Spallation Neutron Source Progress, Challenges and Upgrade Options

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EPAC 2008

June 26, 2008

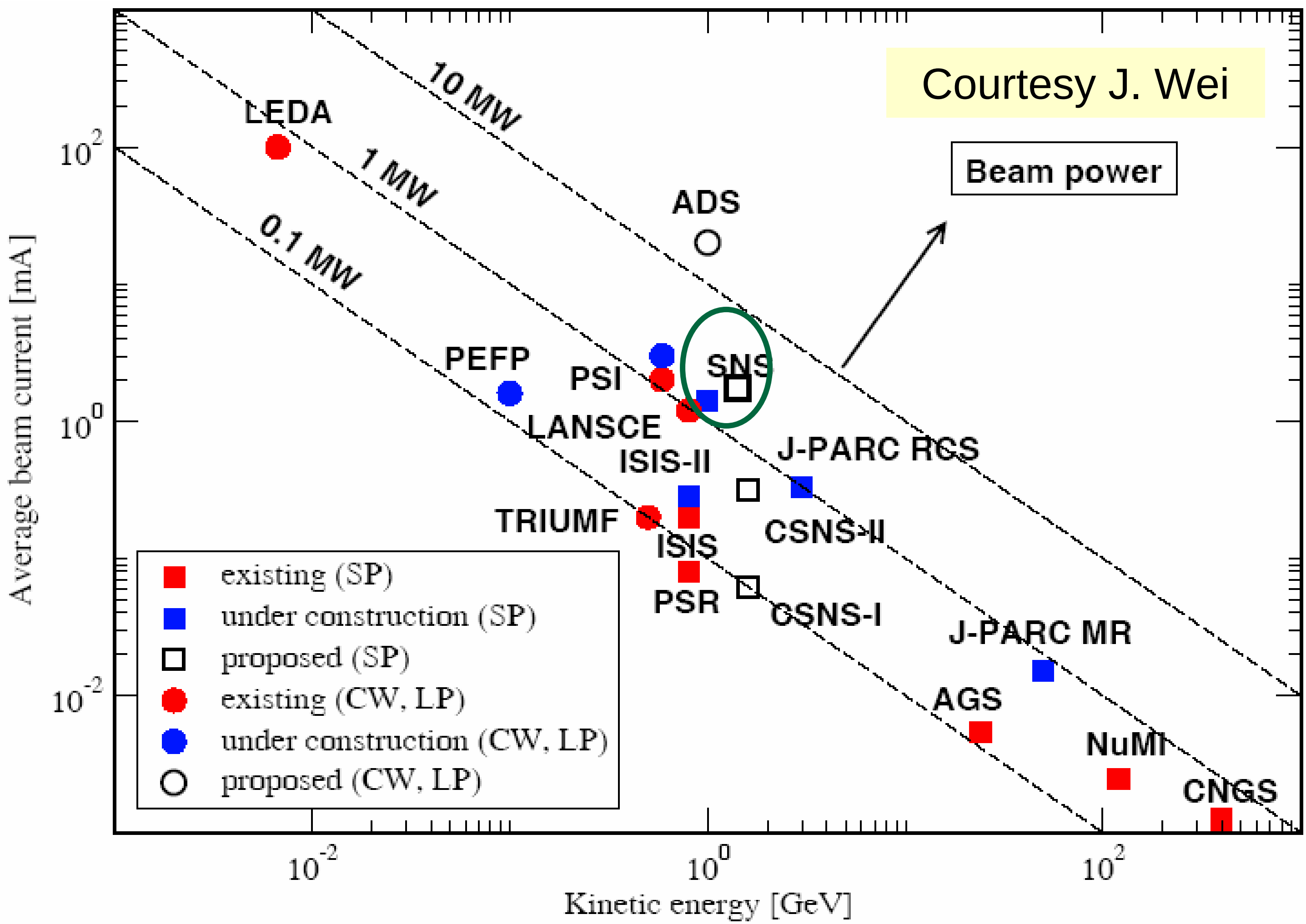
The Spallation Neutron Source

- **The SNS at Oak Ridge National Laboratory is the world's most powerful short-pulse neutron source**
- **The SNS construction project, a collaboration of six US DOE labs, began in 1999 and was completed on-time and within budget in 2006 at a cost of 1.4 B$**
- **SNS mission is to become the world's leading facility for neutron scattering**
- **SNS began formal operation in late 2006, and now routinely provides neutron beams to five scattering instruments**

- **We are half-way through an anticipated 3-year ramp up to MW-class operation**

The Beam Power Frontier for Protons

- Central challenge at the beam power frontier is controlling beam loss to minimize activation
- 1 nA protons at 1 GeV, a 1 Watt beam, activates stainless steel to 80 mrem/hr at 1 ft after 4 hrs

