SNS upgrade and power ramp-up

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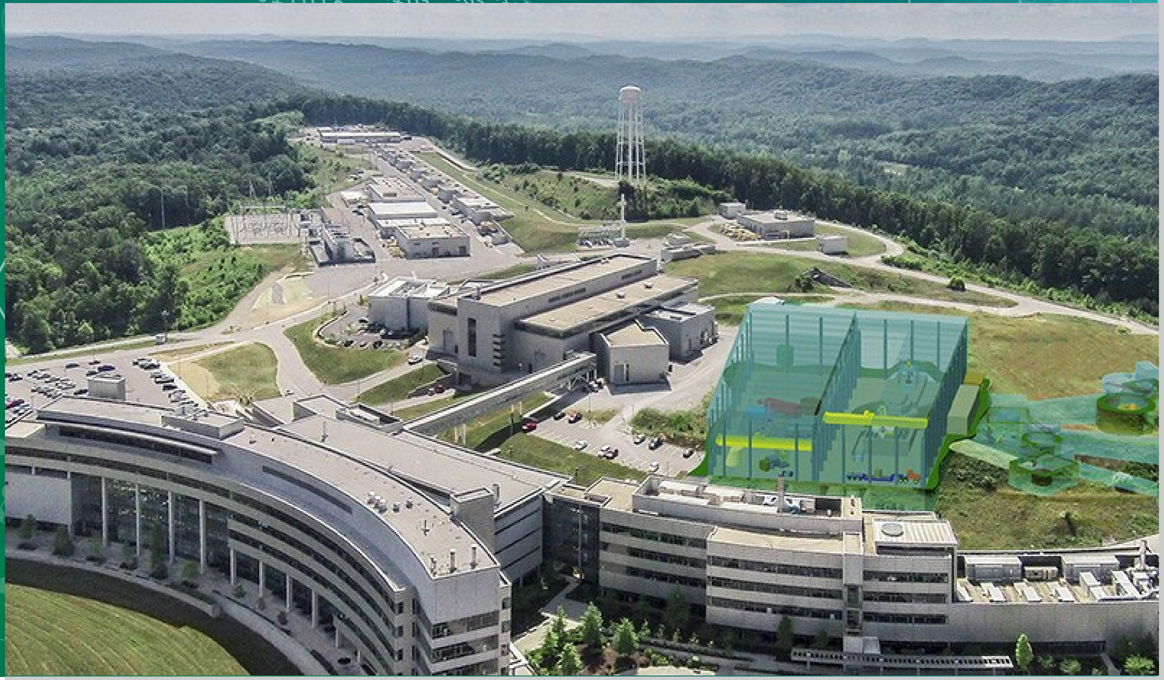

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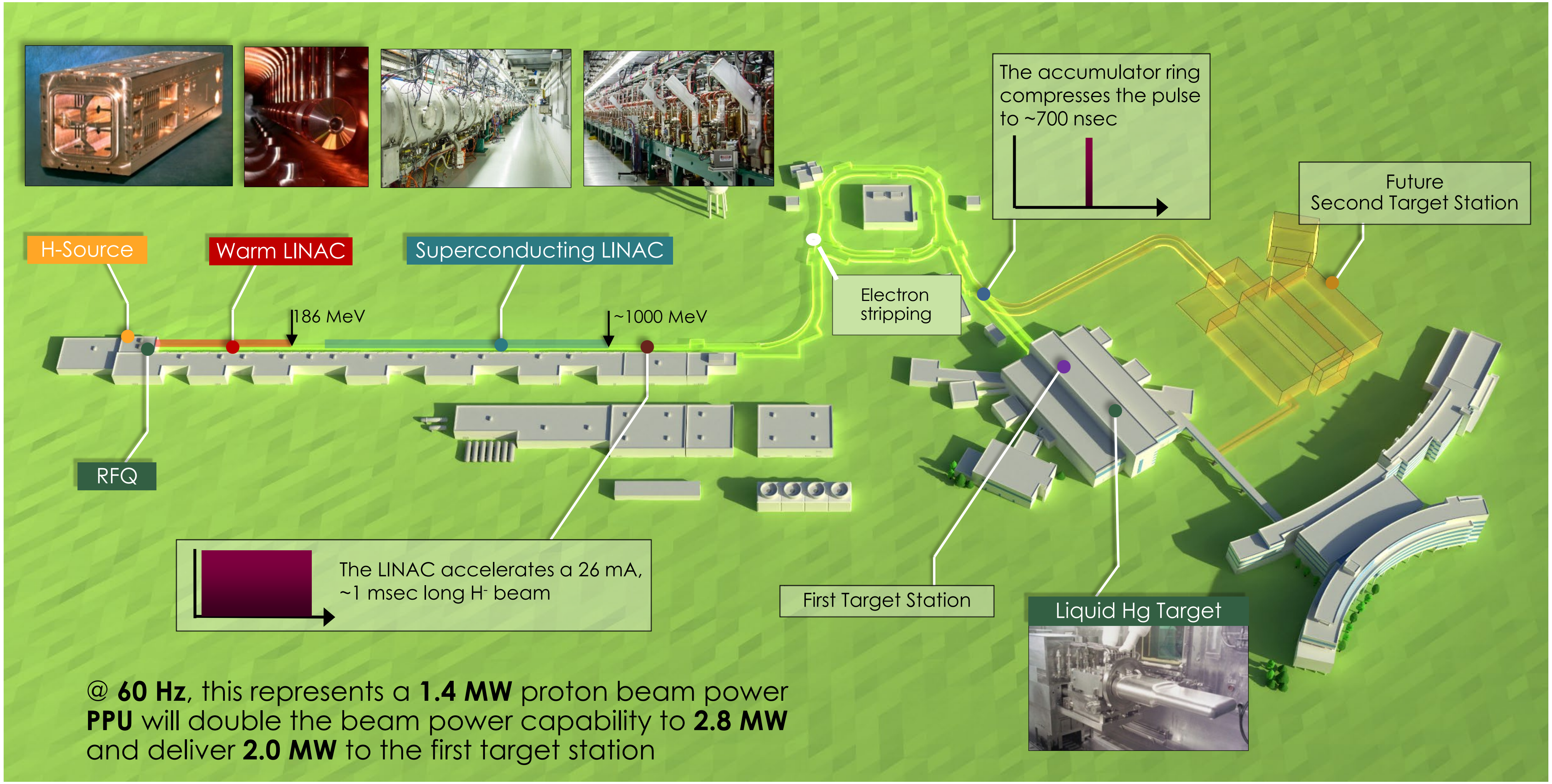
Outline

- SNS overview
- Proton Power Upgrade (PPU)
- SNS operational performance
- Recent power ramp up to 1.7 MW
- Plans to reach 2MW and beyond
- New scientific missions and applications
- Accelerator R&D highlights
- Conclusion

