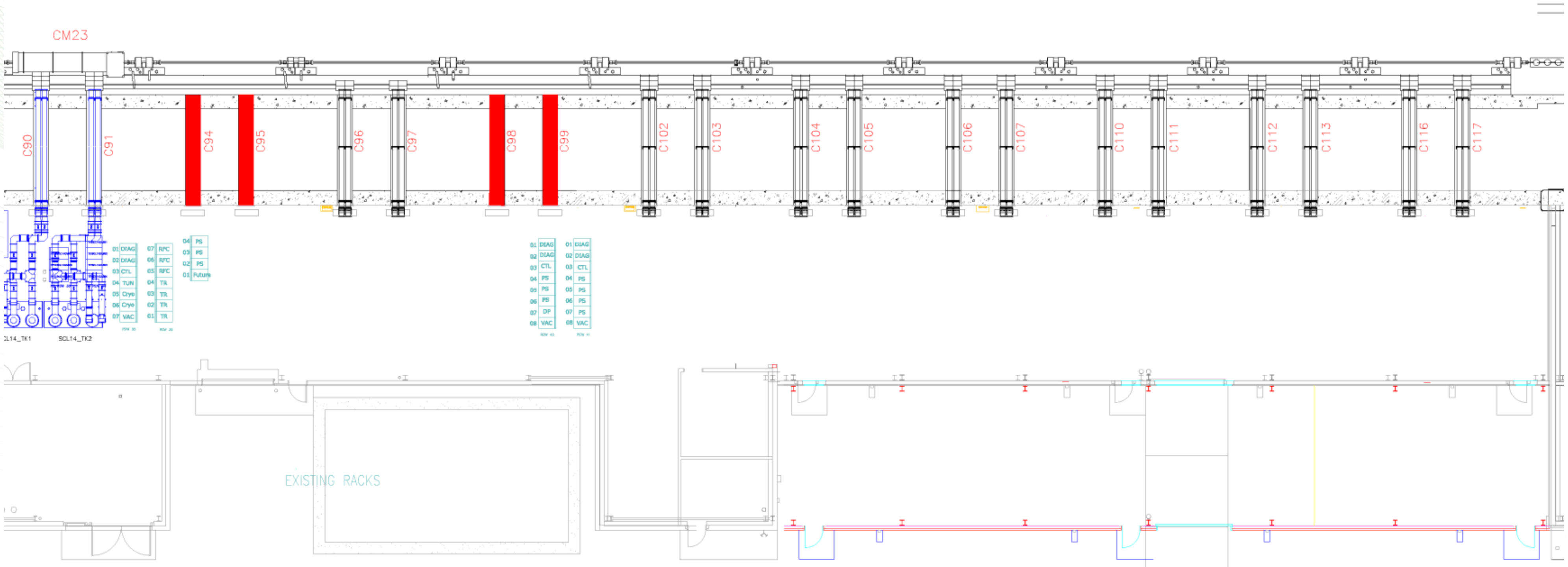
Proton Power Upgrade - Challenges

- Clear cables from chases 102 and 103
- Re-cable, bringing cables up through chase 99
- Install chase inserts and backfill with poly beads

Proton Power Upgrade - Challenges



- Clear cables from chases 102 and 103
- Re-cable, bringing cables up through chase 99
- Install chase inserts and backfill with poly beads
- Install remaining inserts and backfill with poly beads