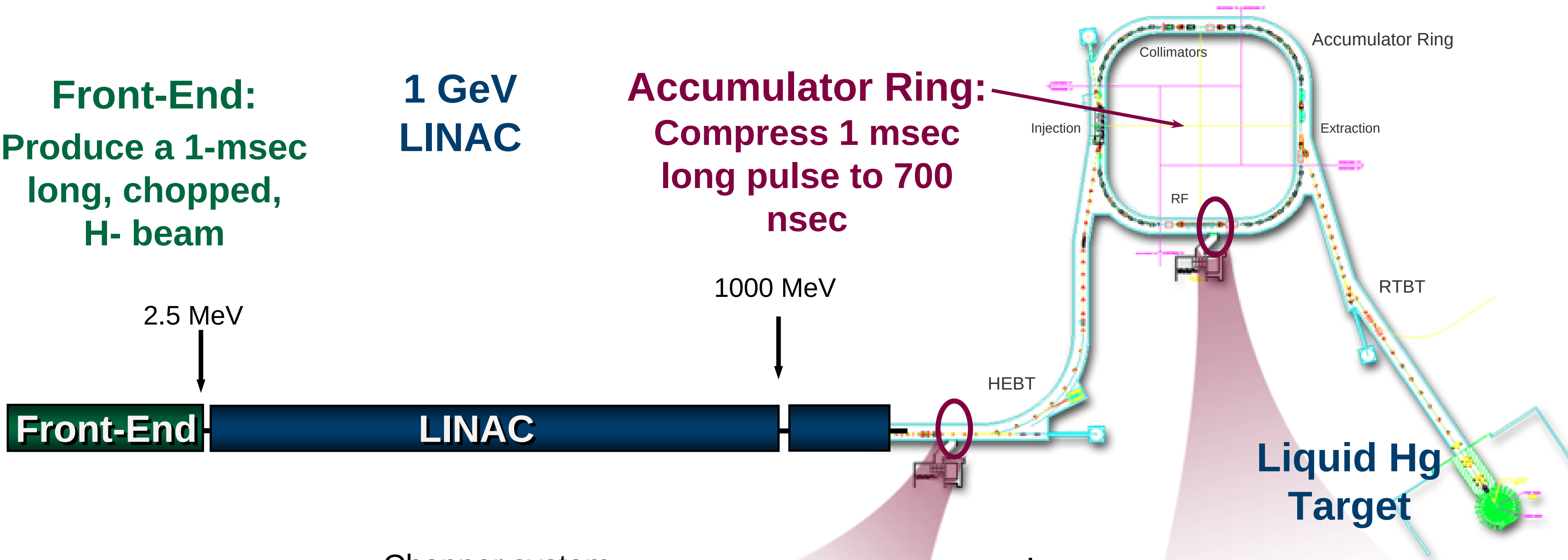


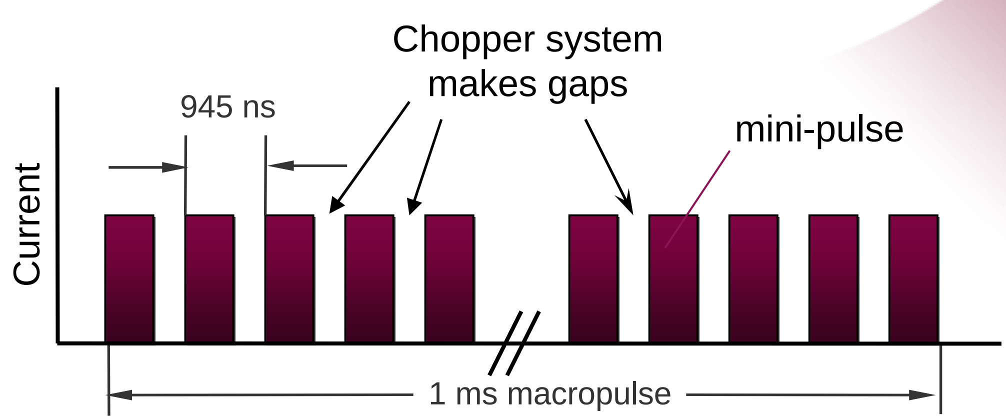
SNS Accelerator Complex

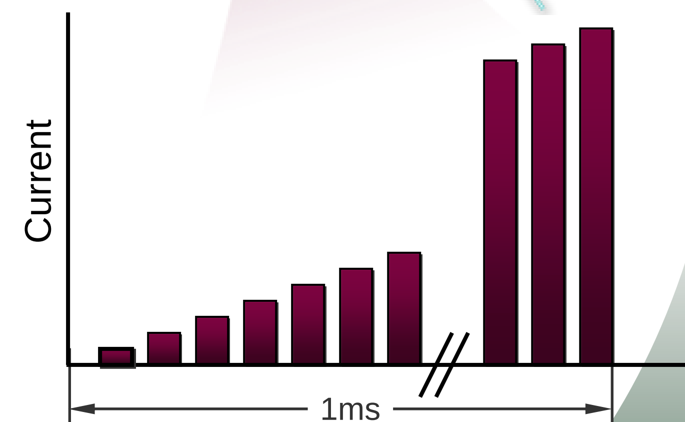
Front-End:
Produce a 1-msec long, chopped, H- beam

1 GeV LINAC

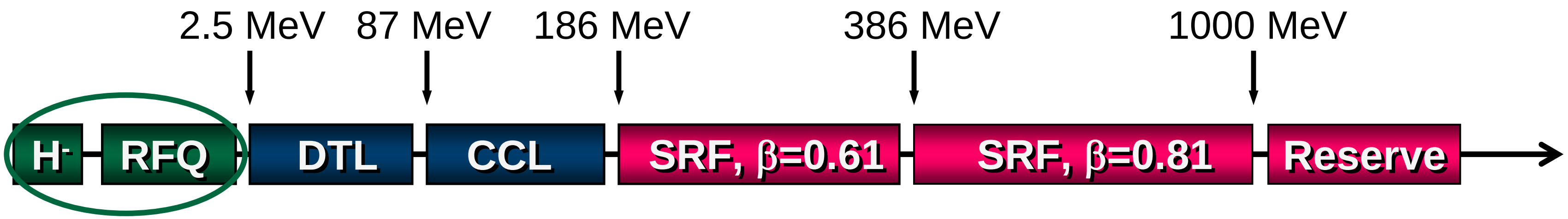
Accumulator Ring:
Compress 1 msec long pulse to 700 nsec



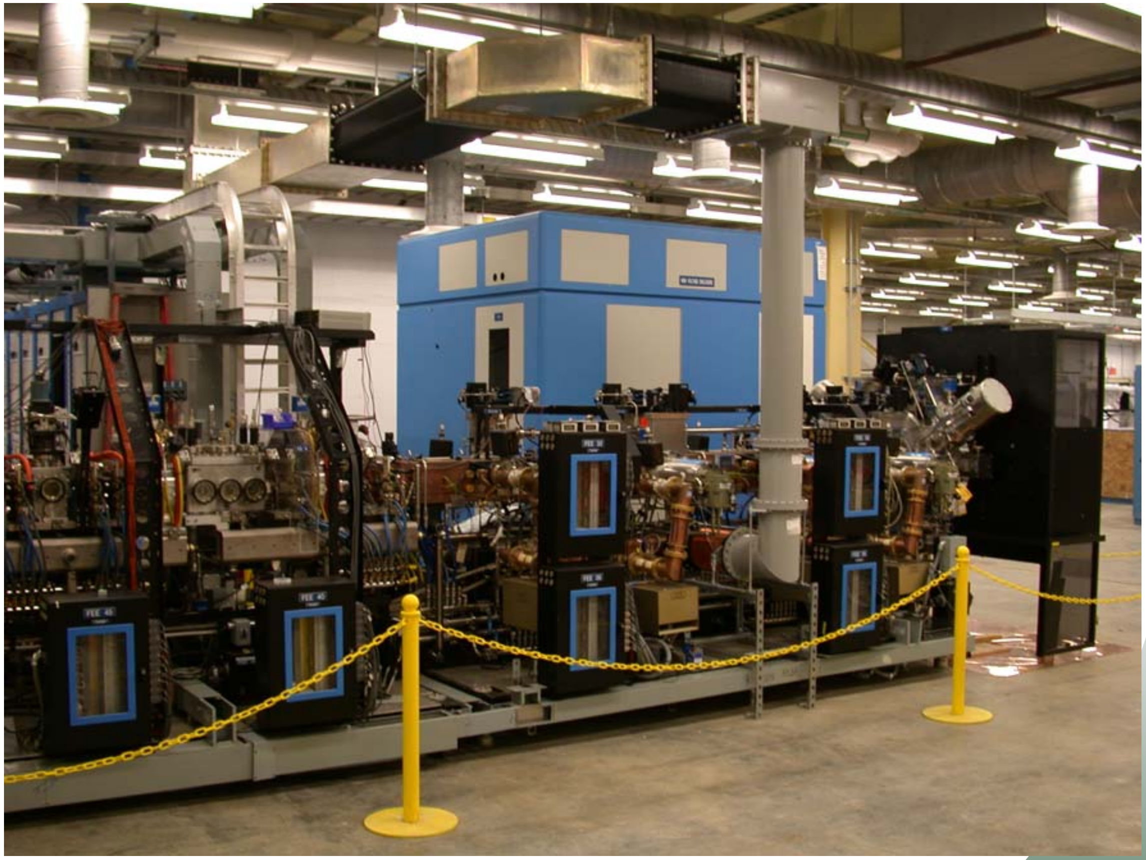




SNS Linear Accelerator



- **Front-end was designed and built by Lawrence Berkeley National Laboratory**



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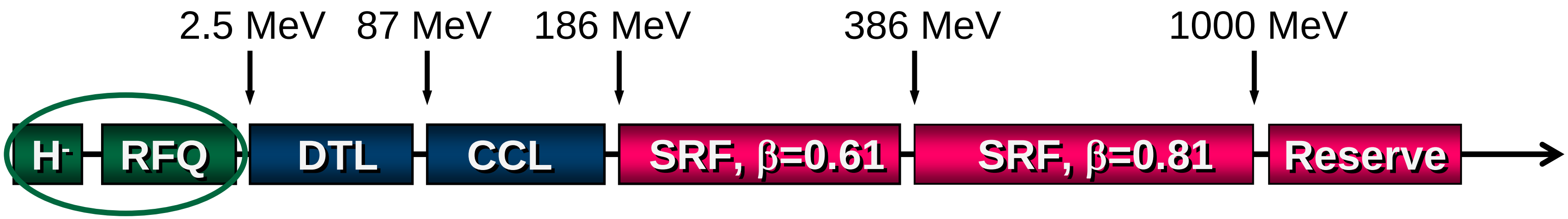
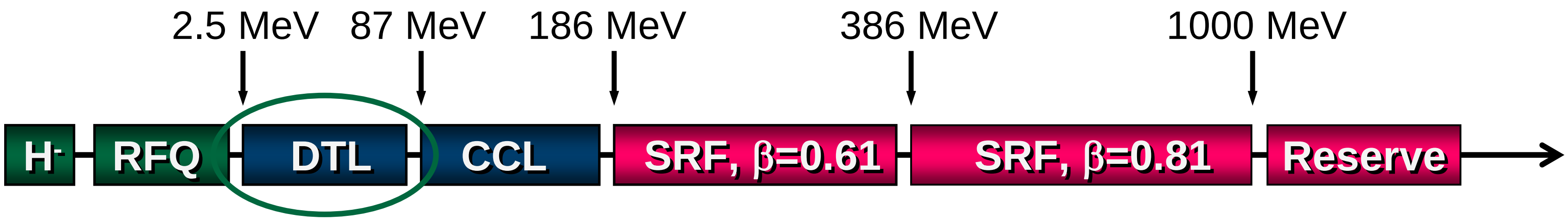