Accelerator overview: how we **generate protons**



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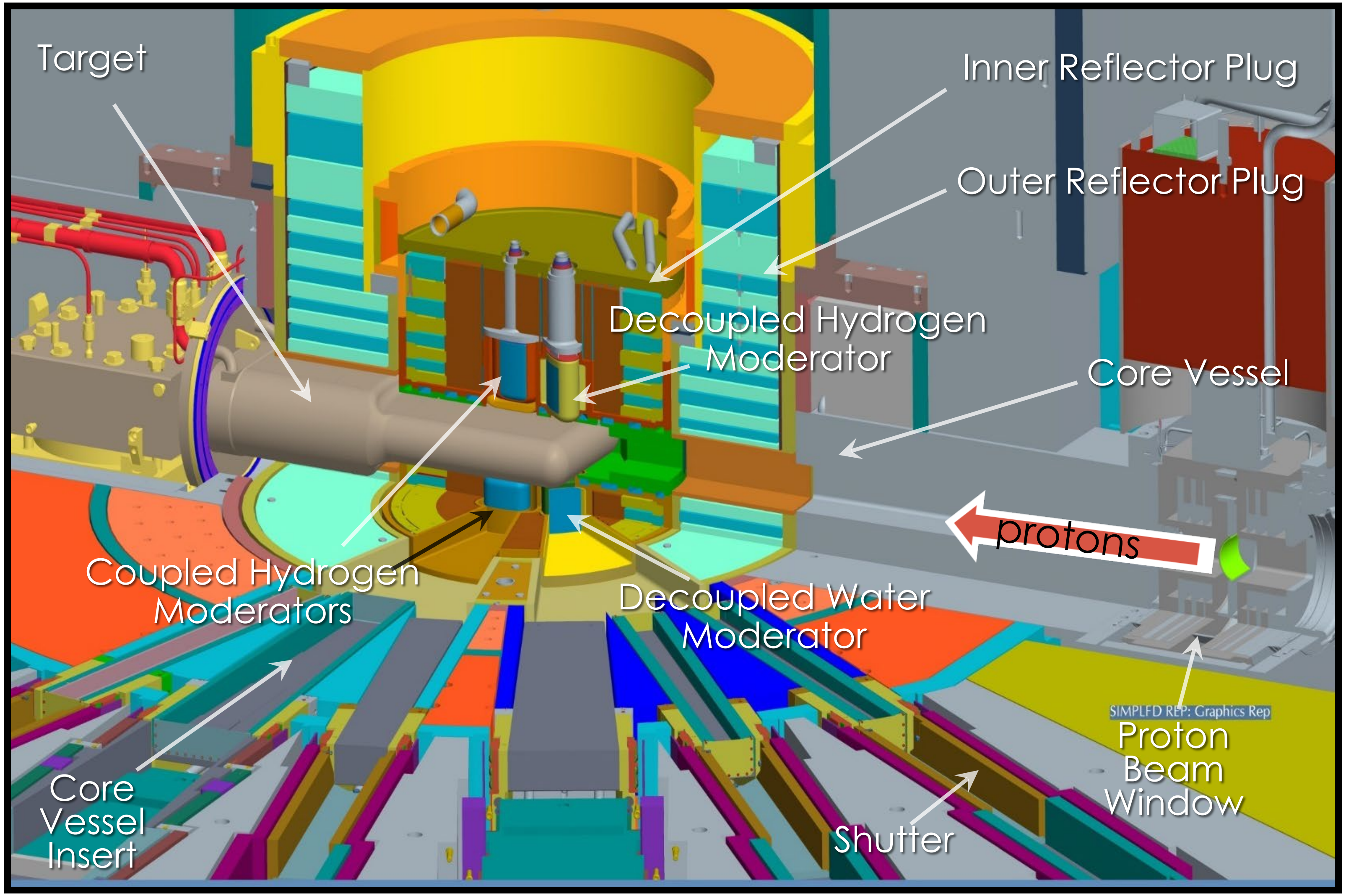
Target systems overview: how we **generate neutrons**

- Target module and mercury systems (Hg Loop)
- Inner reflector plug (IRP)
- Cryogenic moderator system (CMS)
- Proton beam window (PBW)
- Shutters, core vessel inserts
- Target utilities

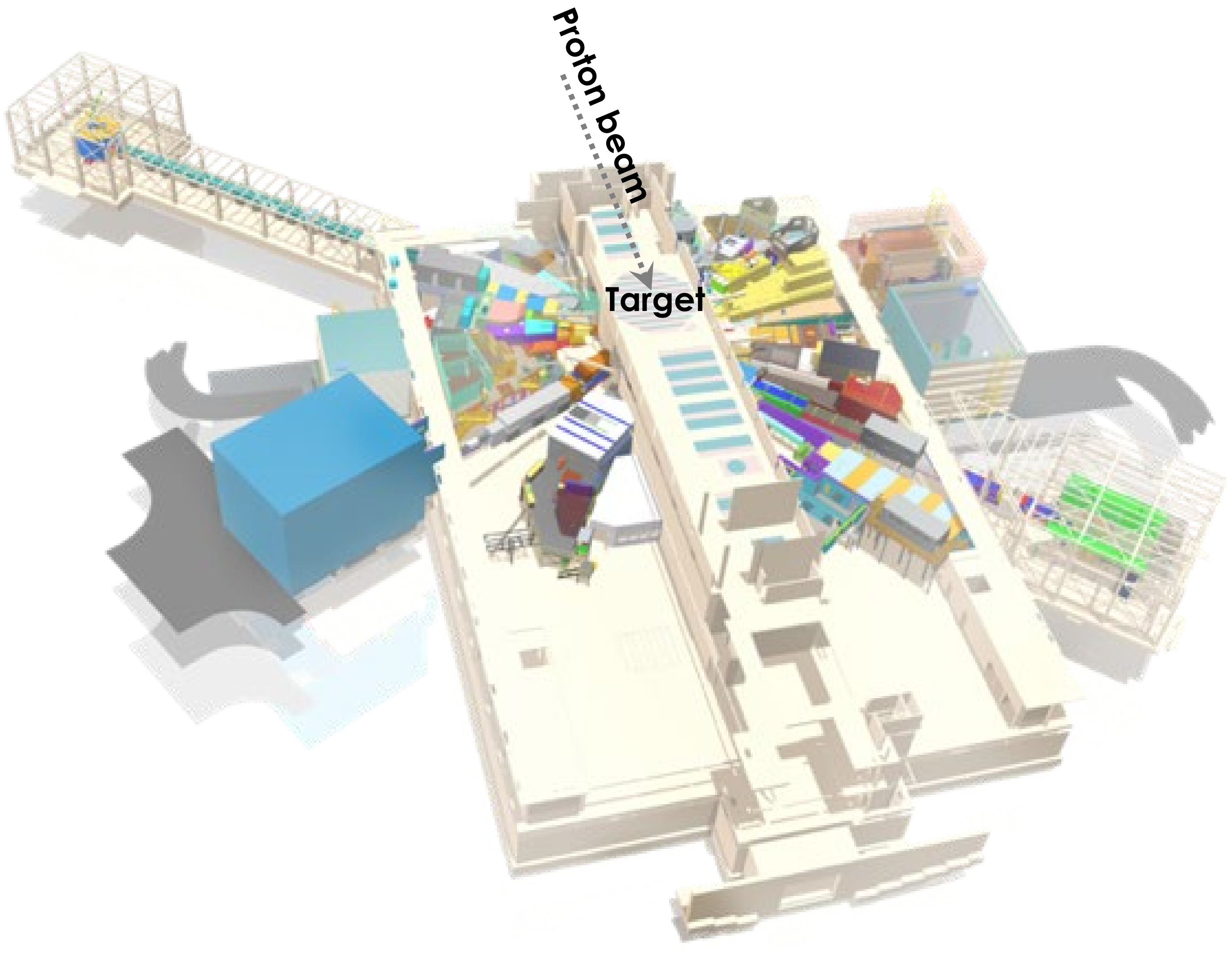


SNS instrument overview: How we **use neutrons**

- 18 operating neutron scattering instruments
- 1 under construction
- 2 fundamental physics experiments:

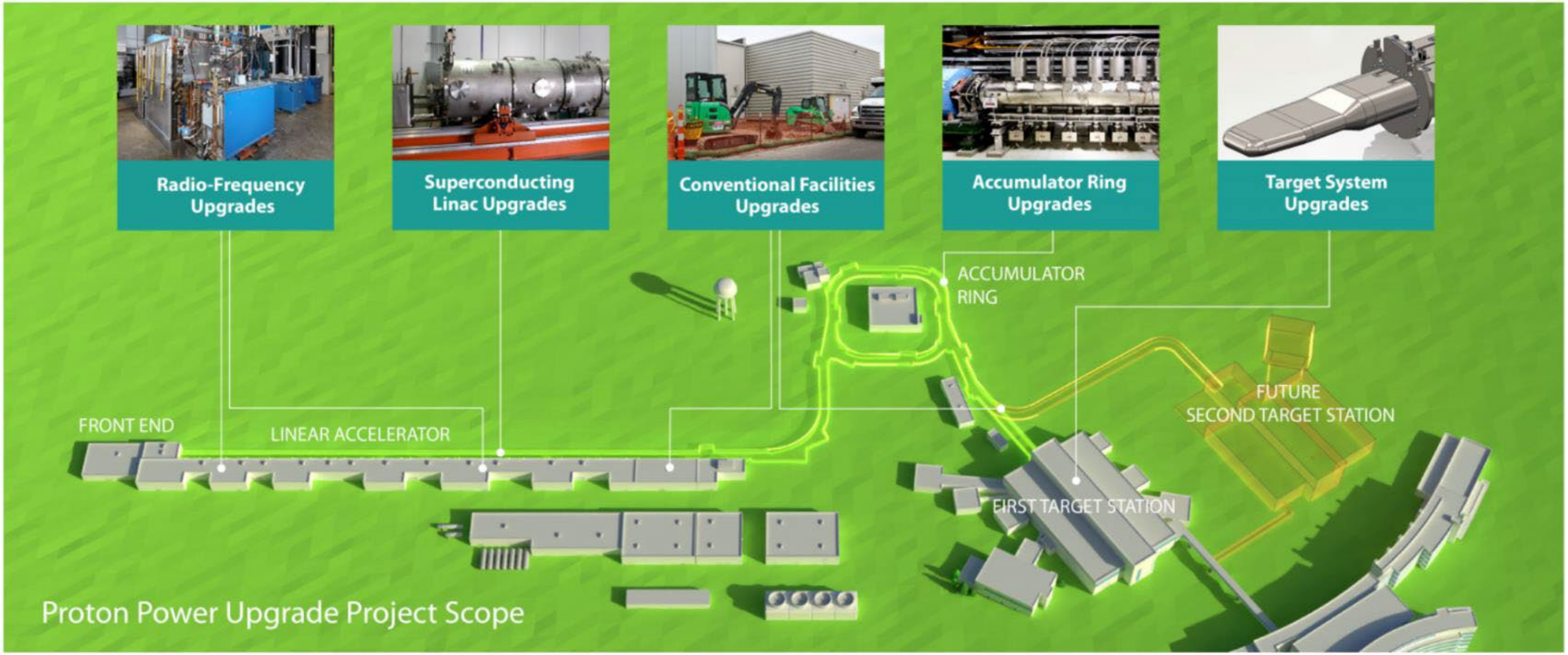
  BL-13/EDM

  Coherent- neutrinos



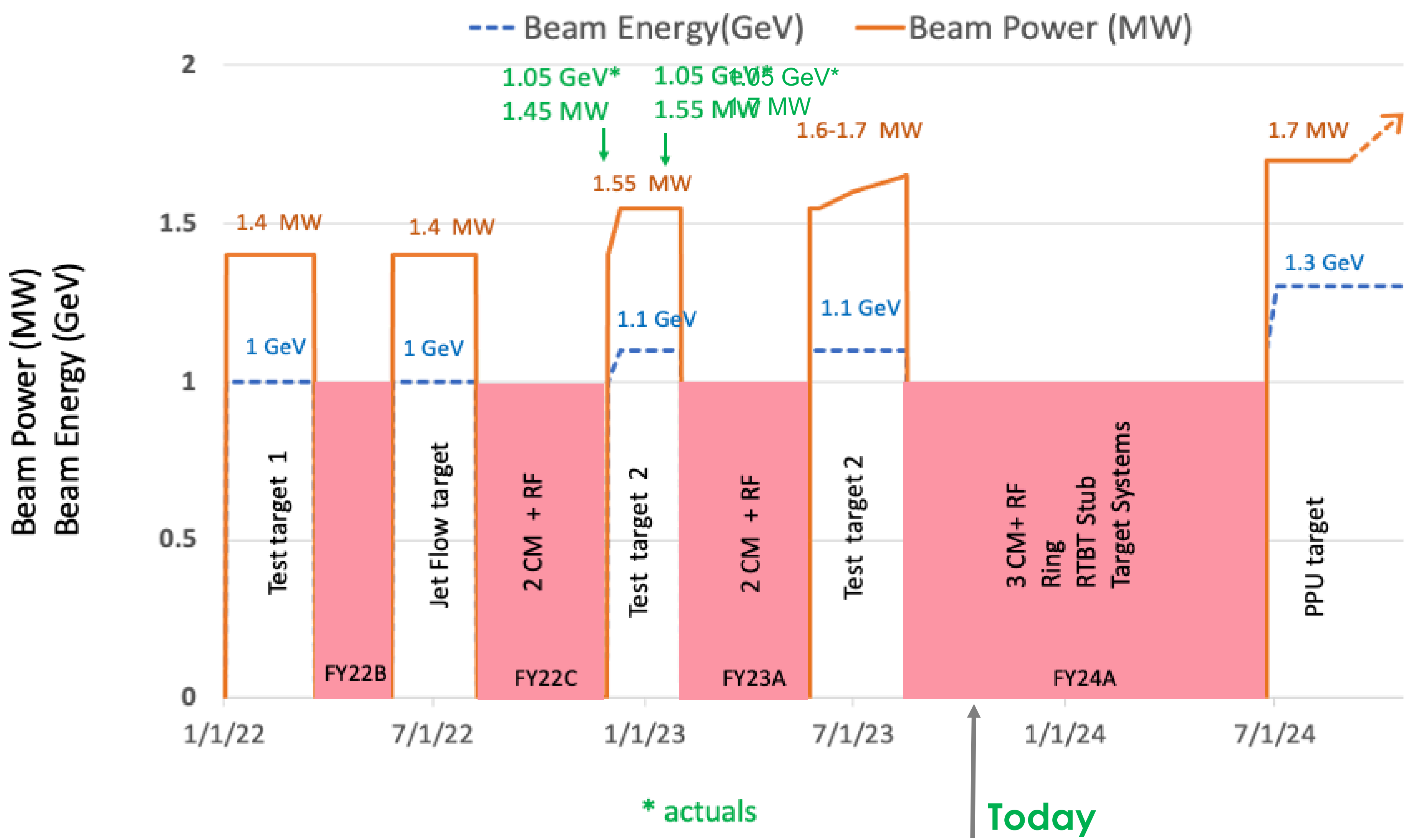
Proton Power Upgrade project scope

- Upgrade the SNS accelerator beam power capability from 1.4 MW to 2.8 MW
  - 30% beam energy increase: 1.0 GeV → 1.3 GeV
  - 50% beam current increase: (at least 46 mA from source, with 90% RFQ transmission)
- Includes scope across much of the neutron source



