Operational Experience of SNS at 1.4 MW and Upgrade Plans for Doubling the Beam Power

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On behalf of the SNS staff

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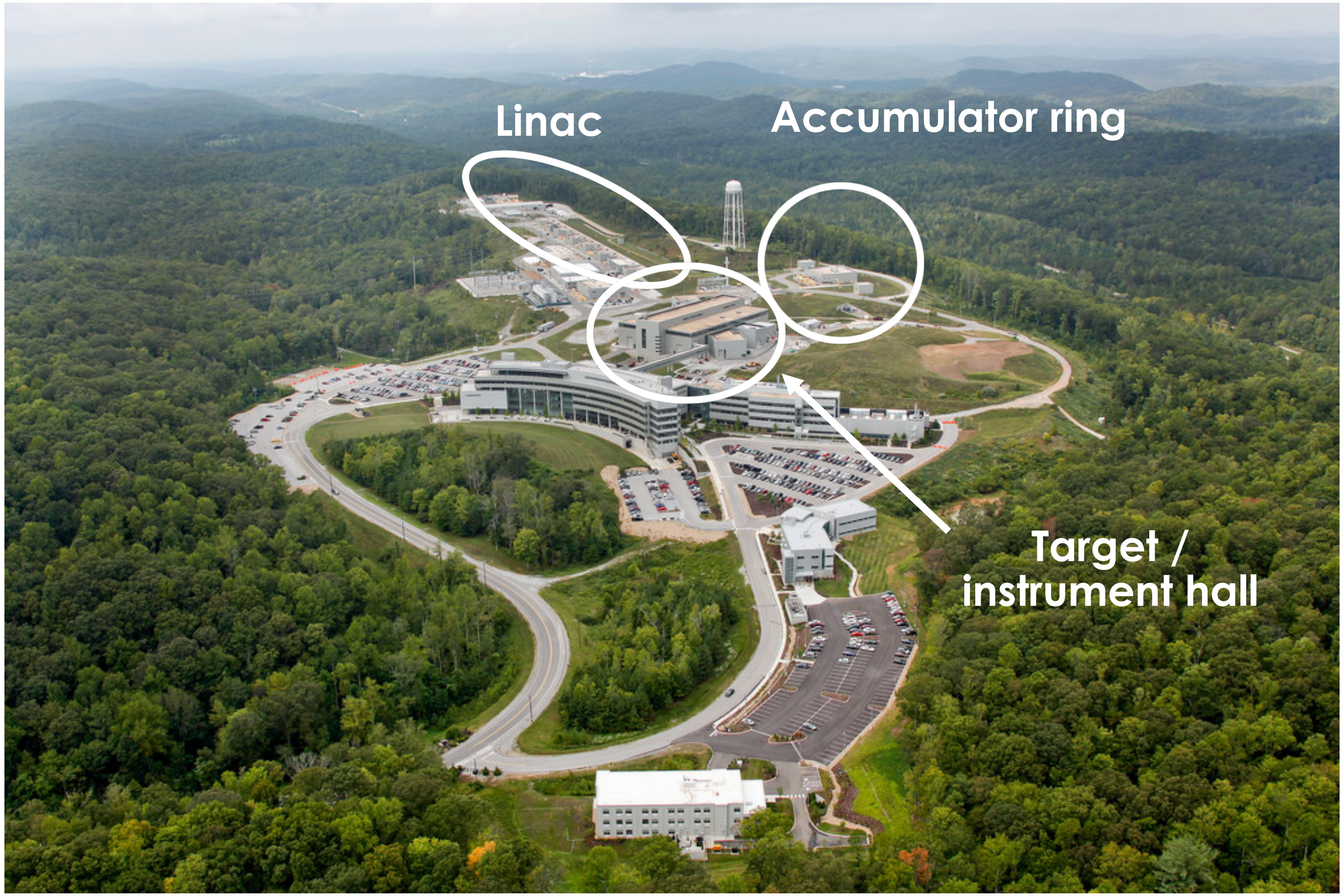
Outline

- Spallation Neutron Source (SNS) introduction
- We are at the design 1.4 MW power level operation
- The Proton Power Upgrade (PPU) project
  - Double the accelerator power capability to 2.8 MW

Upgrades build on experience that paved the way to 1.4 MW operation

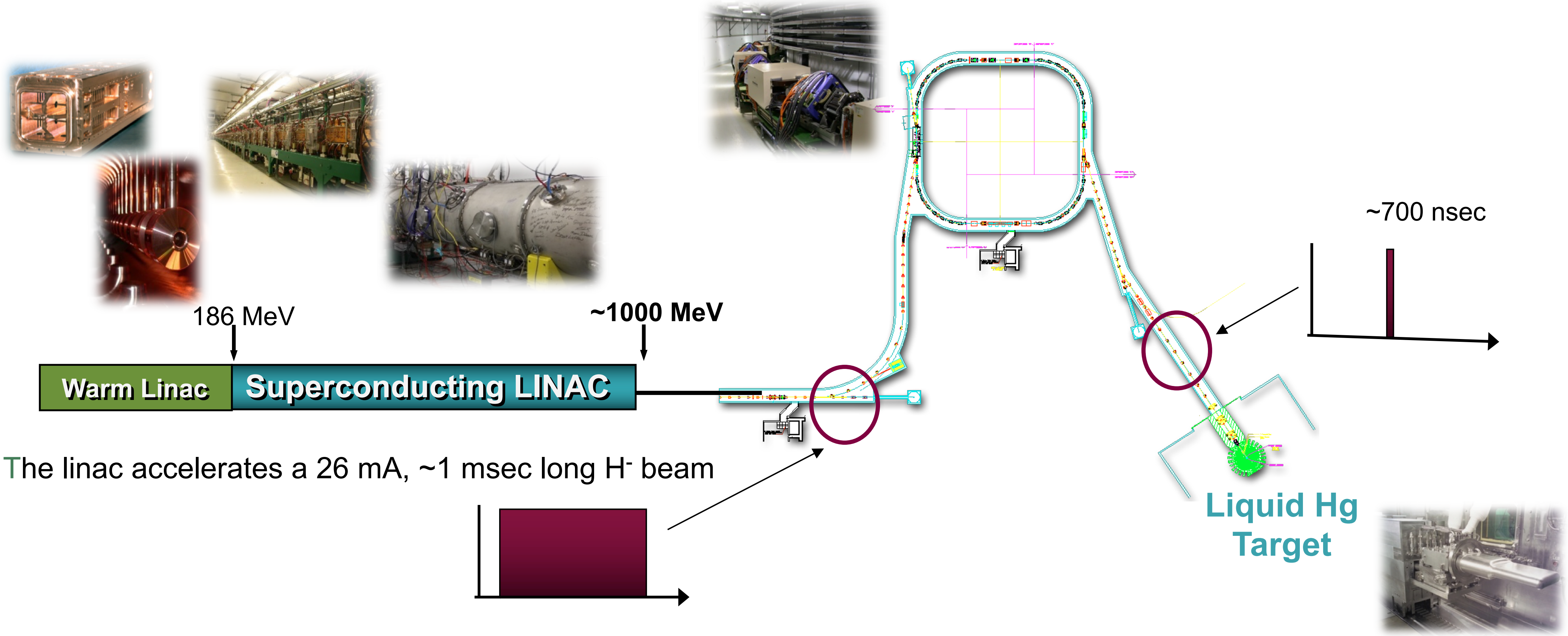
Spallation Neutron Source (SNS): A high intensity short pulse spallation neutron source

- Spallation: accelerator driven, protons
- High intensity neutron: MW power level accelerator
- Short pulse: ring