- **Front-end was designed and built by Lawrence Berkeley National Laboratory**
- **Front-end design parameters:**
  - **38 mA peak current**
  - **68% beam-on chopping**
  - **1.0 msec, 60 Hz, 6% duty**
  - **1.6 mA average current**

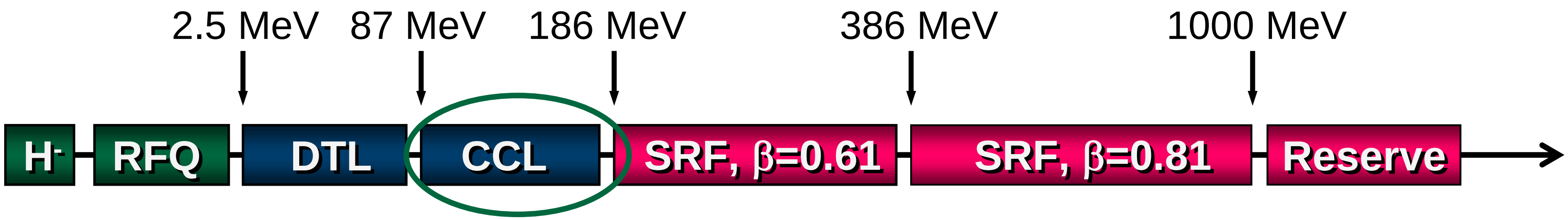
SNS Linear Accelerator



- **SNS linac is the world's highest energy proton/H- linac**
- **SNS linac architecture consists of**
  - **Conventional normal conducting structures to 186 MeV**
  - **Superconducting structures to 1 GeV**
- **Normal conducting linac was designed and built by Los Alamos National Laboratory**
- **Drift Tube Linac to 87 MeV**
- **Coupled Cavity Linac to 186 MeV**

Aleksandrov (THPP073, THPP074), Shishlo (THPC036), Roseberry (TUPD037)

SNS Linear Accelerator



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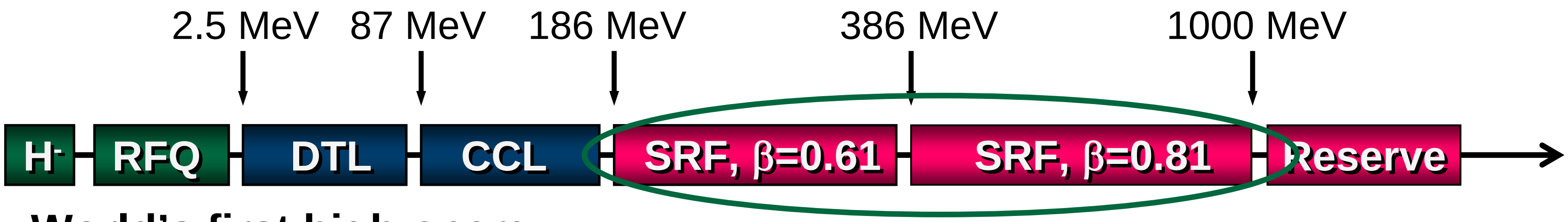
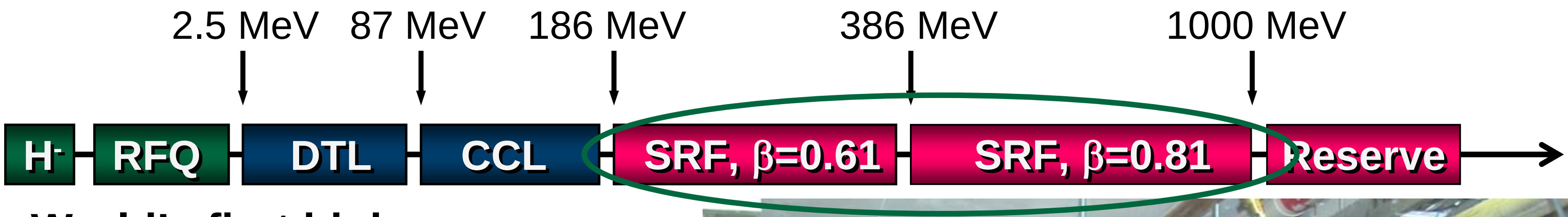


- **World's first high-energy superconducting linac for protons**
- **Cryomodules designed and built by Jefferson Laboratory**

SNS Linear Accelerator



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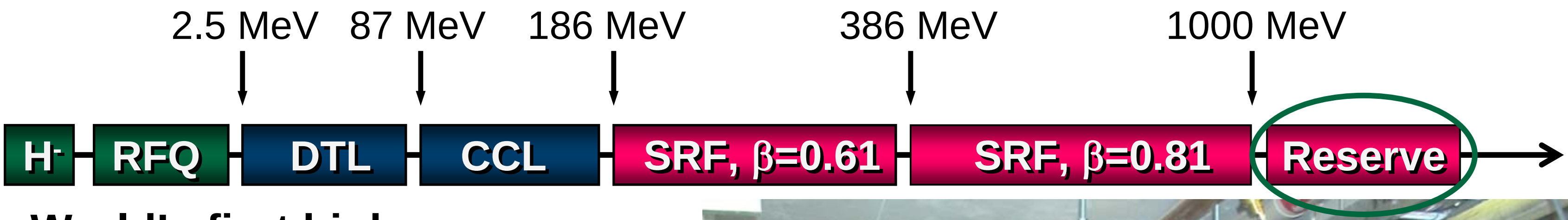
- **81 independently-powered SC cavities, in 23 cryomodules**

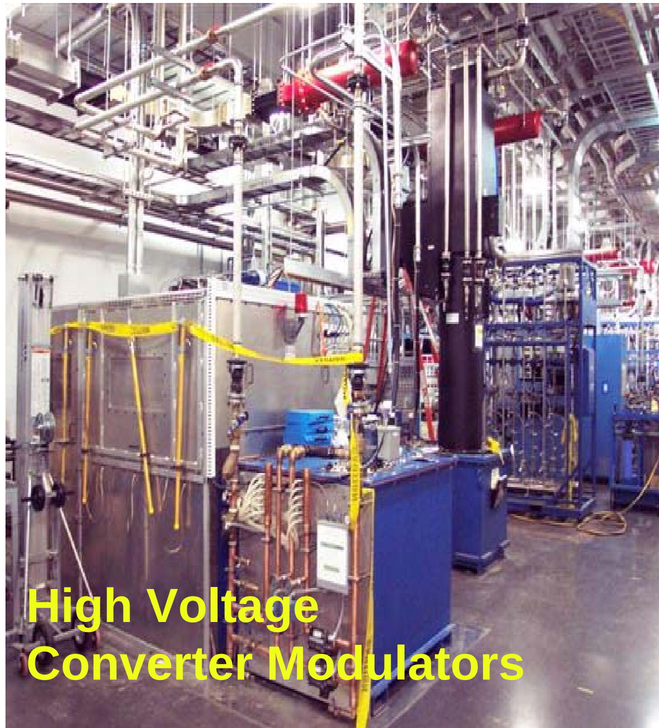
SNS Linear Accelerator



- **World's first high-energy superconducting linac for protons**
- **Cryomodules designed and built by Jefferson Laboratory**
- **81 independently-powered SC cavities, in 23 cryomodules**
- **Space is reserved for additional cryomodules to give 1.3 GeV**

Linac RF Systems

- **Designed by Los Alamos Nat. Lab**
- **All systems 8% duty factor: 1.3 ms, 60 Hz**
- **7 DTL Klystrons: 2.5 MW 402.5 MHz**
- **4 CCL Klystrons: 5 MW 805 MHz**
- **81 SCL Klystrons: 550 kW, 805 MHz**
- **14 IGBT-based modulators each providing 1 MW average power**
- **Digital RF controls with feedback and feedforward**
- **2nd largest klystron and modulator installation in the world!**