Recent PPU achievements

Power Ramp-up Plan



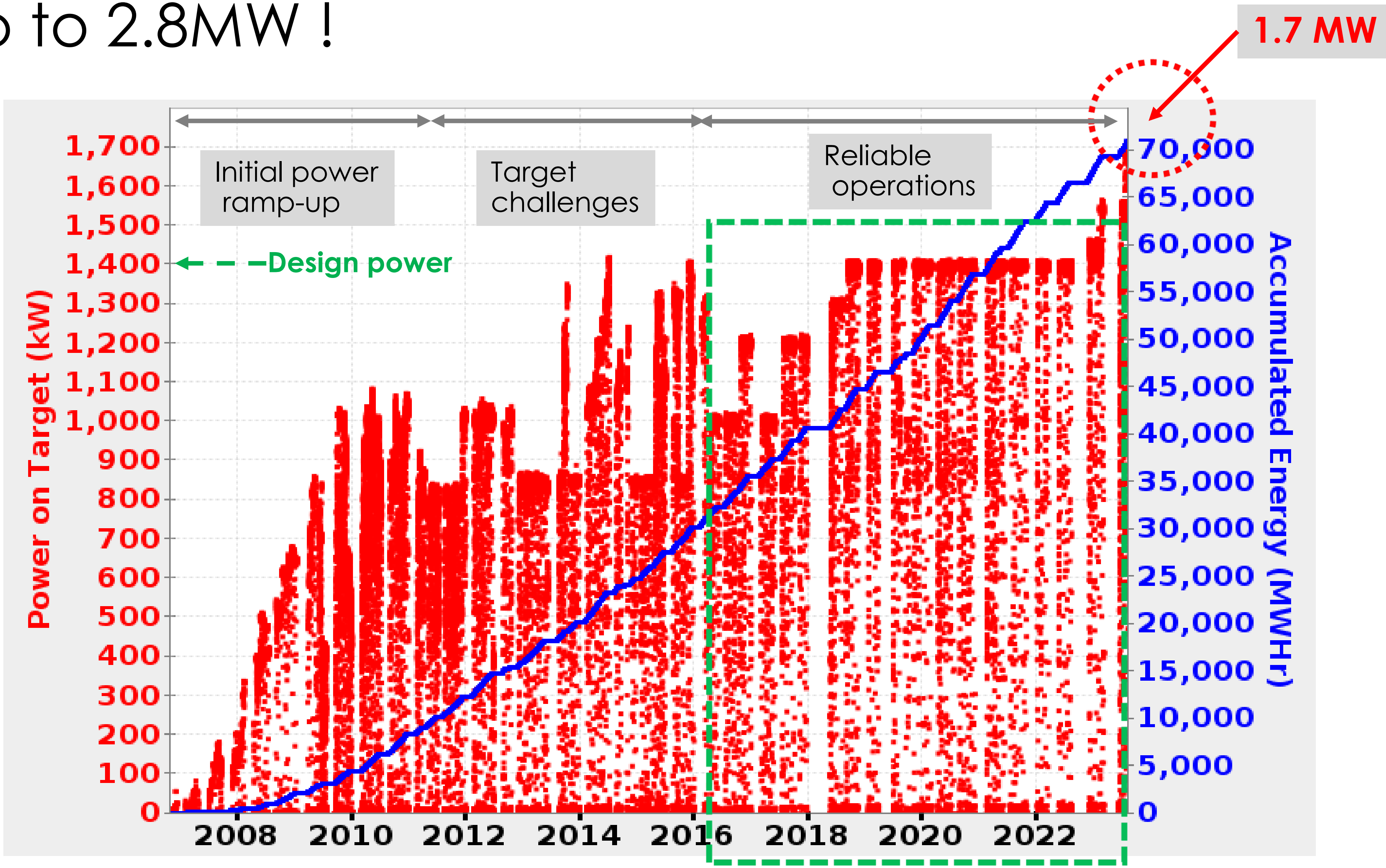
SNS has operated reliably at 1.4 MW and has started the power ramp-up to 2.8MW !

The SNS is the highest power SRF linac world-wide

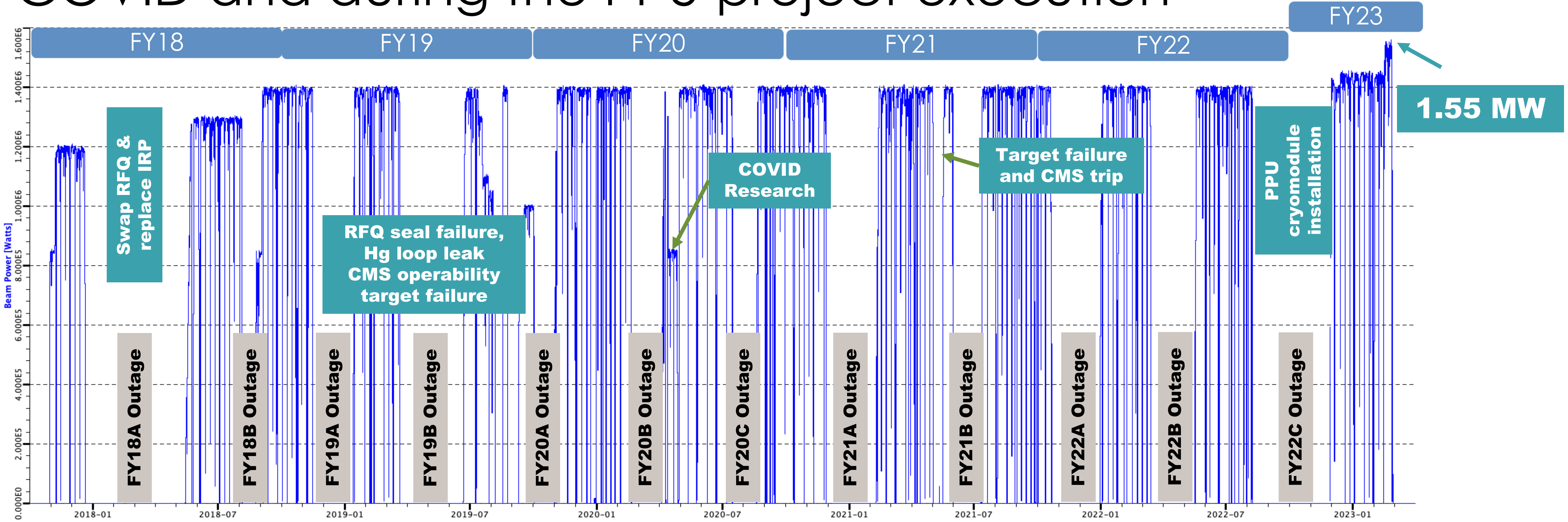
Successfully operated at **1.7MW** this year

Capable of **2.8-3 MW**

SNS doubling in power opens opportunities to leverage the facility potential for new scientific missions and applications, in addition to neutron scattering



SNS has maintained successful operations through COVID and during the PPU project execution