SNS overview: short pulse neutron source

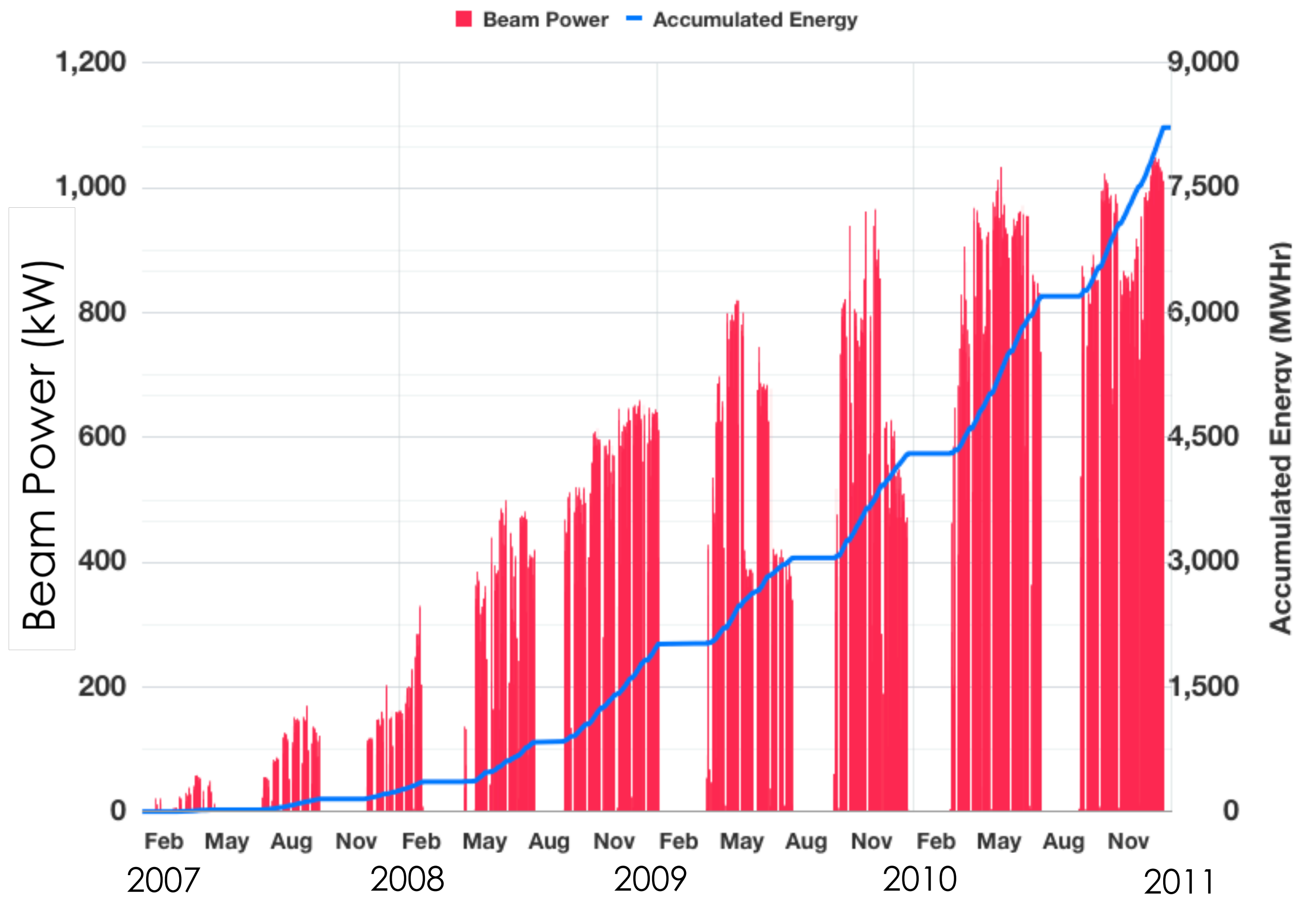
The accumulator ring compresses the pulse to ~700 nsec



The linac accelerates a 26 mA, ~1 msec long H^- beam

@ 60 Hz, this represents a 1.4 MW proton beam power

The early operation years: 2007-2011 “Race to 1 MW”

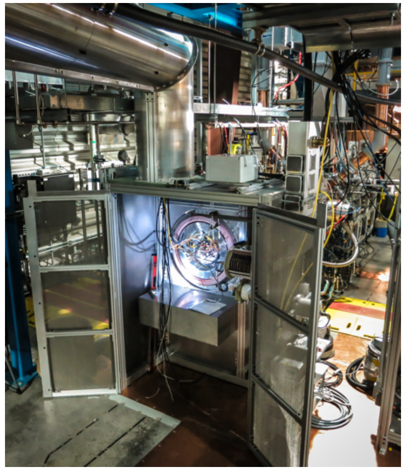


- Ramp up as fast as possible, see what breaks and fix it
  - Limitations: high power RF, ion source, superconducting RF