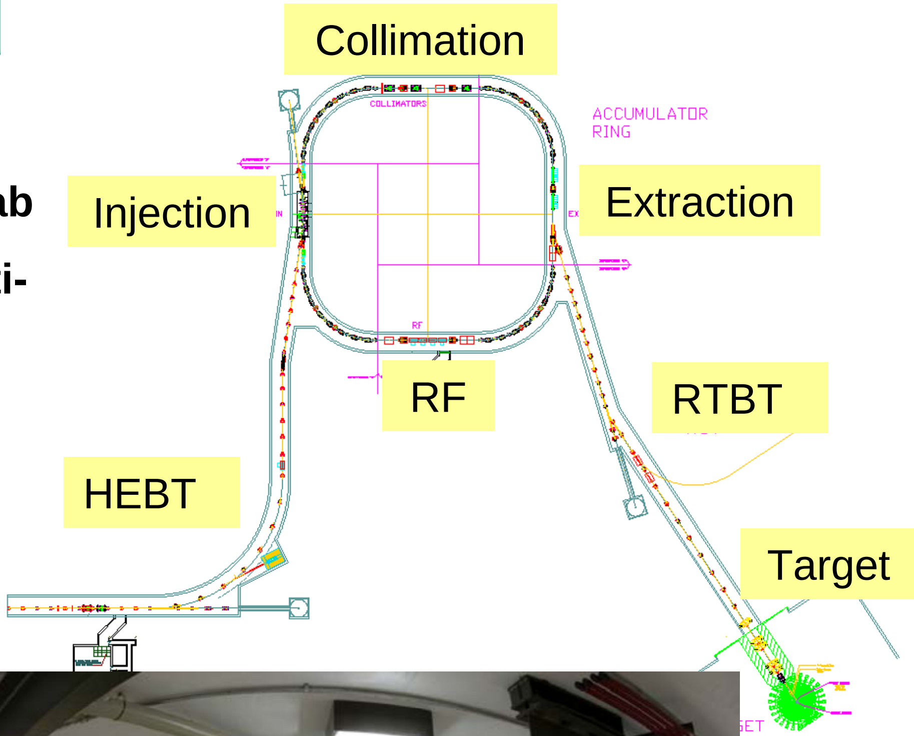


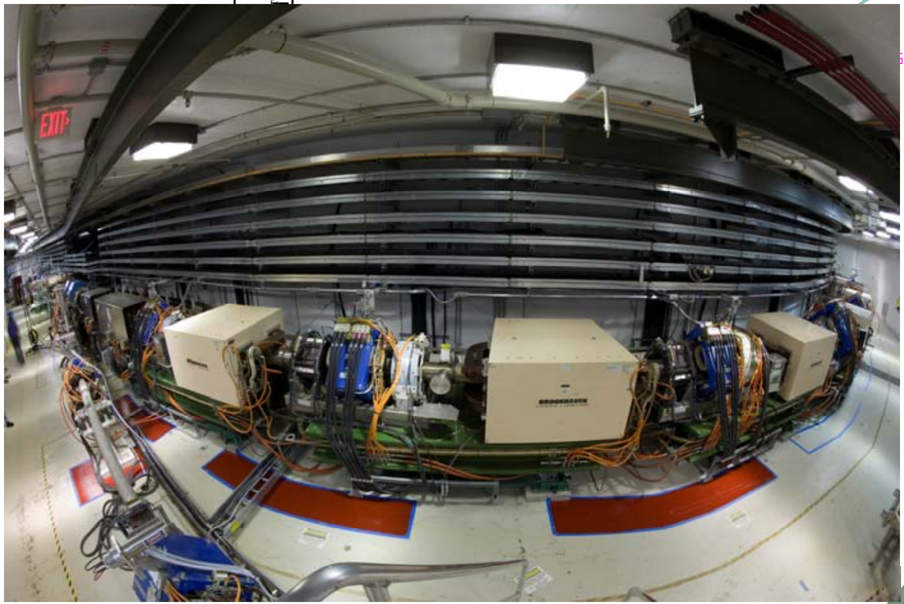
Kang (MOPP091, MOPP092), Williams (MOPP110)

Accumulator Ring and Transport Lines

- **Designed and built by Brookhaven National Lab**
- **Accumulates 1-msec long beam pulse by multi-turn charge exchange injection**

Circum	248 m
Energy	1 GeV
f_{rev}	1 MHz
Q_x, Q_y	6.23, 6.20
Accum turns	1060
Final Intensity	1.5×10^{14}
Current	26 A

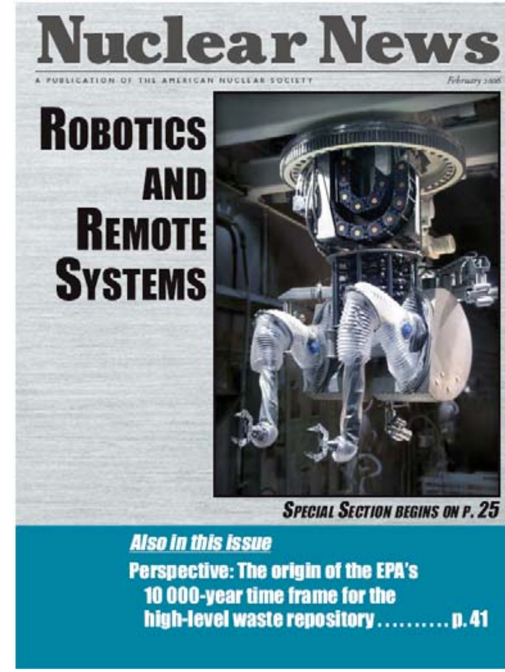


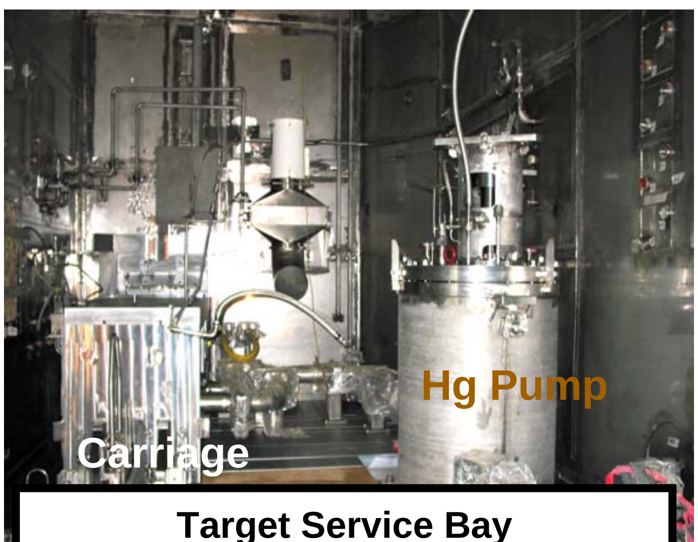


Plum (THPP085, THPP086), Cousineau (THPC006), Murdoch (TUPD034)