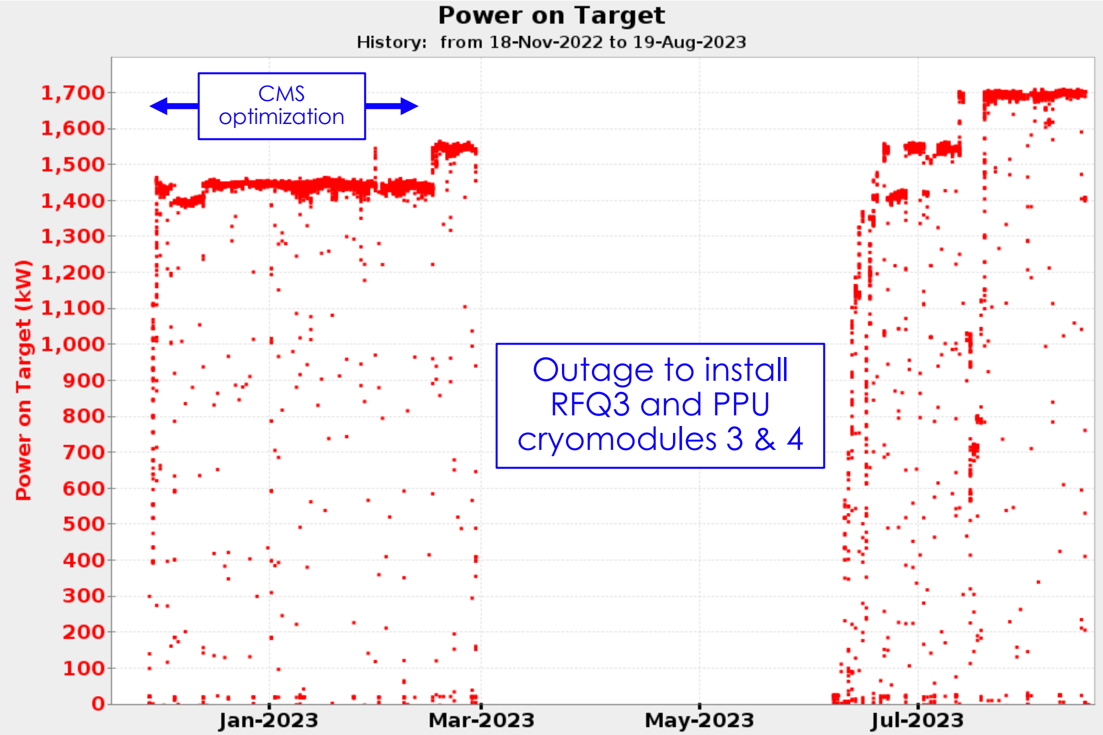


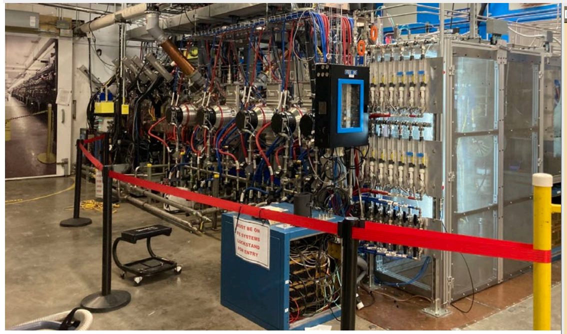
Fiscal year	Hours scheduled	Hours delivered	MWh to target	Availability	PMM goal	% of PMM	Downtime
2018	3185.2	3009.5	4233.1	94.6%	2850	105.6%	175.7
2019	5955.6	3771.2	4928.1	61.0%	4900	77.0%	2184.4
2020	5080.5	4828.9	6843.2	94.9%	4600	105.0%	251.6
2021	5055.1	4503.9	6540.3	88.9%	4600	97.9%	551.2
2022	3792.2	3275.2	4758.5	85.7%	3200	102.4%	517.0
2023	3030.7	2790.1	4412.2	91.8%	2700	103.3%	240.6

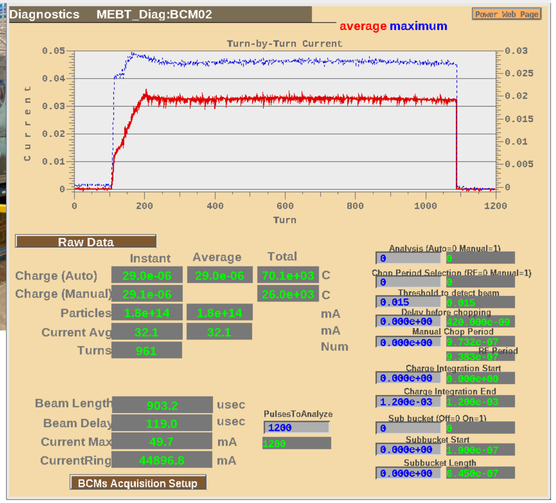
Demonstrated Routine 1.7 MW Operations

- **Early 2023**: production beam power reached 1.55 MW at 1050 MeV though with minimal beam current margin
  - Turned up the **RFQ** field to increase beam current but limited the increase due to worry about potential RFQ seal damage
  - Installed PPU **cryomodules** enabling 1100 MeV beam energy
  - A **ring magnet** (injection dump septum**) saturated** limiting beam energy to 1050 MeV
  - Significant time needed to optimize performance of **Cryogenic Moderator System** (CMS) response to increased beam power and abrupt beam trips

- **Mid 2023**: the new RFQ was installed which allowed for routine 1.7 MW operations at 1050 MeV with appropriate beam current margin