Technology initiatives launched in the early years

Ion source

- World class high current and repeatable performance has been developed

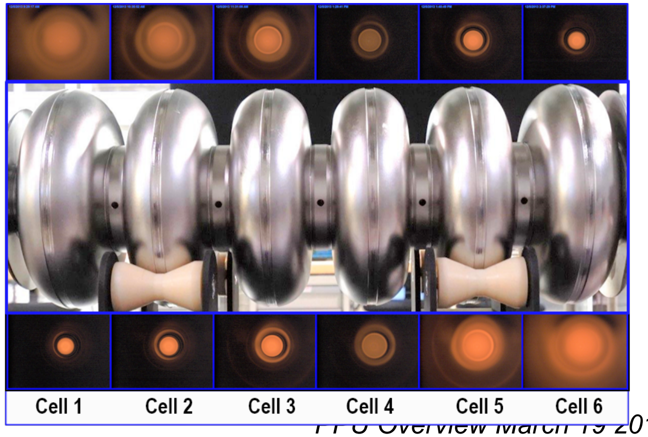


High voltage convertor modulators

- Component and system robustness

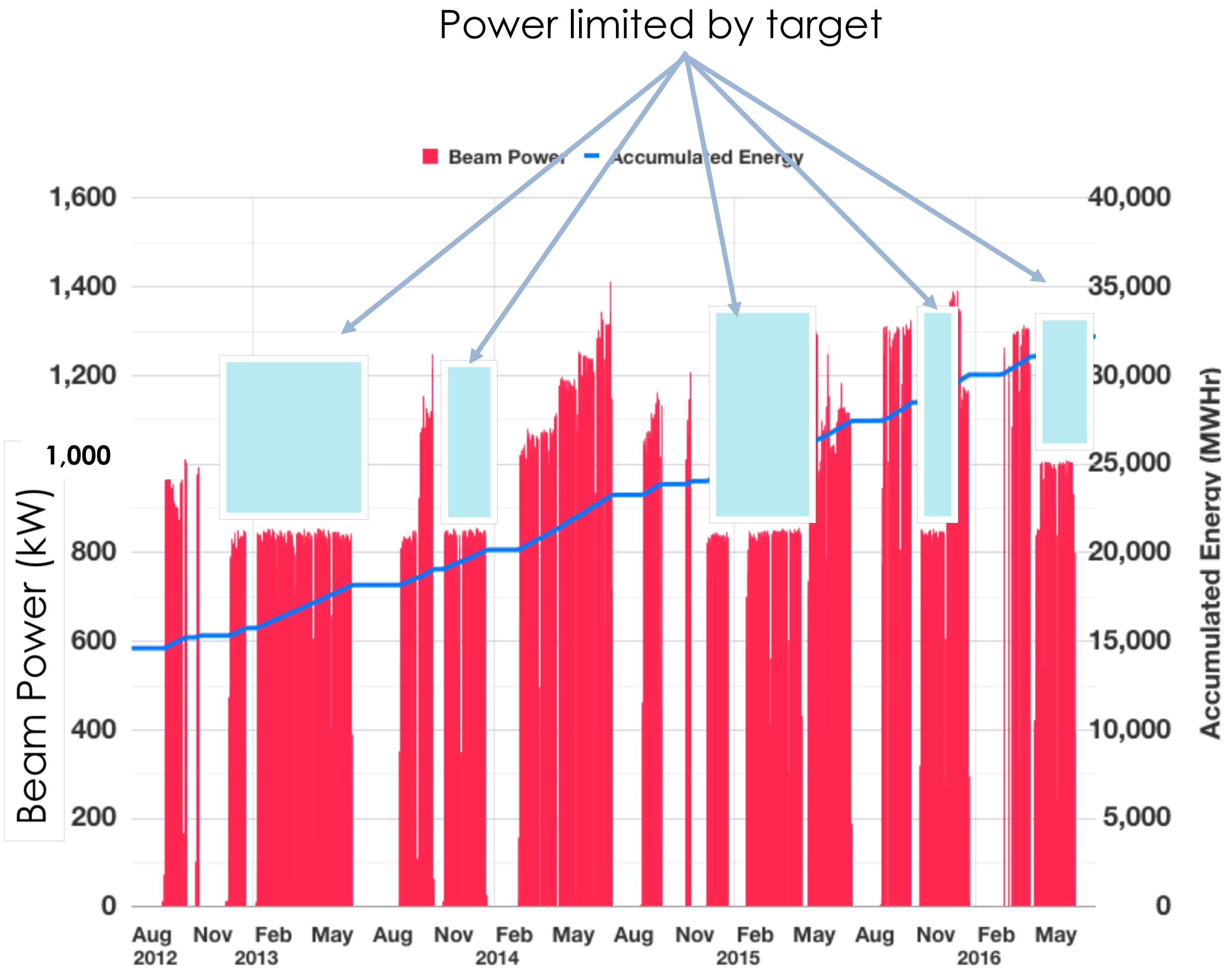
Superconducting RF

- Cryomodule rework: remove un-necessary ancillary equipment (piezo tuners, HOMs)
- Equipment protection: fast beam turn-off with beam loss
- Improve performance: in-situ plasma processing



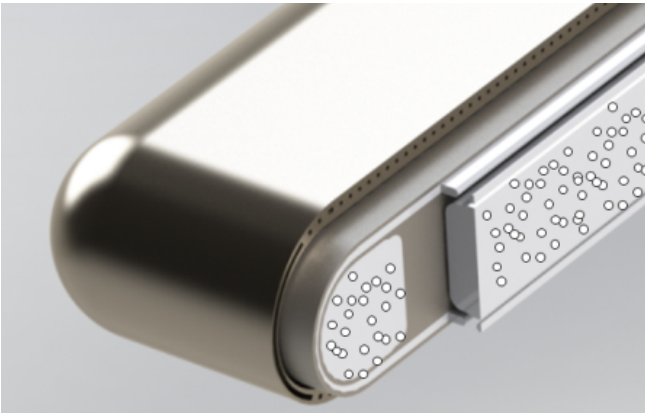
Intermediate years 2012-2016: "It's the target stupid"

- Target failures limited beam power
  - 6 of 8 targets leaked during this period



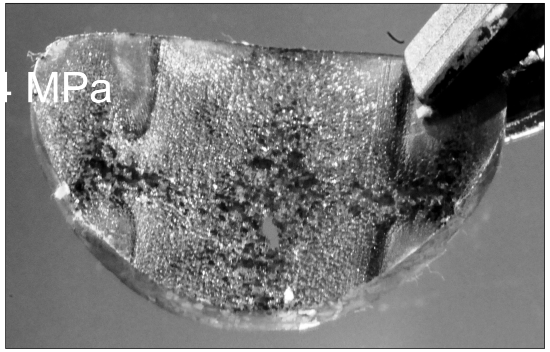
Target improvement campaign

Gas bubble injection into mercury target

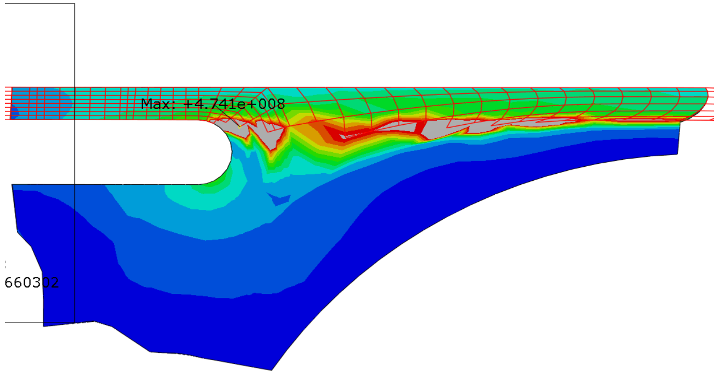


Target instrumentation: strain gauges

Post Irradiation Examination

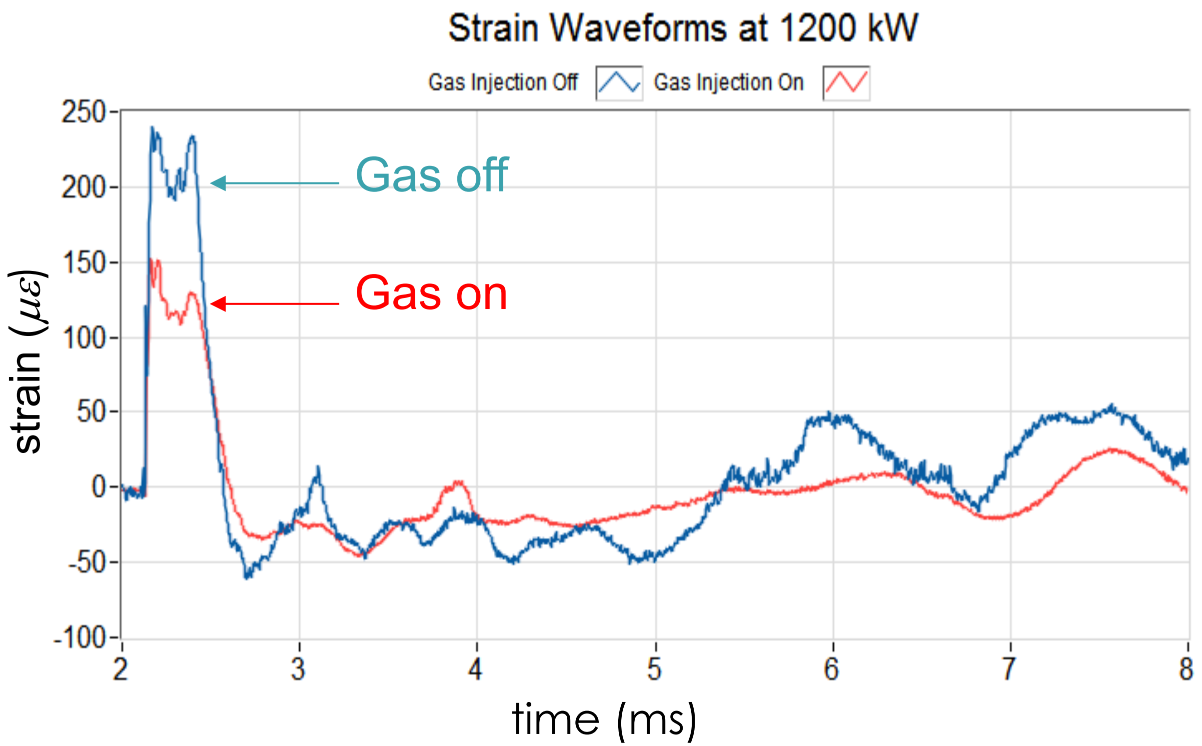


Improved design / fabrication oversight



Gas bubble injection in targets demonstrates strain mitigation

Measurements show clear target vessel strain reductions with gas bubble injection