Mercury Target System and Supercritical H_2 Moderator

Target installed on Carriage with phosphor view-screen

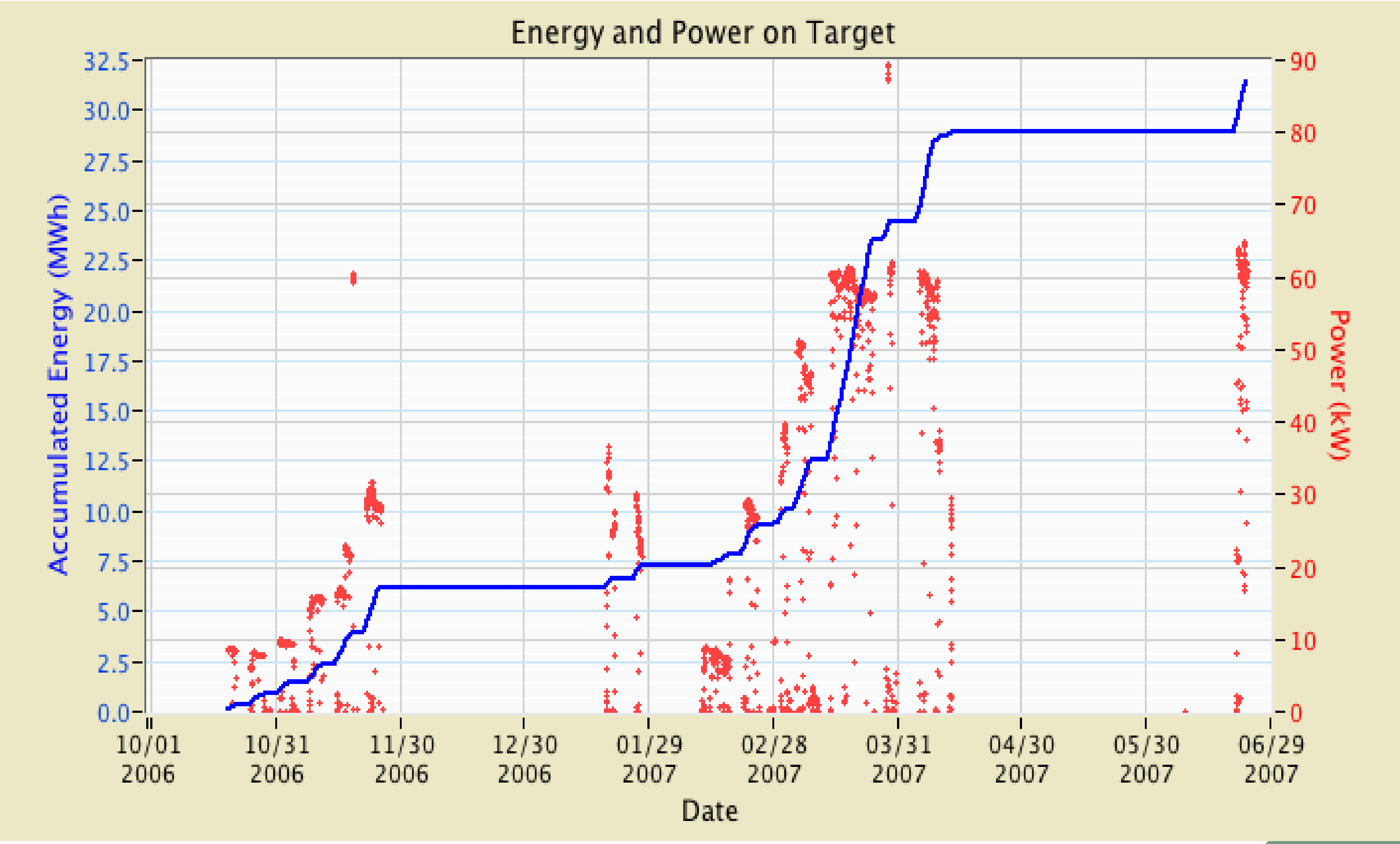




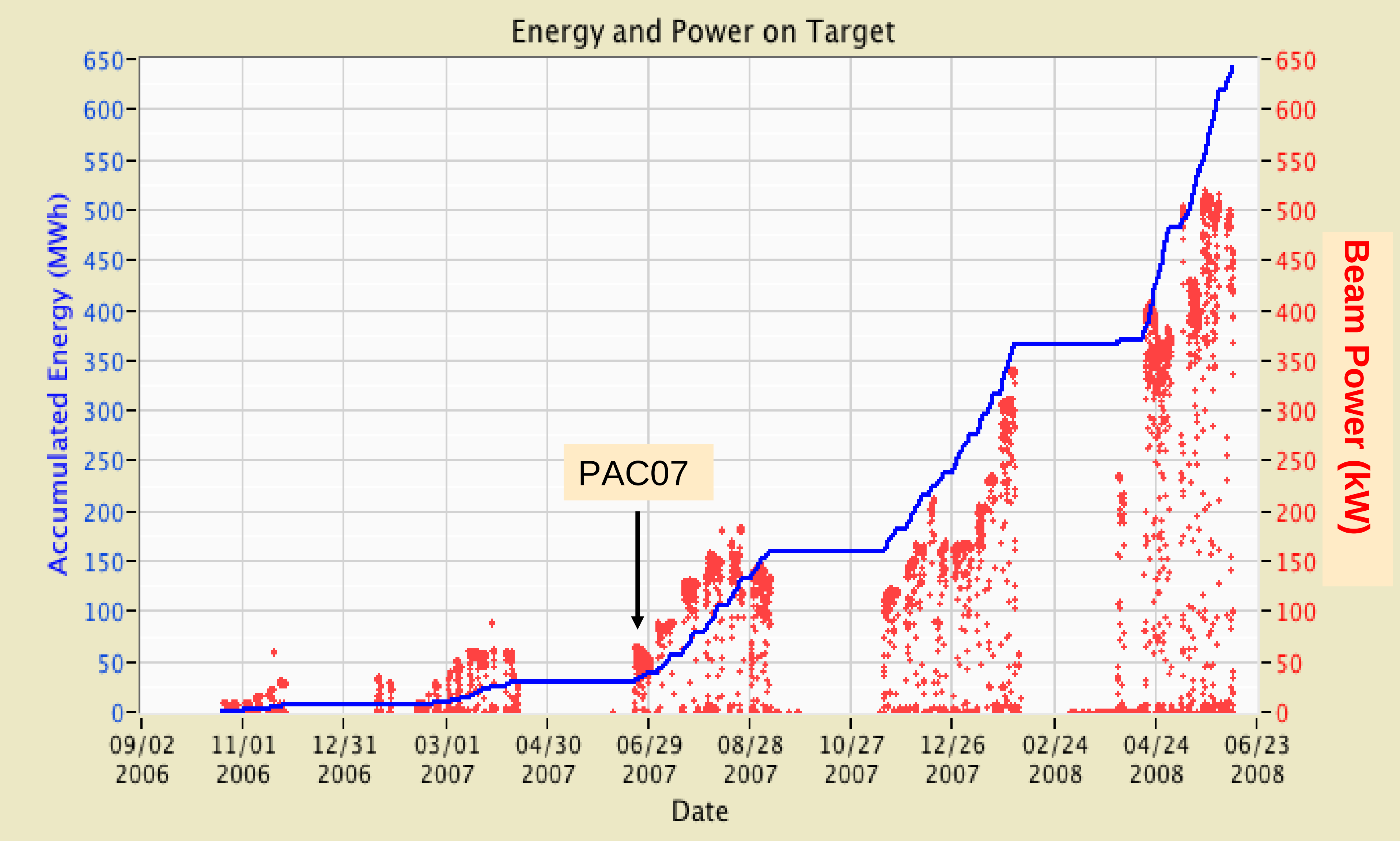
Target Service Bay

Remote-handling Control Room

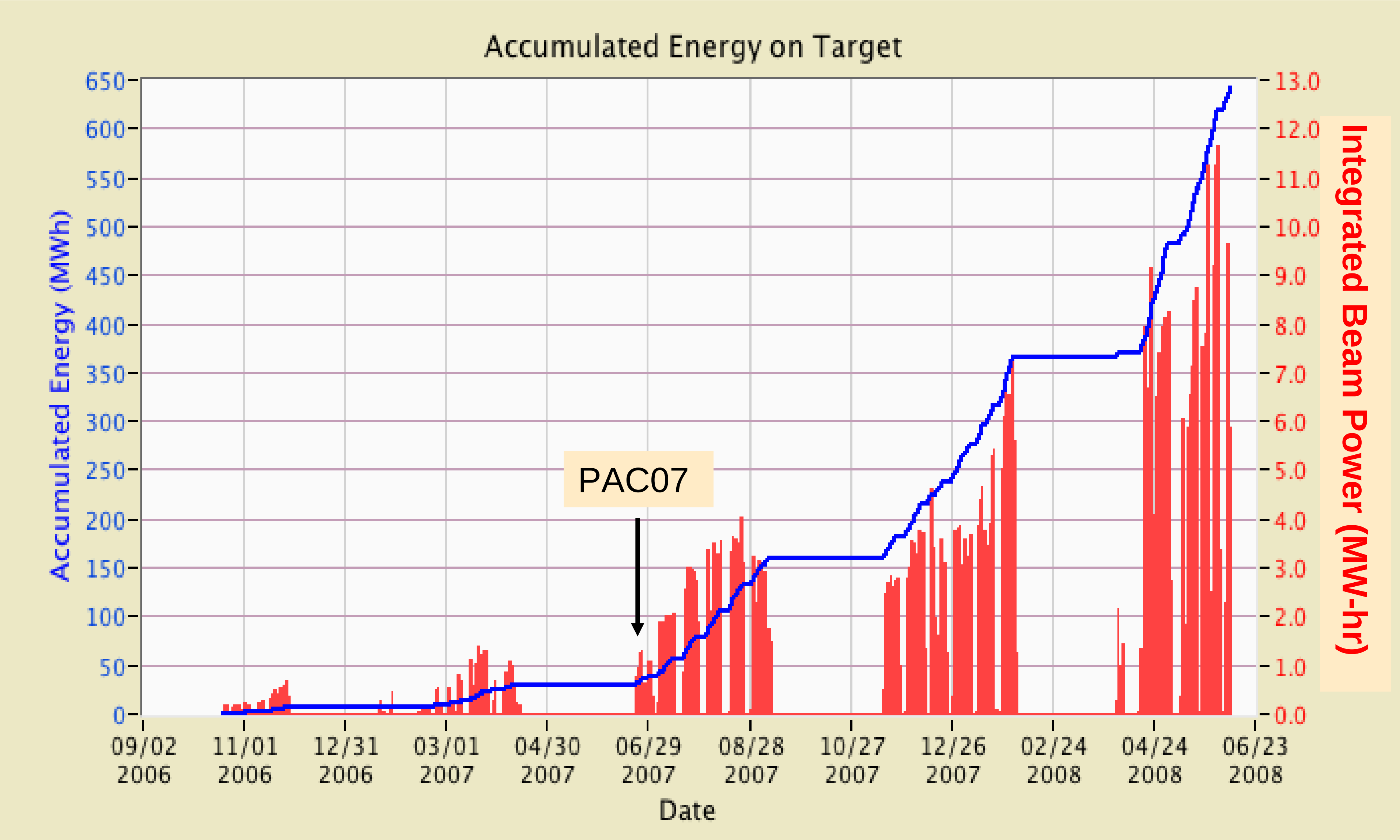
Beam Power History as of PAC 2007



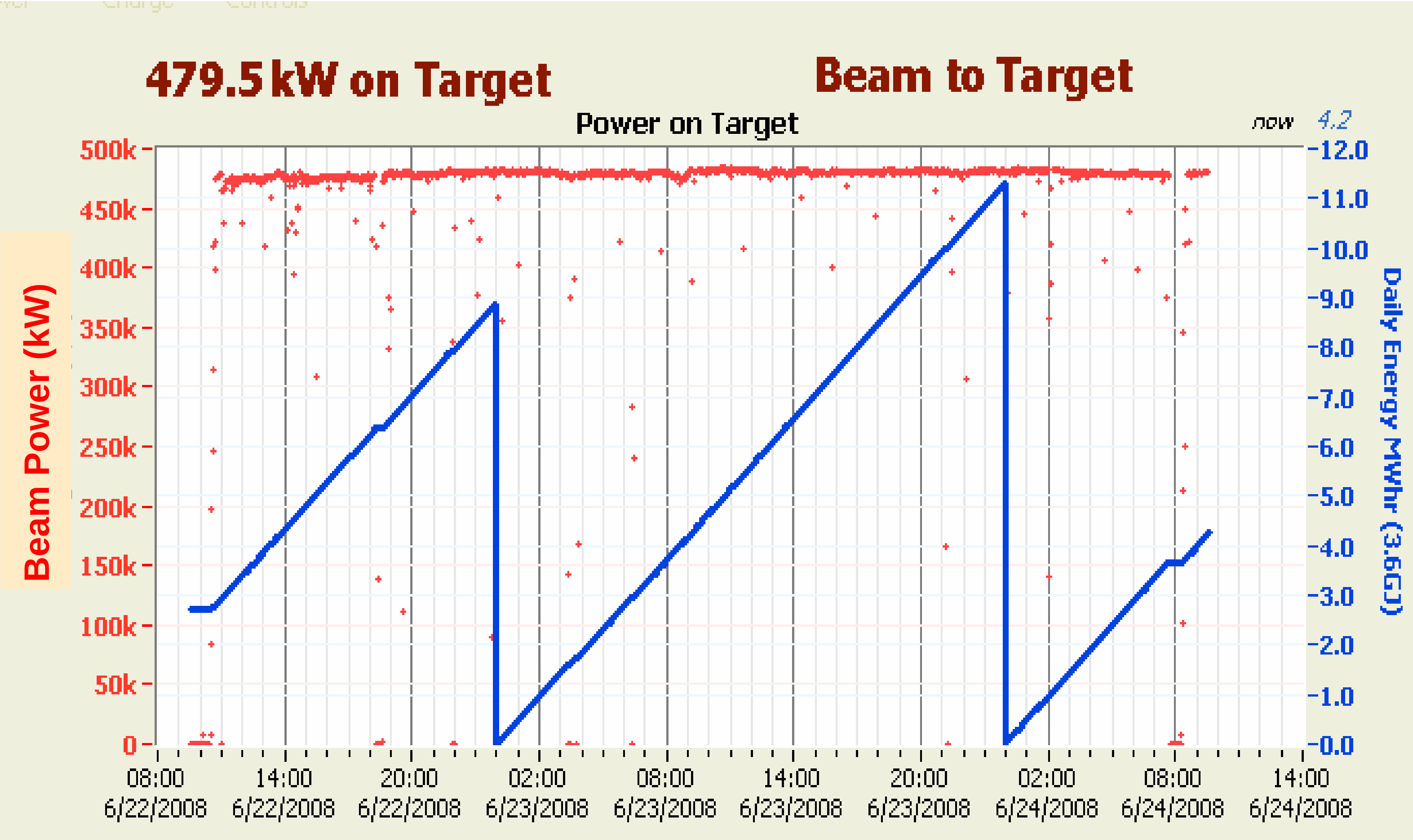
SNS Beam Power Exceeds 0.5 MW



SNS Daily Integrated Beam Power History



Last two days…

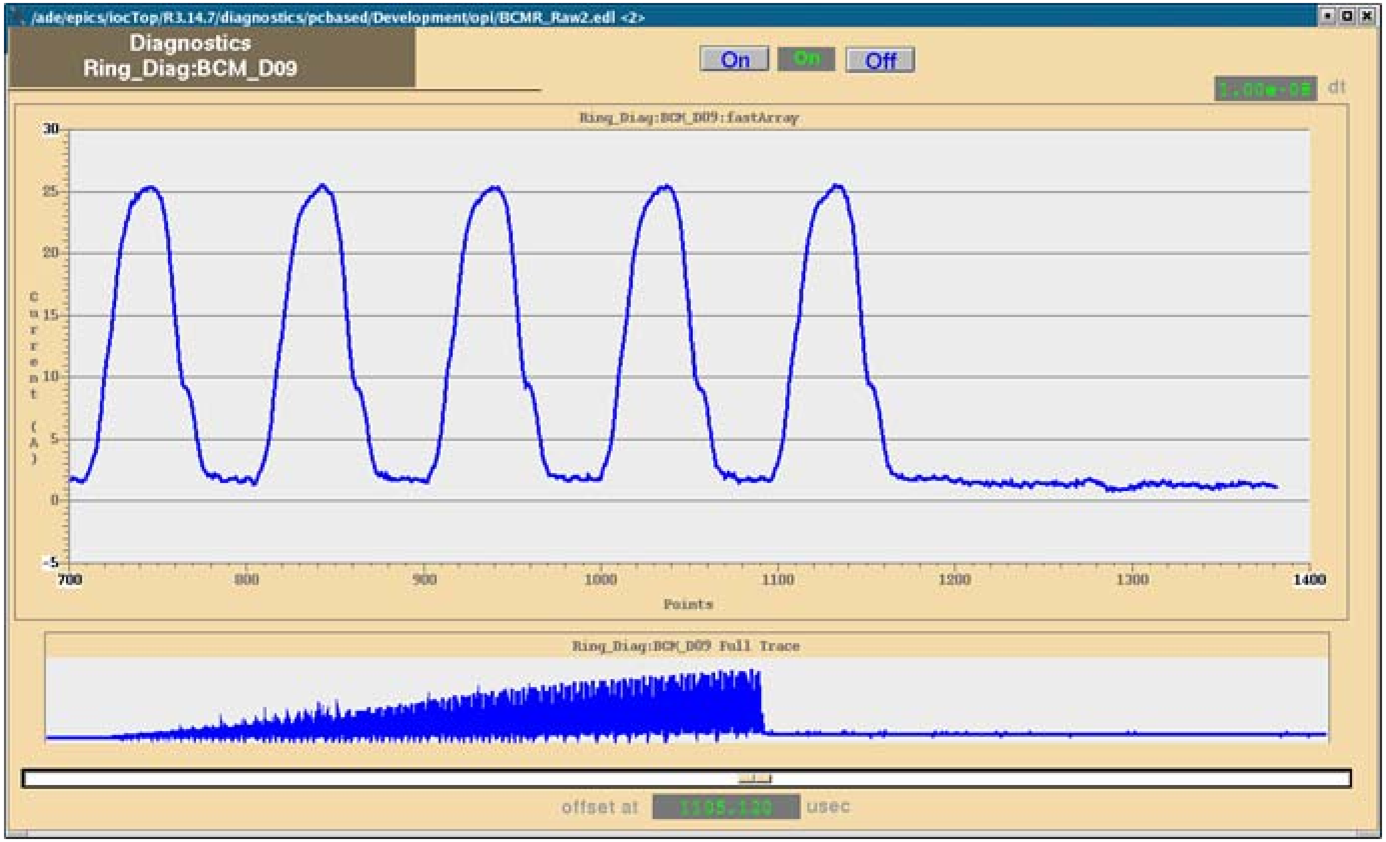


SNS Operating Parameters

	Design	Operation