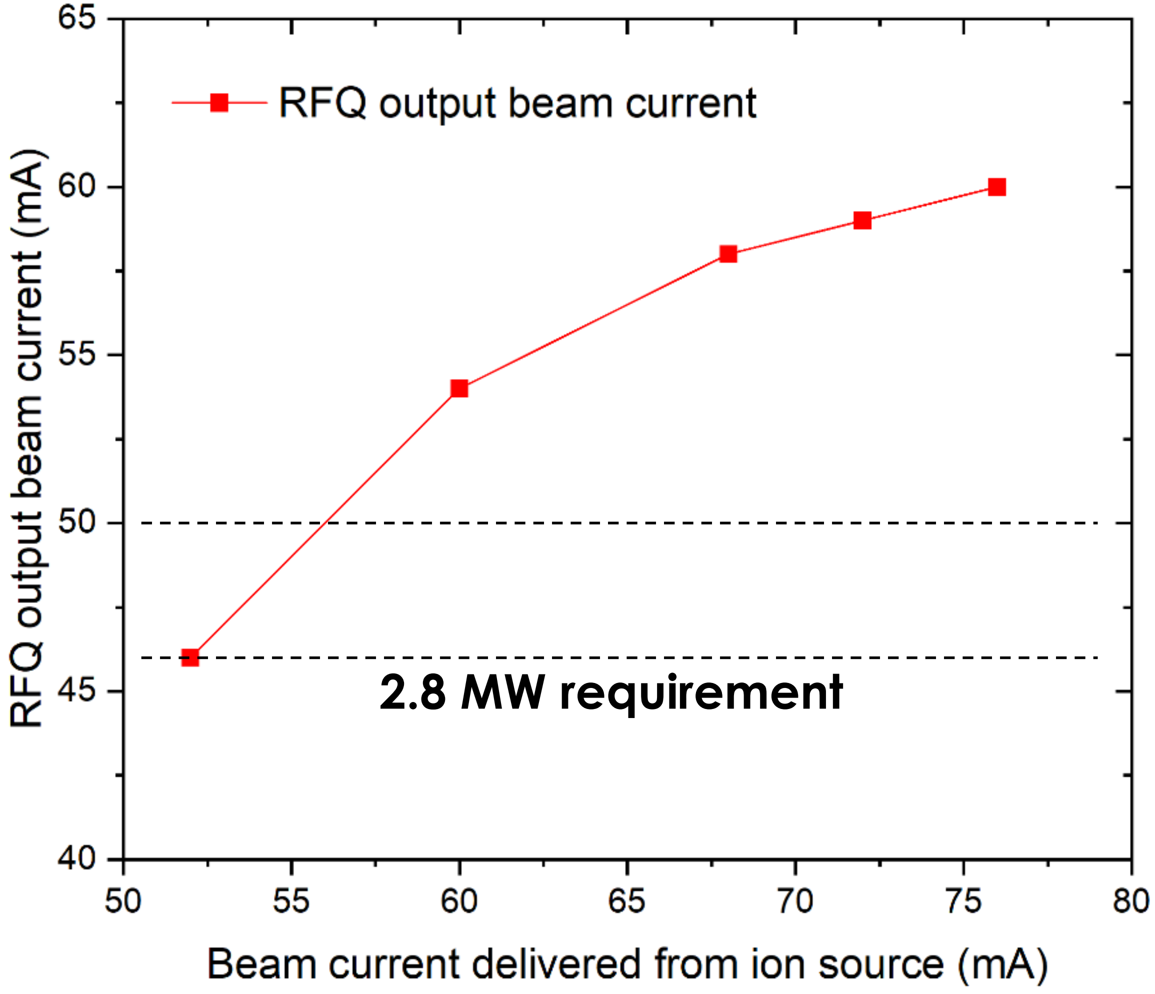




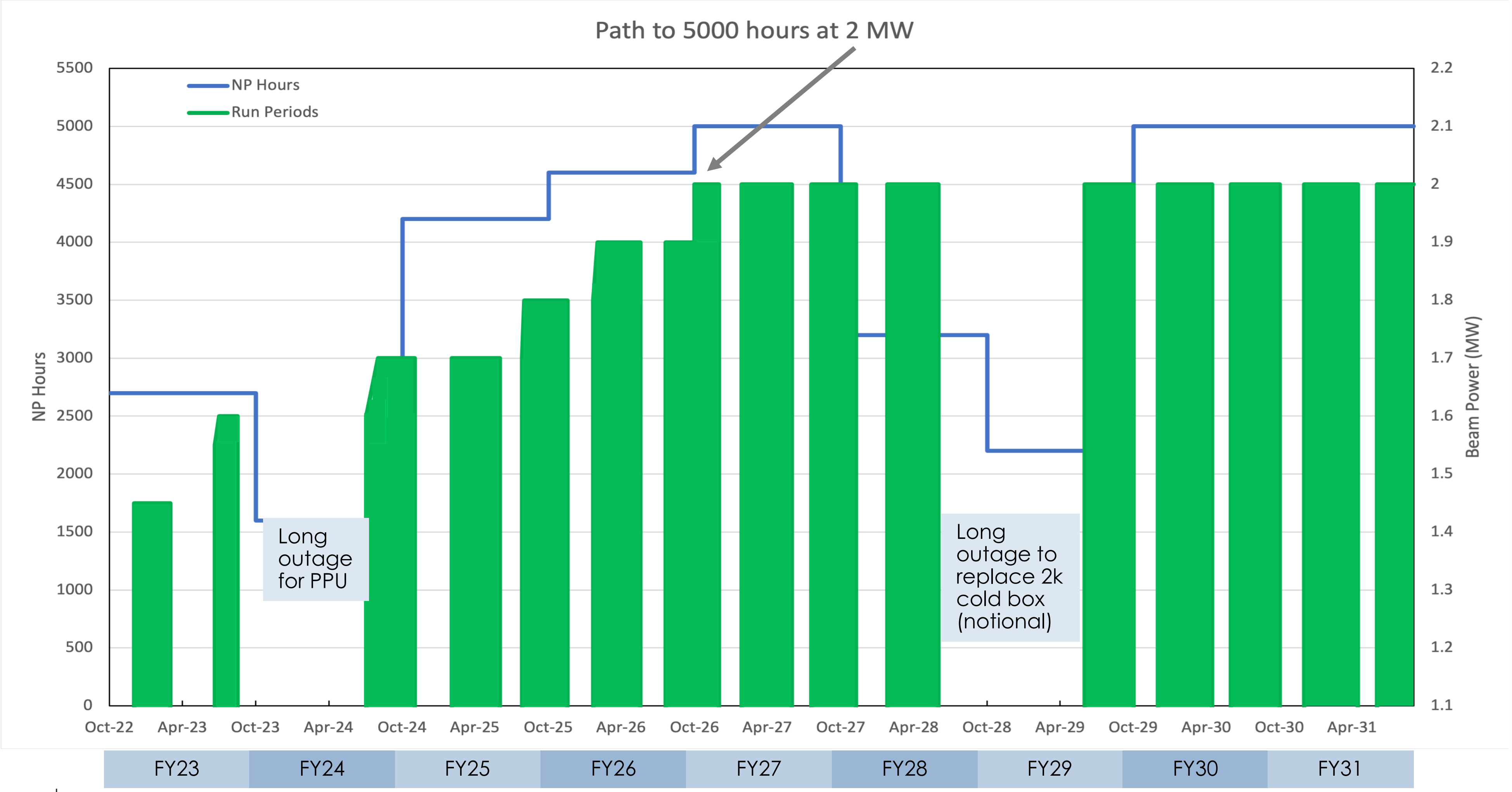
Above: RFQ3 installed
Right: Linac **peak** and **average** beam current

Record beam current achieved at the SNS Front-End

- Tested a newly improved SNS H^- ion source with RFQ on the SNS Front-End
  - Equipped with an advanced extraction system: larger outlet aperture, ϕ**9mm**, and an optimized electron dumping circuit
- Achieved **60 mA RFQ output** beam current
  - The beam current delivered from the ion source was administratively **restricted to <80 mA** per the SNS Operation Envelope Limit
  - The ion source was operated within their routine operational RF power levels (<50 kW) during the testing



The journey towards 2 MW and 5,000 hours (2.8 MW may take 1-2 more years)

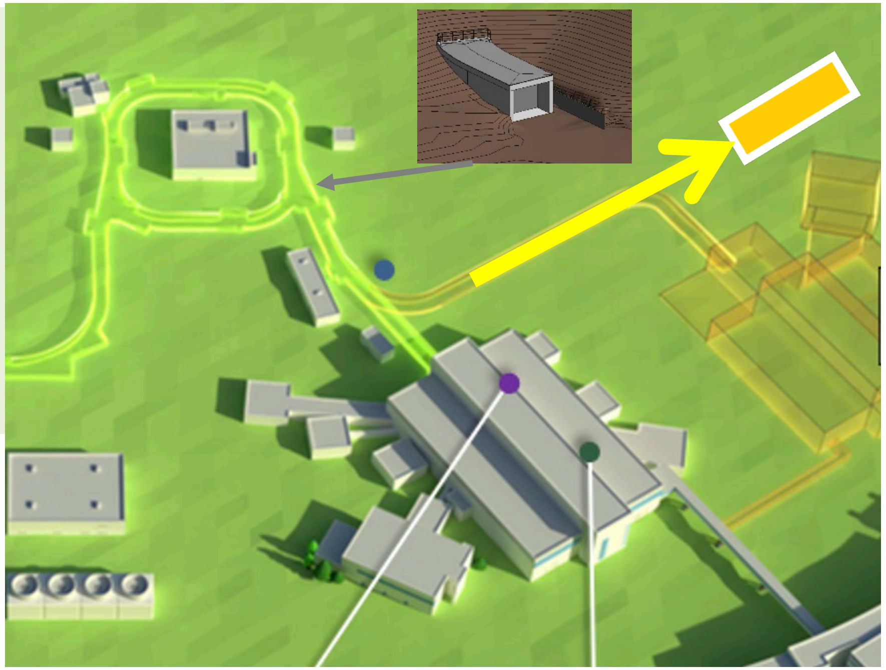


SNS science and opportunities beyond neutron scattering

At **1.7 MW** the SNS linear accelerator is the **highest power proton accelerator in the world**. The facility will be capable of **2.8 MW** after the execution of the Proton Power Upgrade (PPU)

Discussed at the 2021 Neutron Advisory Board and included in NScD 10-year strategic plan

Opportunity:
Advancing the construction of the STS beamline can make the extra power available for use before the STS is completed



A multi-MW **high-power linear accelerator** is the optimal driver for applications such as:

- **Isotope production** (accelerator driven production, ISOL)
- **Irradiation facility** (SEE – *Single Event Effects, High-Power Target Testing Facilities*)
- **Intense muon source** (mSR – *muon spin resonance,* muon beams)
- **Fundamental physics** (neutrinos, neutrons, accelerator R&D for muon collider)
- **Material testing for nuclear fusion** (with extracted SNS beam or target mount)
- **Accelerator driven systems** (transmutation nuclear fuel, energy production)

Why the time is now?