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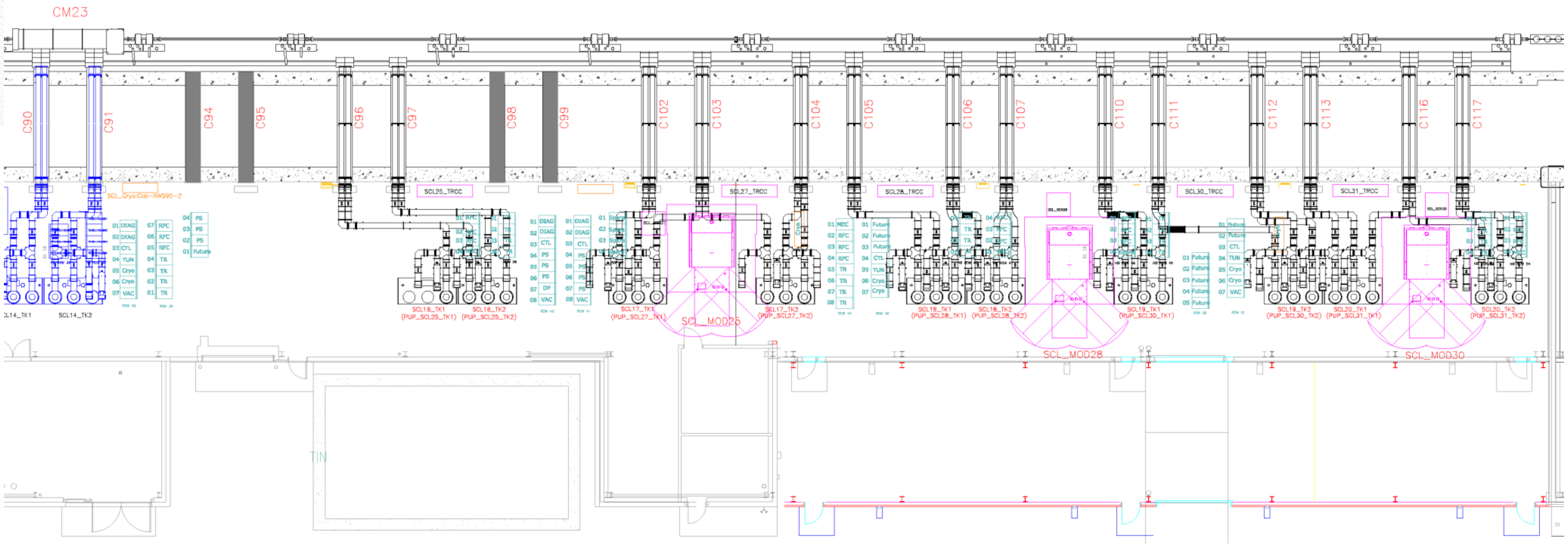
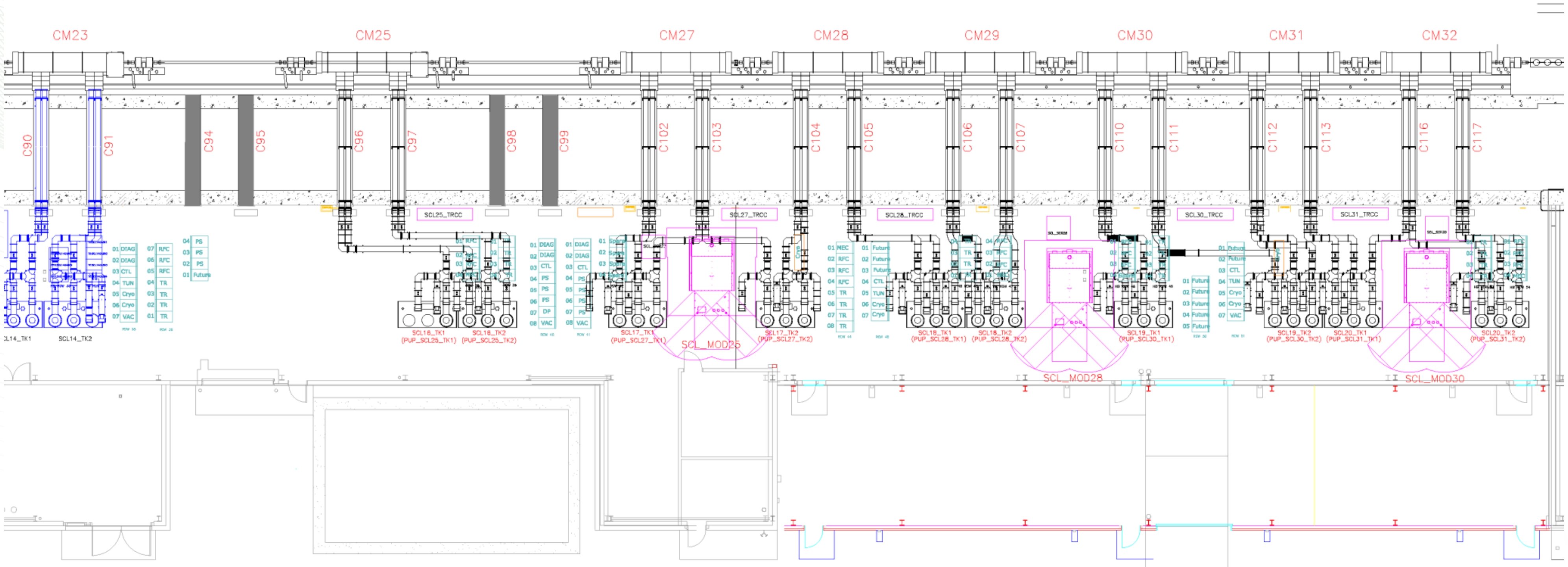
Proton Power Upgrade - Challenges