Kinetic Energy	1.0 GeV	0.88 GeV
Beam Power	1.44 MW	0.52 MW
Linac Beam Duty Factor	6%	3%
Modulator/RF Duty Factor	8%	4%
Peak Linac Current	38 mA	32 mA
Average Linac Current	1.6 mA	0.57 mA
Linac pulse length	1.0 msec	0.5 msec
Repetition Rate	60 Hz	60 Hz
SRF Cavities	81	75
Ring Accumulation Turns	1060	530
Ring Current	25 A	9 A
Ring Bunch Intensity	1.5×10^{14}	0.5×10^{14}
Ring Space Charge Tune Spread	0.15	0.05

World Record Beam Intensity

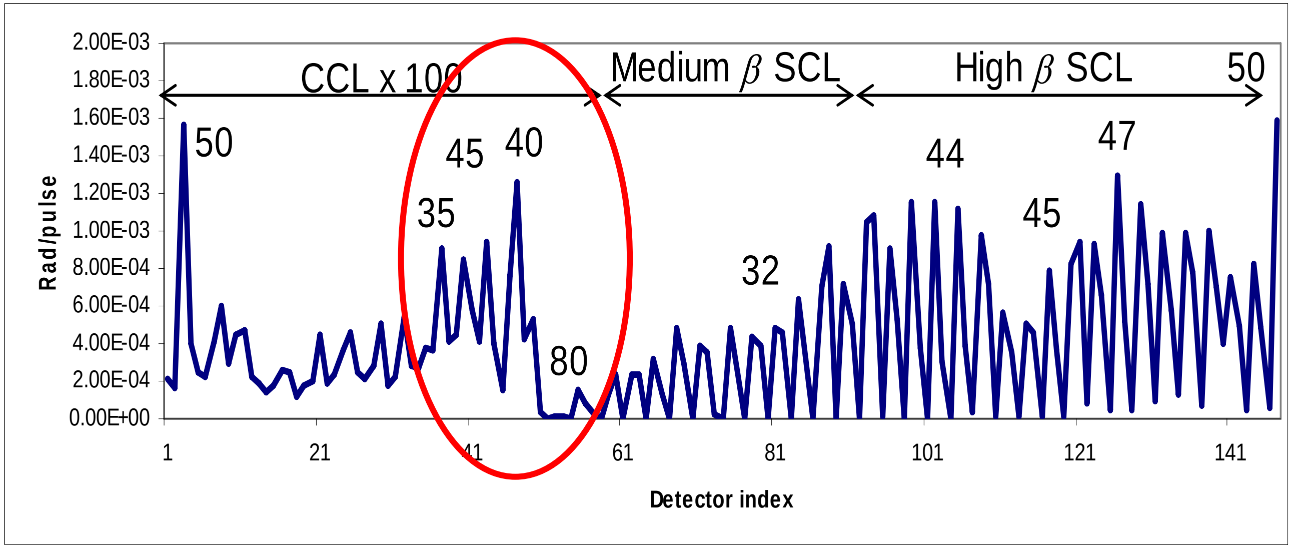
– **1.3x10^{14} protons in 1000 μs pulses accelerated, accumulated, extracted and transported to the target**