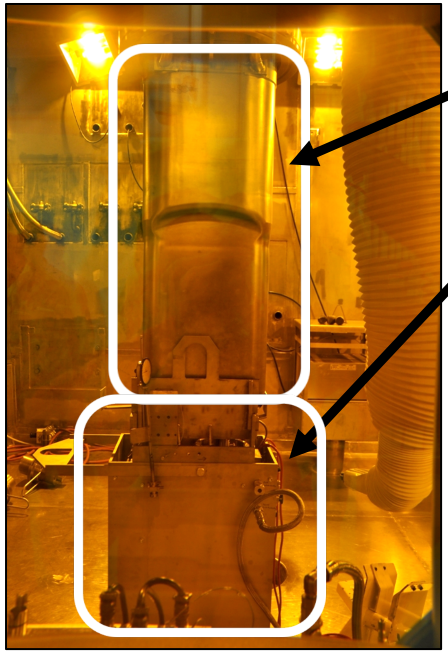


- *Demonstrates strain reduction required for PPU 2 MW design*

Gas bubble injection in targets demonstrates cavitation mitigation

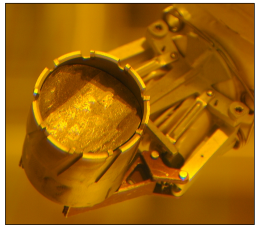
Disc specimens are regularly taken from irradiated target nose regions

Operating in the service bay



Vertical target

specimen cutter

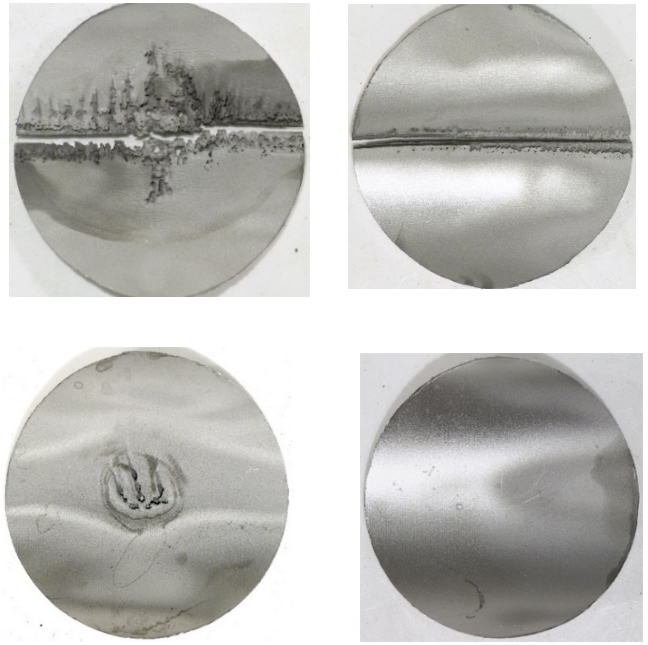


disc specimen

Post irradiation core samples indicate clear reductions in cavitation damage

Last target without gas

First target with gas



center

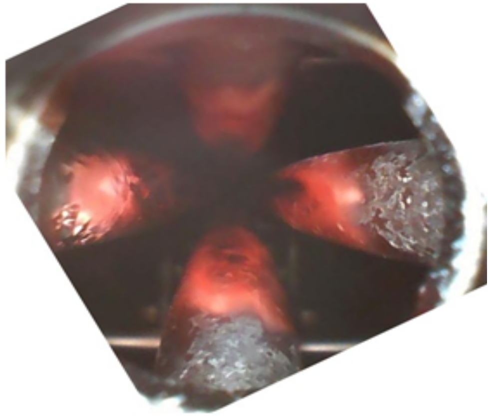
edge

- *Last 8 operational targets: no leaks*

New RFQ provides beam current (power) headroom

Original RFQ had performance issues

- Original RFQ had performance issues
  - Sudden frequency shifts
  - Gradual field profile change
    - Transmission reduced ~ 20-30%



Upstream view of the original SNS RFQ vanes

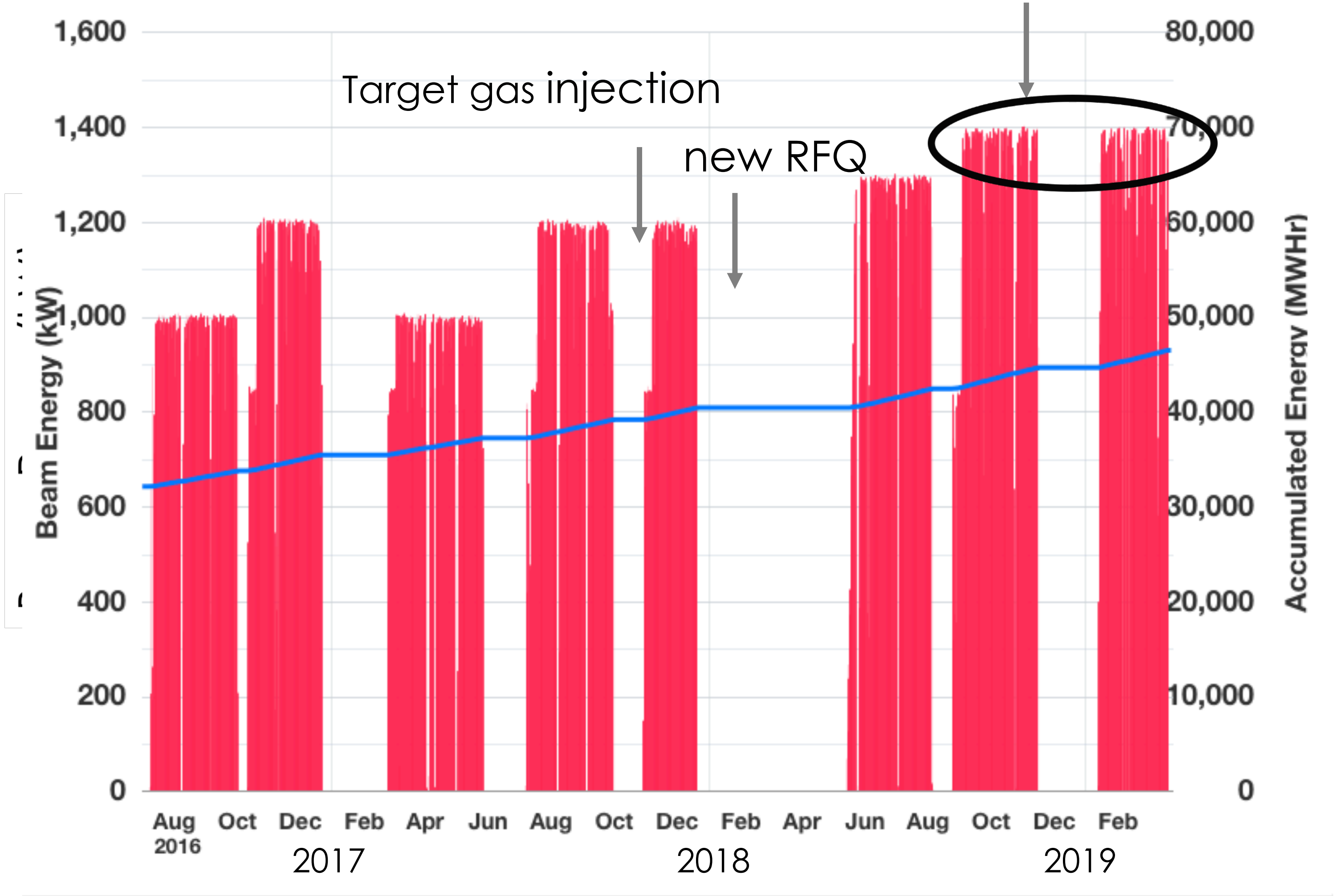
New RFQ installed in 2018

- Recovered 90% design transmission which provides power margin

2016-2019: “Systematic approach” to 1.4 MW design level

- New RFQ provides beam power headroom
- Gas injection mitigates target damage
  - No mercury leaks
- Developments in other accelerator systems provide a basis for reliable high power operation.