- Clear cables from chases 102 and 103
- Re-cable, bringing cables up through chase 99
- Install chase inserts and backfill with poly beads
- Install remaining inserts and backfill with poly beads
- Install equipment in klystron gallery

Proton Power Upgrade - Challenges



- Clear cables from chases 102 and 103
- Re-cable, bringing cables up through chase 99
- Install chase inserts and backfill with poly beads
- Install remaining inserts and backfill with poly beads
- Install equipment in klystron gallery
- Install cryomodules

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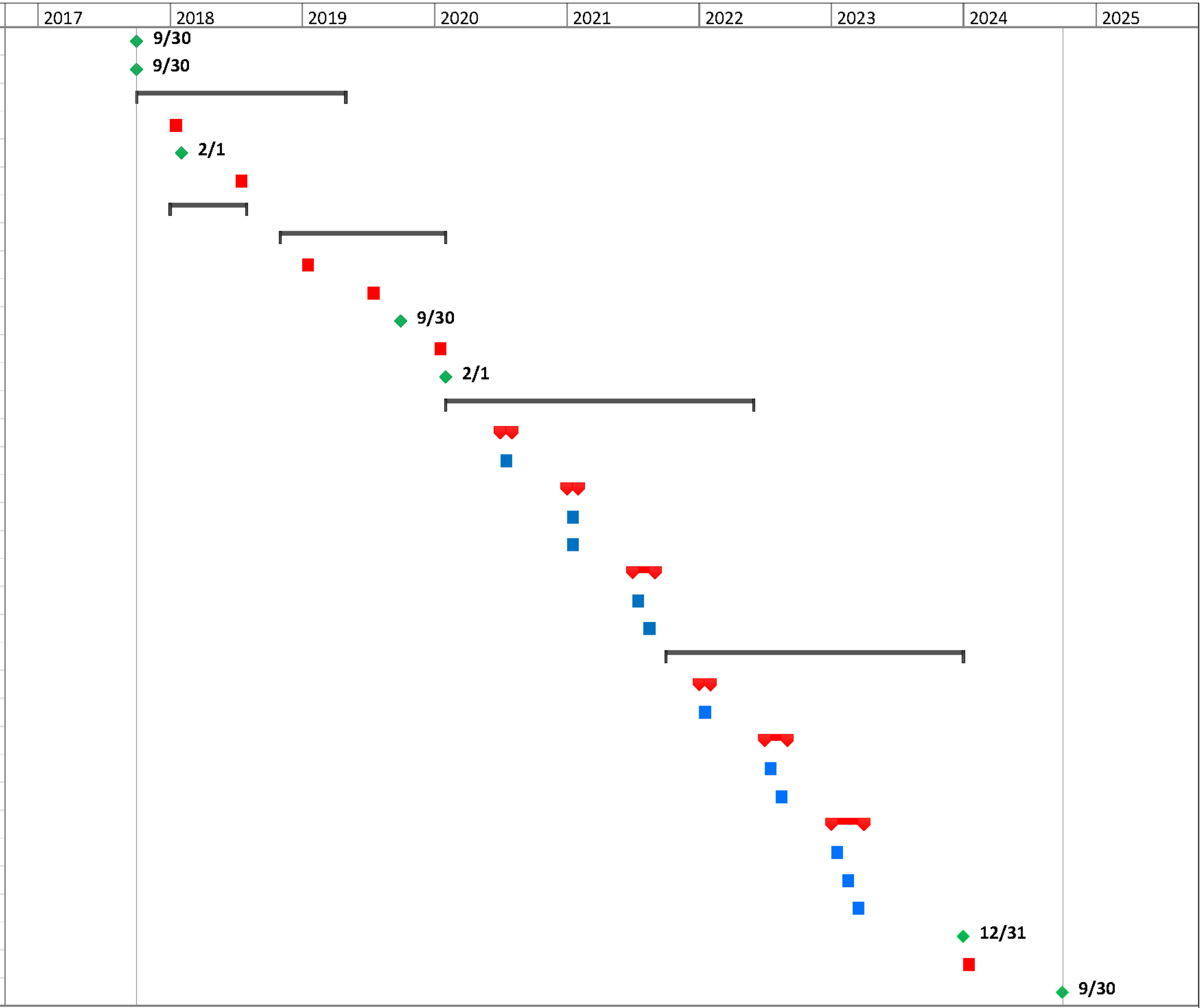
Proton Power Upgrade - Schedule