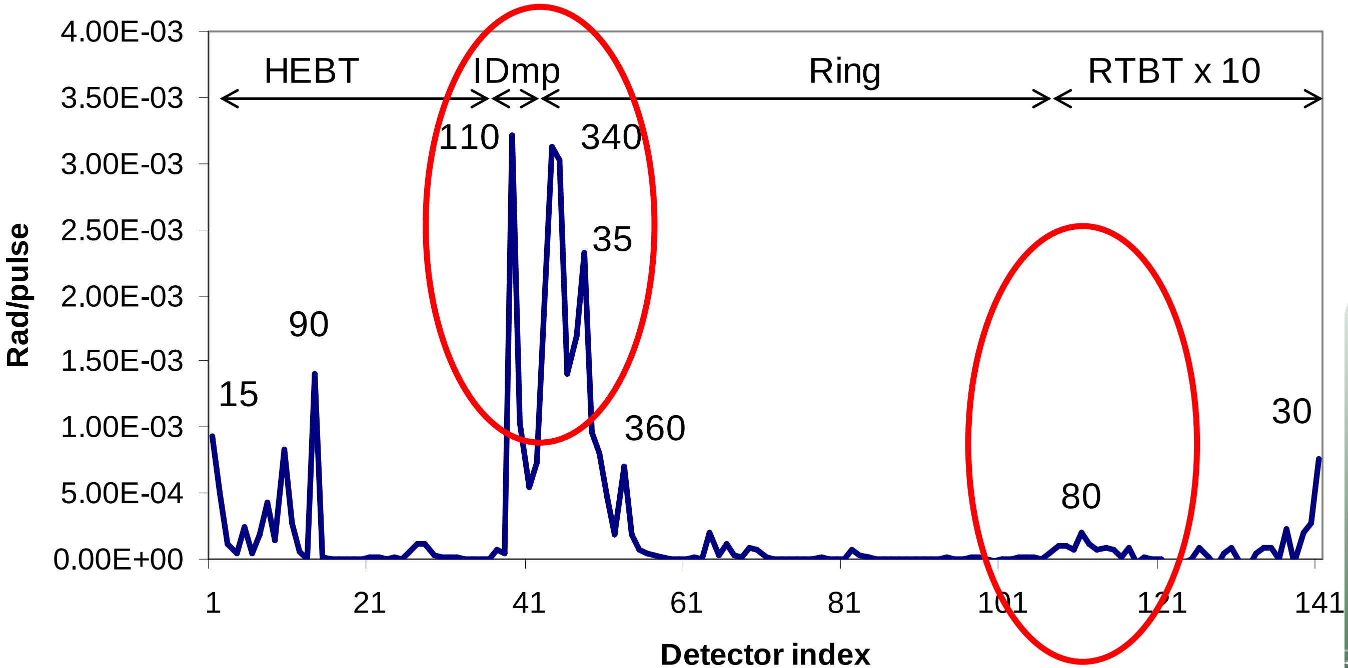


Holmes (TUPP043)

Challenges: Controlling Beamloss

- **BLM signals and activation levels (mrem/hr at 30cm after 24 hr) from a recent 10 day run at 475 kW**
- **Losses in most of the accelerator are in line with expectations**
- **We measure higher than desired losses in the**
  - **CCL/SCL transition (due to off-energy particles)**
  - **Ring Injection and Injection Dump Line (waste-beam handling & foil)**
  - **Extraction region (poor chopping)**