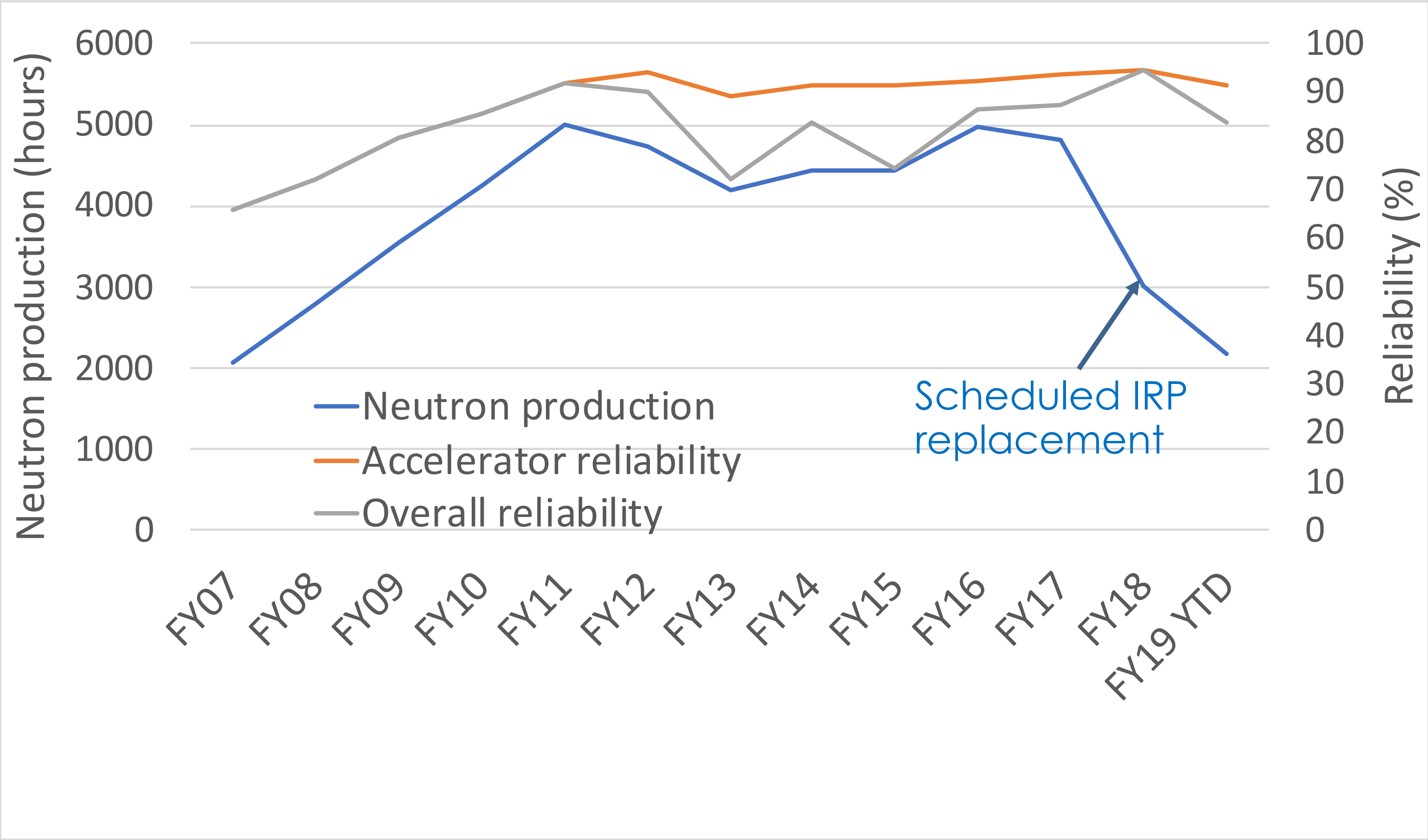
SNS is operating at its design power of 1.4 MW



Operation at 1.4 MW

- Trip frequency is not affected by beam power
  - Reliability dominated by infrequent but long outages
- Beam loss is proportional to beam power
  - Activation levels have never limited beam power
- Operational rhythm is much the same as before

SNS operation metric history

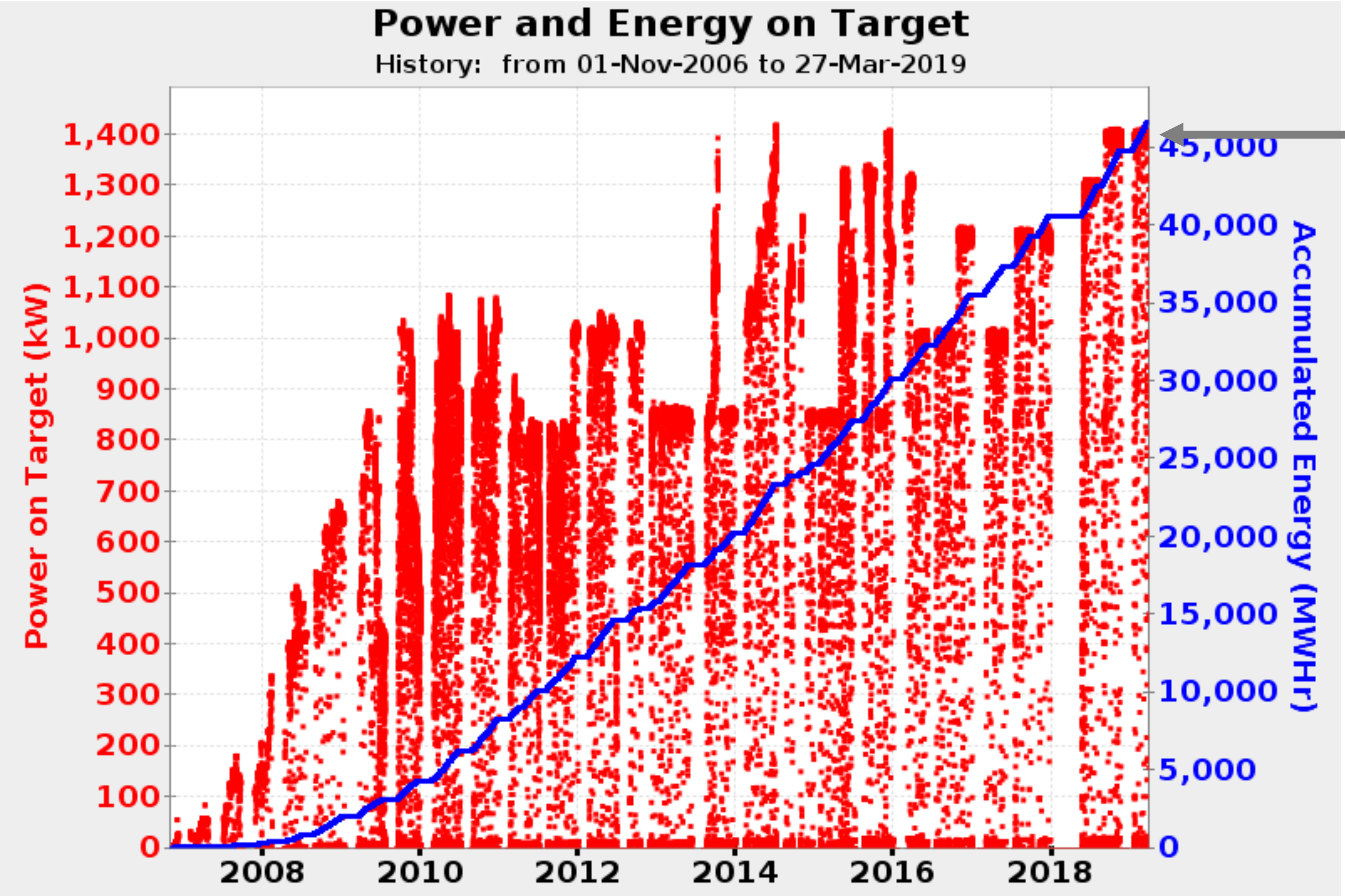


> 90% accelerator reliability

75%-95 % overall reliability (dominated by major failures)