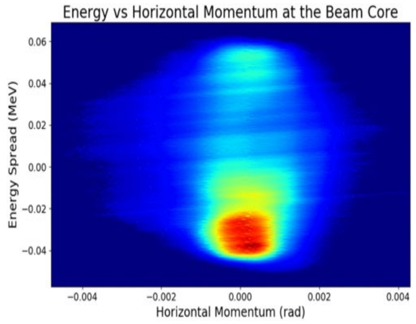
- We are on the verge of doubling SNS power
- Multi-B$ investment on SNS, STS from the US taxpayers → maximize facility utilization
- ~10 years ago, the focus/concern was facility performance (operation at 1.4 MW) and reliability (targets) …on both counts we succeeded, and we can do more.
- Utilize the extra power that will be available after PPU:
  - Anticipating the construction of the STS beamline can enable early utilization of up to **800 kW** of beam power (STS early CD4 now in FY38)
  - Concurrent operation of FTS, STS and additional facility is possible
- Multiple missions strengthen a facility: all neutron sources in the world (J-PARC, PSI, ISIS, LANL….) are supporting multiple missions and ESS is planning to. HIFR at ORNL supports multiple missions.

Accelerator R&D program produced several "firsts"

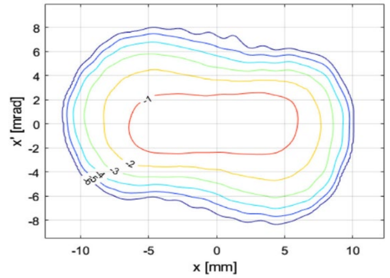
Focused on SNS improvements and advanced research – *leverages SNS unique capabilities*

New records in dimension & dynamic range at BTF

- Completed the first 6D phase space measurement

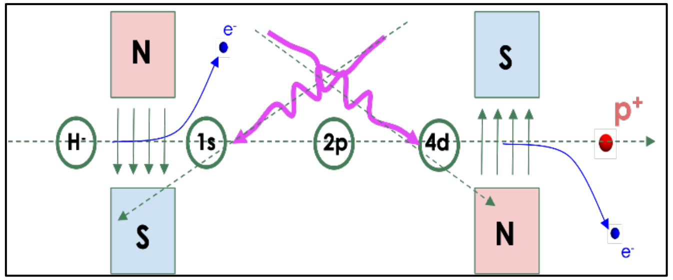


- Completed the first 1part-per-million 2D phase space measurement



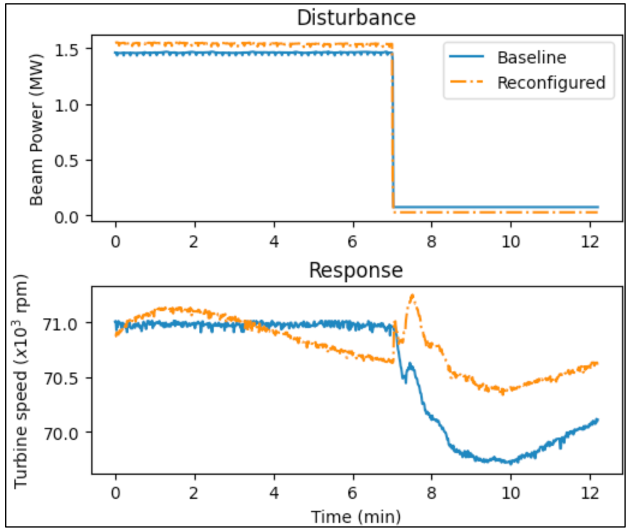
Laser power challenges solved for LACE

- Two new techniques - sequential resonance excitation, crab crossing – have made 1 ms laser assisted charge (LACE) exchange feasible for the first time with the use of commercial lasers
- Next step is the design of an injection system for the SNS to test operational efficiency



Model-based, ML-assisted tuning of CMS achieved

- A model-based approach with machine learning was used to improve performance of the Cryogenic Moderator System
- Resulted in improved system behavior required for future 1.7 MW operation



HB2023 contributions from SNS

Tuesday 10/10

- Trent Thompson - *Effect of three-dimensional quadrupole magnet model on beam dynamics in the FODO line at the SNS Beam Test Facility*
- Austin Hoover - *The impact of high-dimensional phase space correlations on the beam dynamics in a linear accelerator*
- Andrei Shishlo - *SNS Linac Beam Dynamics: What We Understand, and What We Don't*
- Timofey Gorlov - *Laser stripping of H- beam*

Wednesday 10/11

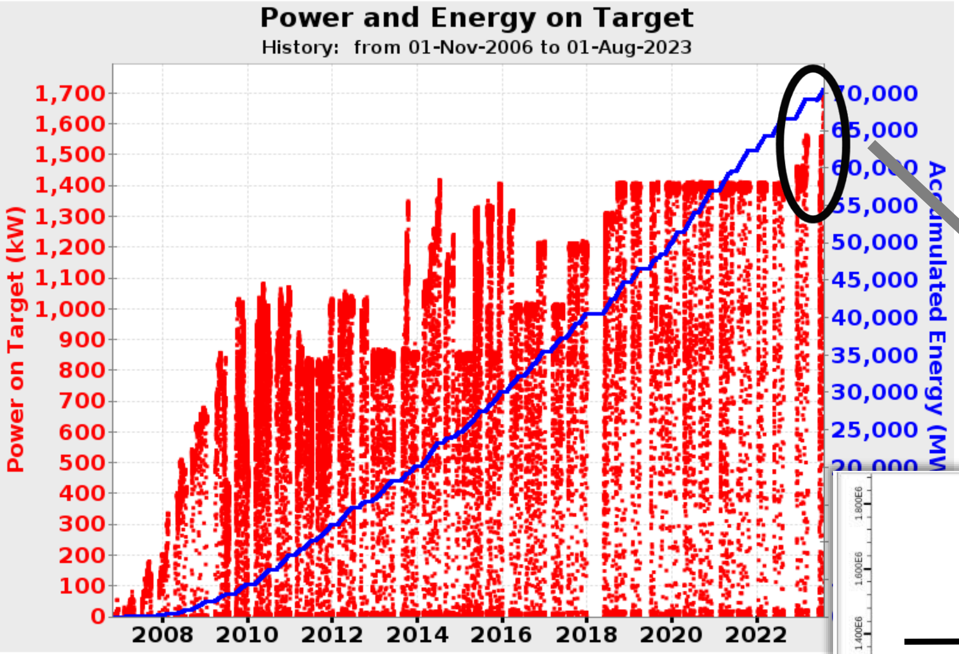
- Abdurahim Oguz - *Two-Dimensional Temperature Measurements of Nanocrystalline Diamond Stripper Foils at the High Intensity Hydrogen Ion Beams at SNS*
- Nicholas Evans - *Self-Consistent Injection Painting for Space Charge Mitigation*