ID	Task Name	Duration	Start	Finish	Predecessors
1	CD-1 Approval	0 days	Sat 9/30/17	Sat 9/30/17	
2	**Approval of advance procurements**	0 days	Sat 9/30/17	Sat 9/30/17	
3	**Conventional Facilities**	**577 days**	**Sun 10/1/17**	**Tue 4/30/19**	
9	Winter Outage 2018	31 days	Mon 1/1/18	Wed 1/31/18	
10	**First project funding for advance procurements**	0 days	Thu 2/1/18	Thu 2/1/18	
11	Summer Outage 2018	30 days	Mon 7/2/18	Tue 7/31/18	
12	**Linac Tunnel and Klystron Gallery**	**211 days**	**Mon 1/1/18**	**Mon 7/30/18**	
21	**SCL**	**457 days**	**Thu 11/1/18**	**Fri 1/31/20**	
30	Winter Outage 2019	31 days	Tue 1/1/19	Thu 1/31/19	
31	Summer Outage 2019	31 days	Mon 7/1/19	Wed 7/31/19	
32	CD-2/3 Approval	0 days	Mon 9/30/19	Mon 9/30/19	
33	Winter Outage 2020	31 days	Wed 1/1/20	Fri 1/31/20	
34	**Rest of project funding available**	0 days	Sat 2/1/20	Sat 2/1/20	
35	**EAST GROUP**	**851 days**	**Sat 2/1/20**	**Tue 5/31/22**	
52	Summer Outage 2020	**31 days**	**Wed 7/1/20**	**Fri 7/31/20**	
53	**Install insulating vacuum section 8**	31 days	Wed 7/1/20	Fri 7/31/20	
54	Winter Outage 2021	**31 days**	**Fri 1/1/21**	**Sun 1/31/21**	
55	**Install insulating vacuum section 8**	31 days	Fri 1/1/21	Sun 1/31/21	
56	**Install insulating vacuum section 7**	31 days	Fri 1/1/21	Sun 1/31/21	
57	Summer Outage 2021	**62 days**	**Thu 7/1/21**	**Tue 8/31/21**	
58	**Cryomodule 32**	**31 days**	**Thu 7/1/21**	**Sat 7/31/21**	
70	**Cryomodule 31**	**31 days**	**Sun 8/1/21**	**Tue 8/31/21**	
82	**WEST GROUP**	**822 days**	**Fri 10/1/21**	**Sun 12/31/23**	
100	Winter Outage 2022	**31 days**	**Sat 1/1/22**	**Mon 1/31/22**	
101	**Install insulating vacuum section 7**	31 days	Sat 1/1/22	Mon 1/31/22	
102	Summer Outage 2022	**62 days**	**Fri 7/1/22**	**Wed 8/31/22**	
103	**Cryomodule 30**	**31 days**	**Fri 7/1/22**	**Sun 7/31/22**	
115	**Cryomodule 29**	**31 days**	**Mon 8/1/22**	**Wed 8/31/22**	
127	Winter Outage 2023	**90 days**	**Sun 1/1/23**	**Fri 3/31/23**	
128	**Cryomodule 28**	**31 days**	**Sun 1/1/23**	**Tue 1/31/23**	
140	**Cryomodule 27**	**31 days**	**Wed 2/1/23**	**Fri 3/3/23**	
152	**Cryomodule 25**	**31 days**	**Wed 3/1/23**	**Fri 3/31/23**	
164	CD-4 early finish	0 days	Sun 12/31/23	Sun 12/31/23	
165	Winter Outage 2024	30 days	Mon 1/1/24	Tue 1/30/24	
166	CD-4 late finish	0 days	Mon 9/30/24	Mon 9/30/24	



Summary

2004	CD-0 approved for power upgrade (energy only)
2009	CD-0 approved for STS
2011	Indefinite postponement
2013	Started pre-conceptual design effort for STS (included power upgrade)
2015	Published Technical Design Report
2016	PPU was split out
2017	Publish Conceptual Design Report
2017	CD-1 Approval
2018	CD 2/3 Funding for advanced procurements
2018	Conventional facilities complete
2023	Klystron gallery installation complete
2023	Last cryomodule installed
2023	CD-4 Early project finish
STA?	2MW beam on target

Merci beaucoup de votre attention!