Run 4000-5000 hrs/yr

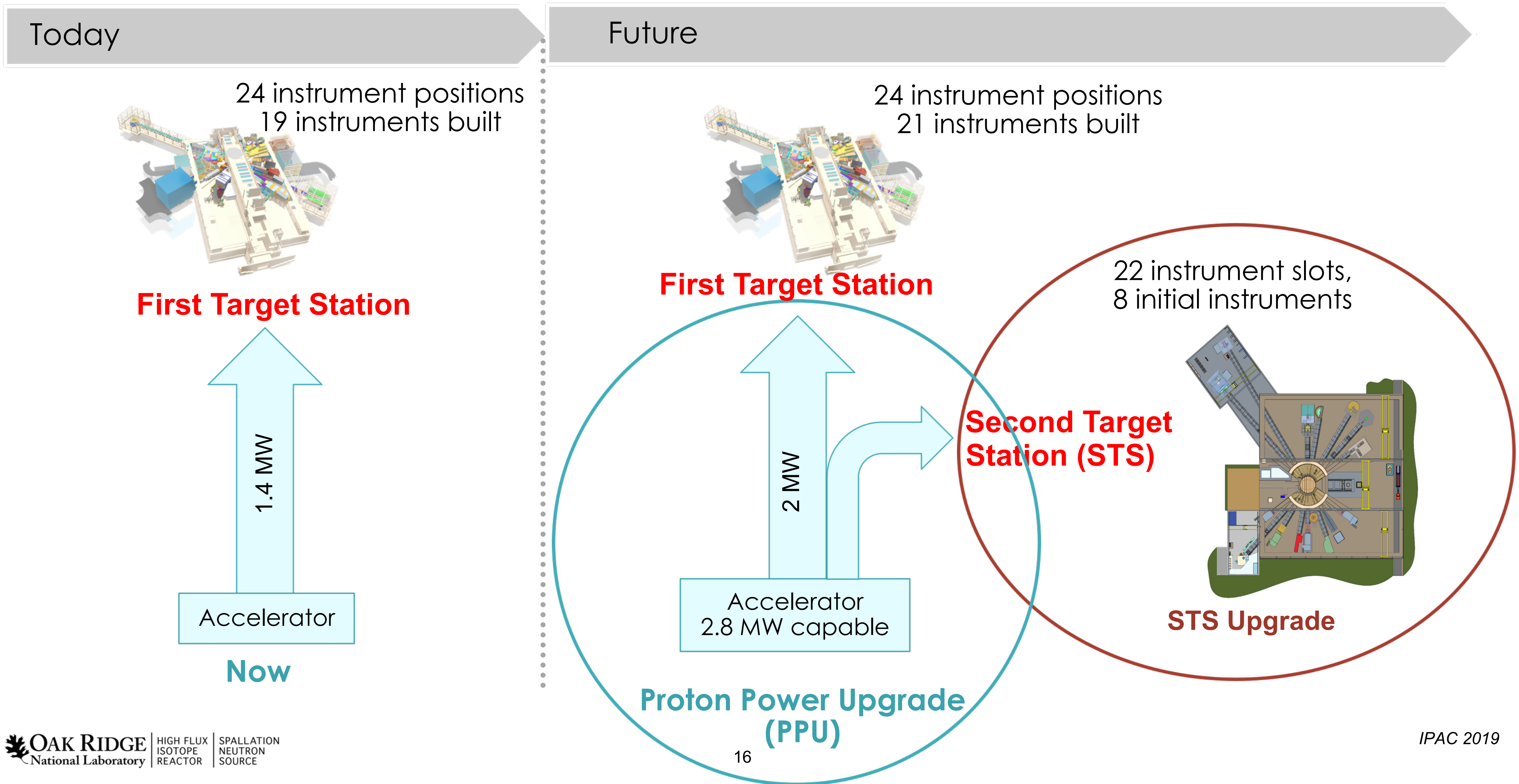
SNS beam power summary



1.4 MW

Time to upgrade the SNS!

SNS Upgrade Plans



PPU parameters

	SNS 1.4 MW	PPU full upgrade capability	PPU FTS 60 Hz operation
Proton beam power capability (MW)	1.4	2.8	2.0
Beam energy (GeV)	1.0	1.3	1.3
RFQ output peak beam current (mA)	33	46	46
Average linac chopping fraction (%)	22	18	41
Average macropulse beam current (mA)	25	38	27
Energy per pulse (kJ)	23	47	33
Pulse repetition rate (Hz)	60	60	60
Macro-pulse length (ms)	1	1	1
FTS decoupled moderator brightness/pulse (AU)	1	2.04	1.43
FTS coupled moderator brightness/pulse (AU)	1	2.16	1.51

33% energy increase

50% current increase: front end is good to go

No change

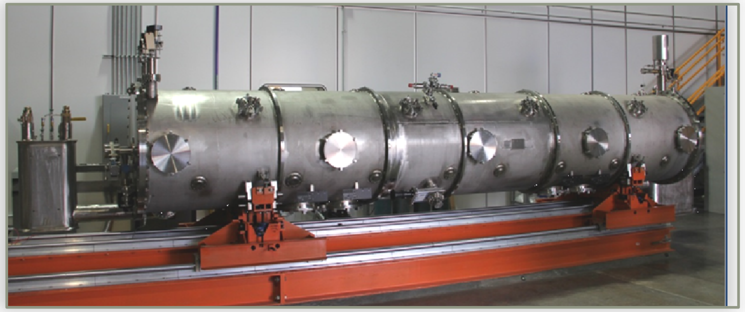
Superconducting linac (SCL): 7 new cryomodules

Cavities

- Cavities are presently being procured
  - Similar as existing cavities
  - 16 MV/m gradient, $Q_0 > 5 \times 10^9$

Cryomodules

- JLab is a PPU partner and is providing the cryomodules
  - Similar to existing SNS spare cryomodule

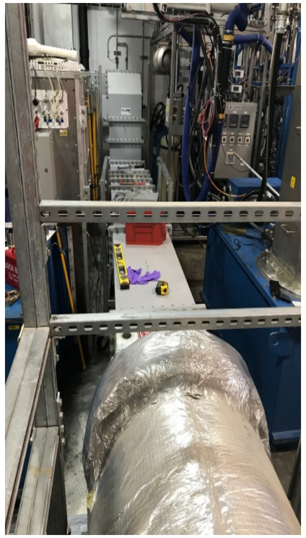


9 empty slots are available in the tunnel

Radio frequency upgrades

Upgrade some existing RF installations

- Tests done on existing systems
  - CCL and existing SCL RF systems: OK
  - DTL systems: upgrade from 2.5 to 3 MW

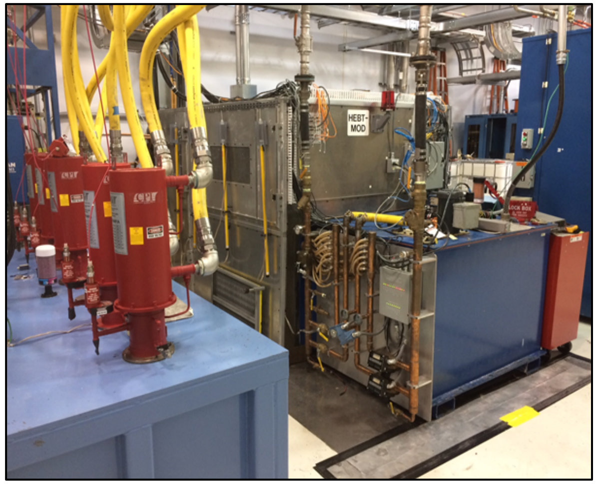


Testing RF

DTL RF system

New equipment to power the new cryomodules

- High voltage convertor modulators use new topology
- Klystrons will be same as presently in use