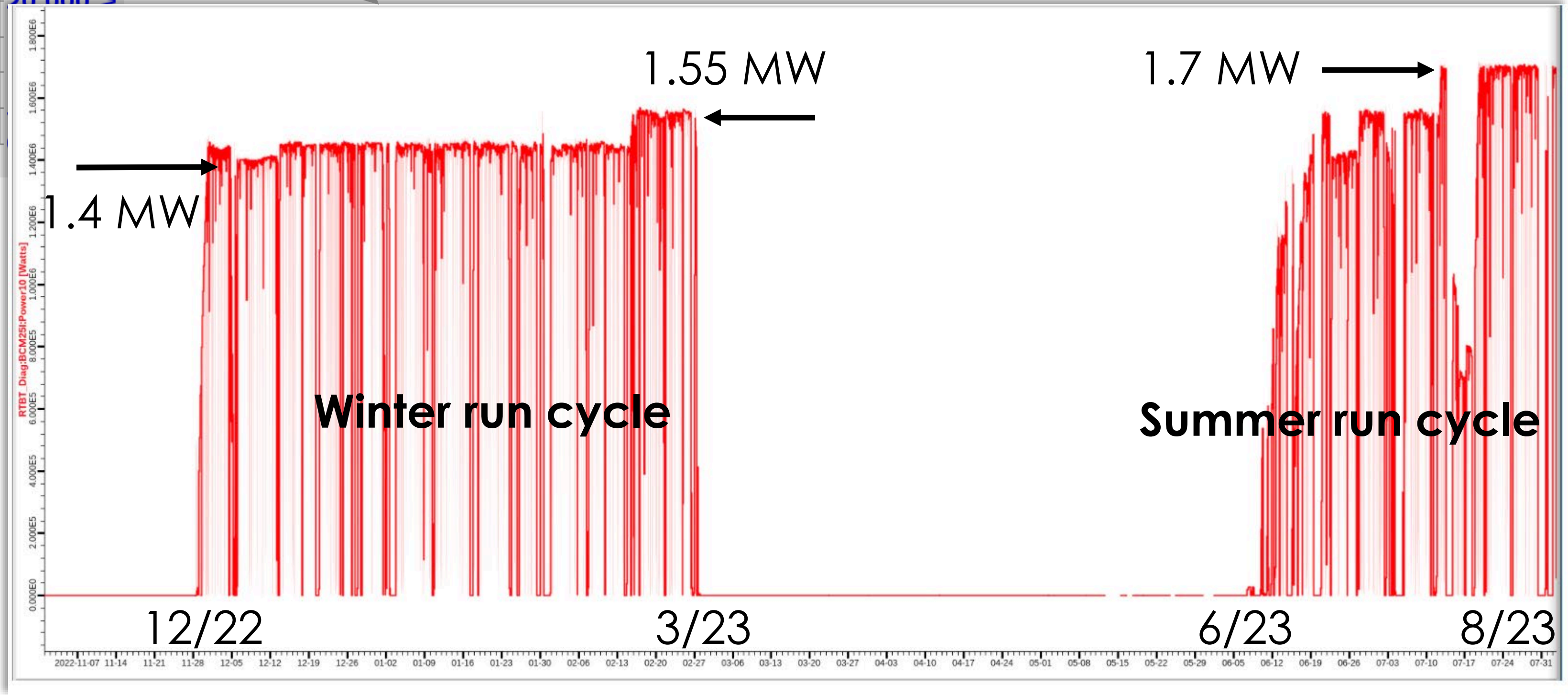
Summary

- The SNS has delivered a vibrant science program in neutron scattering, instrument development, accelerator R&D, and fundamental physics
- SNS has operated safely and reliably at 1.7 MW, and continues the ramp-up towards 2 MW and ultimately 2.8 MW
- The facility goal for post-PPU operation is 5,000 hours of neutron production. This will require a strong focus on operational excellence, facility availability and system reliability (with particular emphasis on target support systems)
- We have ambition to grow our scientific mission and application portfolio

BACK-UP

Power ramp-up result: after 5 years of running 1.4 MW, beam power is increasing



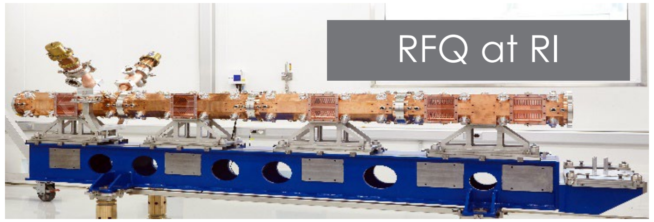


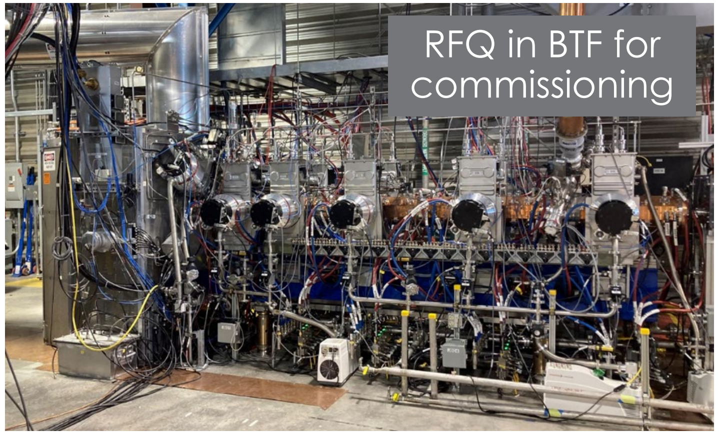
- Power ramp-up more or less follows the plan
- New equipment operates reliably

Other key systems improvements to support ramp-up

New RFQ ready for operations in the SNS Front end

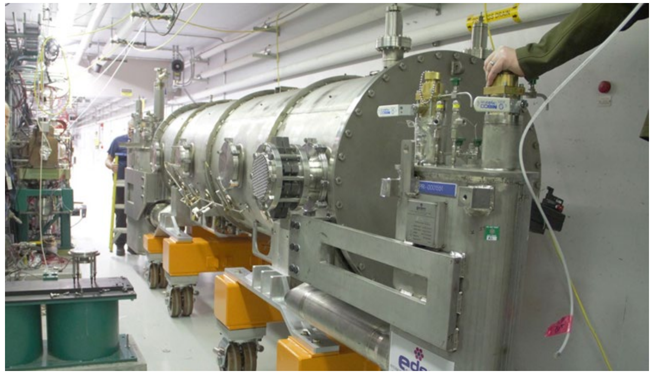
- RFQ built at RI (DE), delivered on June 27, 2022
- Tested and commissioned in BTF
- Now in operation at the SNS front-end





High and medium-beta spare cryomodules

- Spare cryomodules fabricated in-house by SNS personnel allows SNS to repair medium beta cryomodules
- Spare high-beta and medium-beta cryomodules and is-situ plasma processing insure constant beam energy



Installation of the spare medium beta cryomodule in the slot 1 in February 2020

Lesson learned driving improvement in Hg Loop

- Moved gas supplies to high-bay
- Corrected and improved instrumentation → detected and mitigated leak in 2022