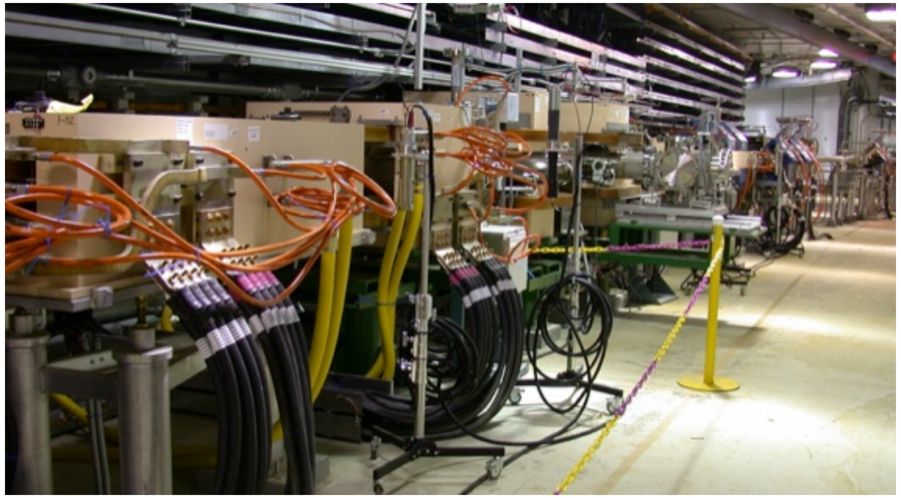
AT HVCM undergoing heat test

SCL klystrons

Accumulator ring upgrades

Injection magnets

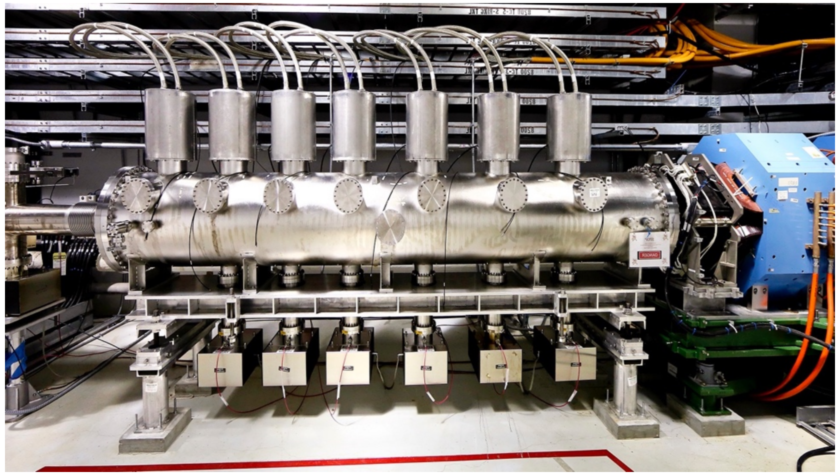
- Some chicane magnets need replacement



Partnering with FNAL

Extraction region

- Extraction kickers: upgrade existing power supplies rather than add new kickers

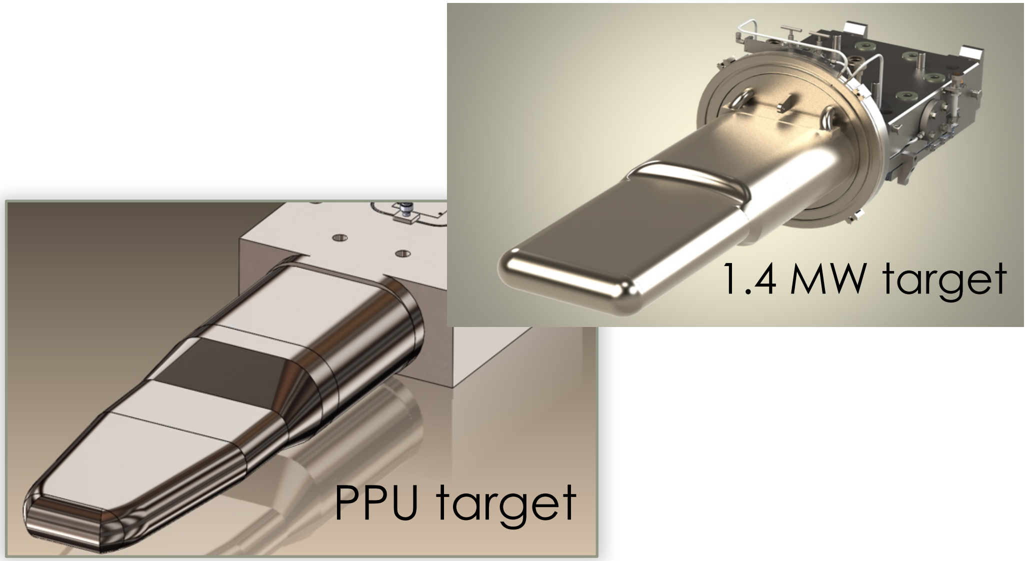


96% of magnets and power supplies are 1.3 GeV capable now

Target upgrades

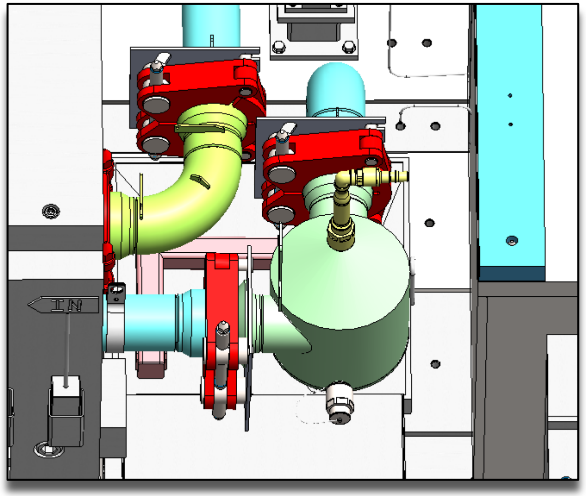
New 2 MW mercury target vessel

- Enhanced structural design
- Enhanced gas bubble injection
  - 10x increase flow rate
- Gas wall in nose



Other target systems

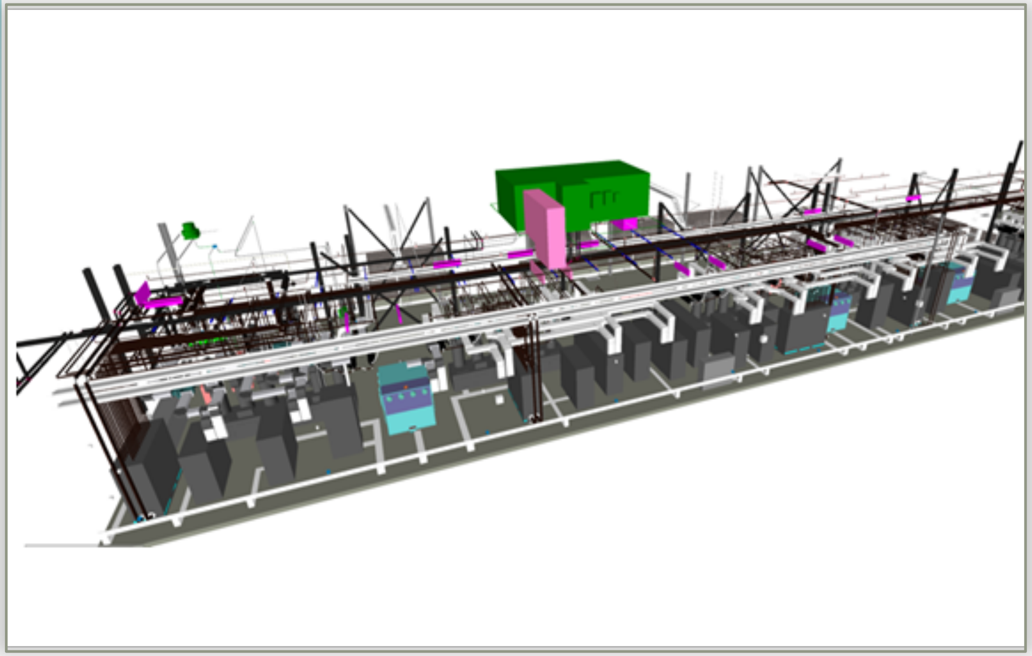
- Recirculating injected He gas in service bay
- Ensuring 2MW capable systems



Conventional facility upgrades

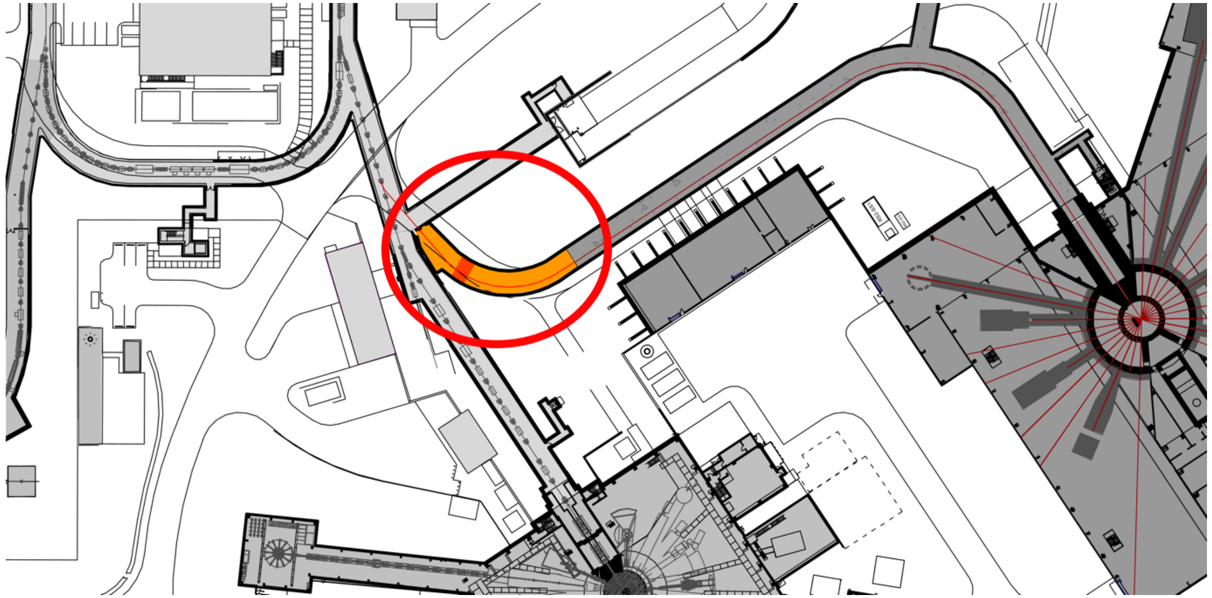
Klystron gallery buildout

- Coupled CF / technical systems 3-D layout to facilitate installation



Tunnel stub to Second Target Station (STS)

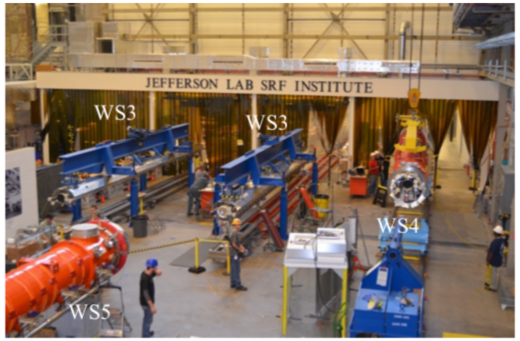
- Facilitates seamless tie-in to STS

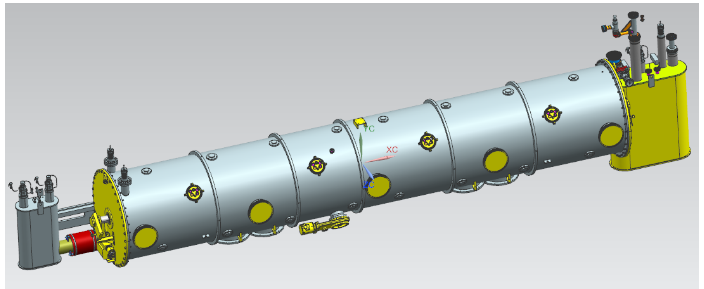


PPU is partnering with other laboratories

J-Lab is building the new superconducting cryomodules

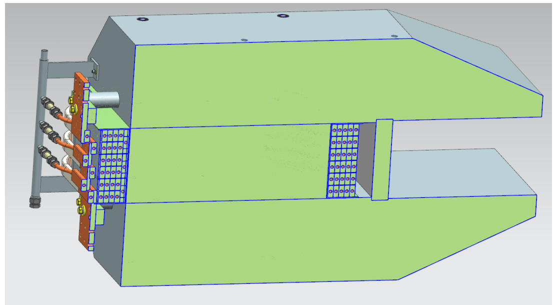
- J-Lab built the original SNS cryomodules, has the resources and facilities for this task



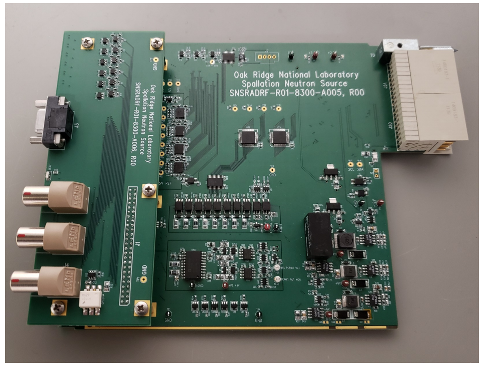


FNAL: Ring magnet scope

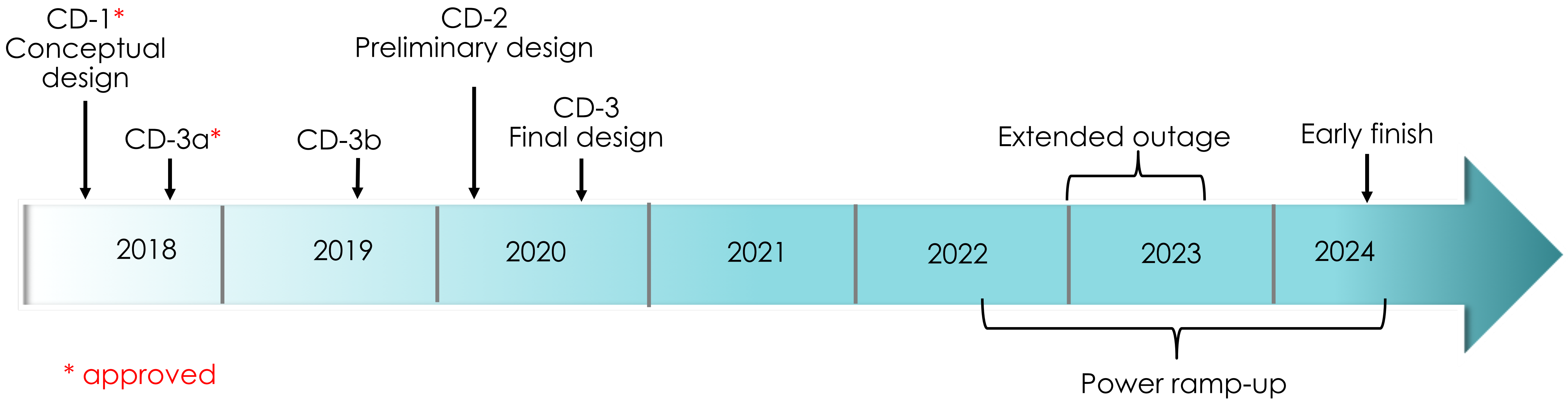
FNAL chicane magnet design



LBNL: LLRF



Power upgrade project timeline



- Aggressively pursuing "early procurements" to accelerate schedule
  - CD-3a, CD-3b
- Plan a power ramp-up starting in 2022
- Early finish in 2024

Summary

- SNS has reached its design operational power of 1.4 MW
  - Builds on many years of development
  - Target and RFQ improvements are most recent steps forward

- An accelerator upgrade project (PPU) is underway to double the power capability
  - Largely based on existing accelerator technology
  - Partnering with other labs to leverage fabrication capabilities

Thanks!

Questions ?