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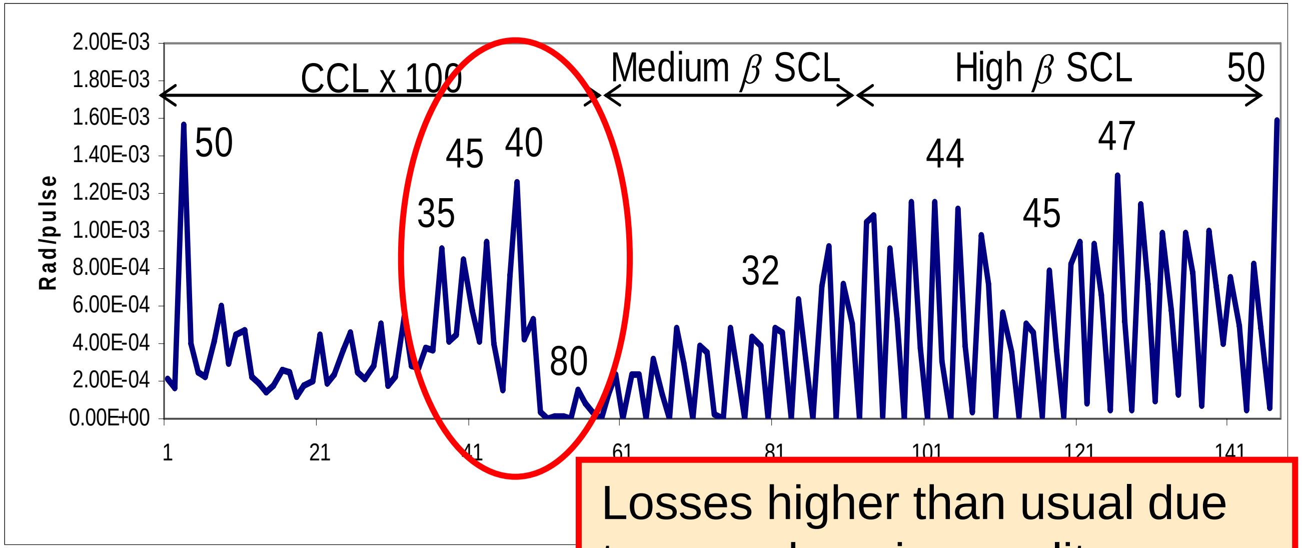
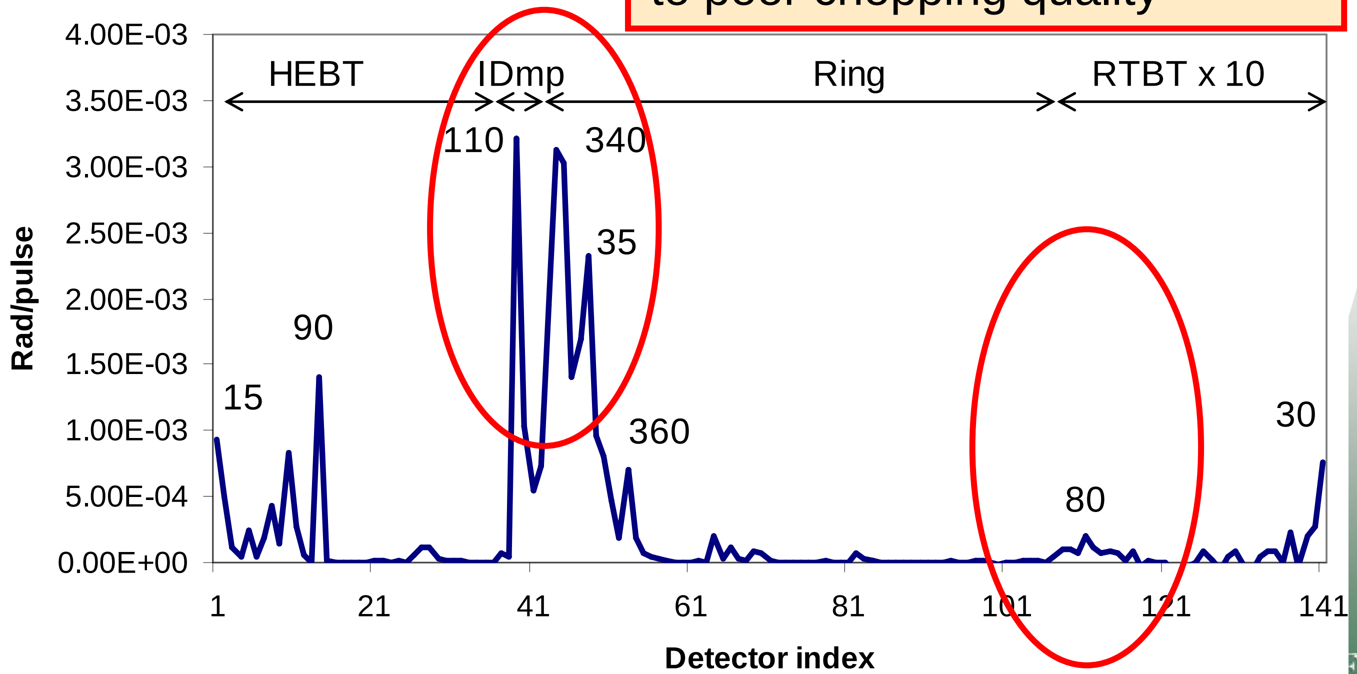
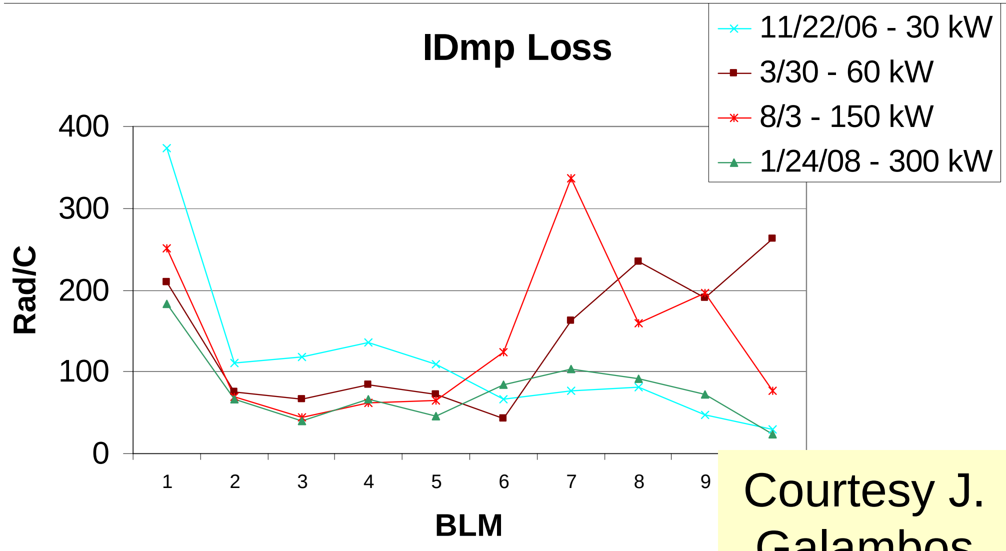


Losses higher than usual due to poor chopping quality

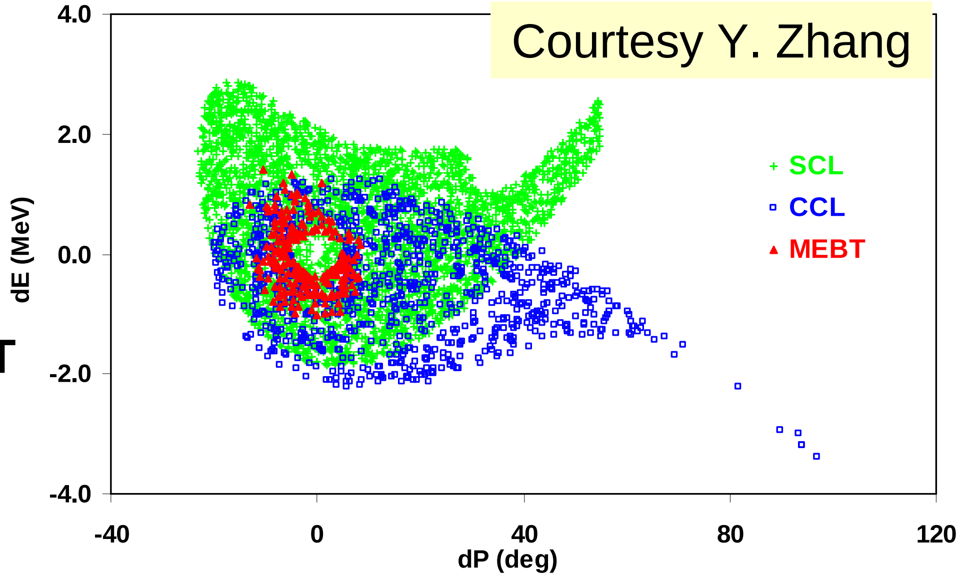


Challenges: Controlling Beamloss

- **Injection Region**
  - **Reworked magnets, increased aperture, added additional correctors, thinner foils, .., Wang (WEPC163), Holmes (THPC015)**
- **Losses arising from poor chopping**
  - **LEBT Chopper system risetime limited by arc protection circuits**
  - **Will install new LEBT chopper system in upcoming maintenance period**
  - **Recently brought our fast "MEBT Chopper" system on-line**
- **CCL/SCL matching losses**
  - **Due to off-energy particles lost at FODO/Doublet lattice transition**



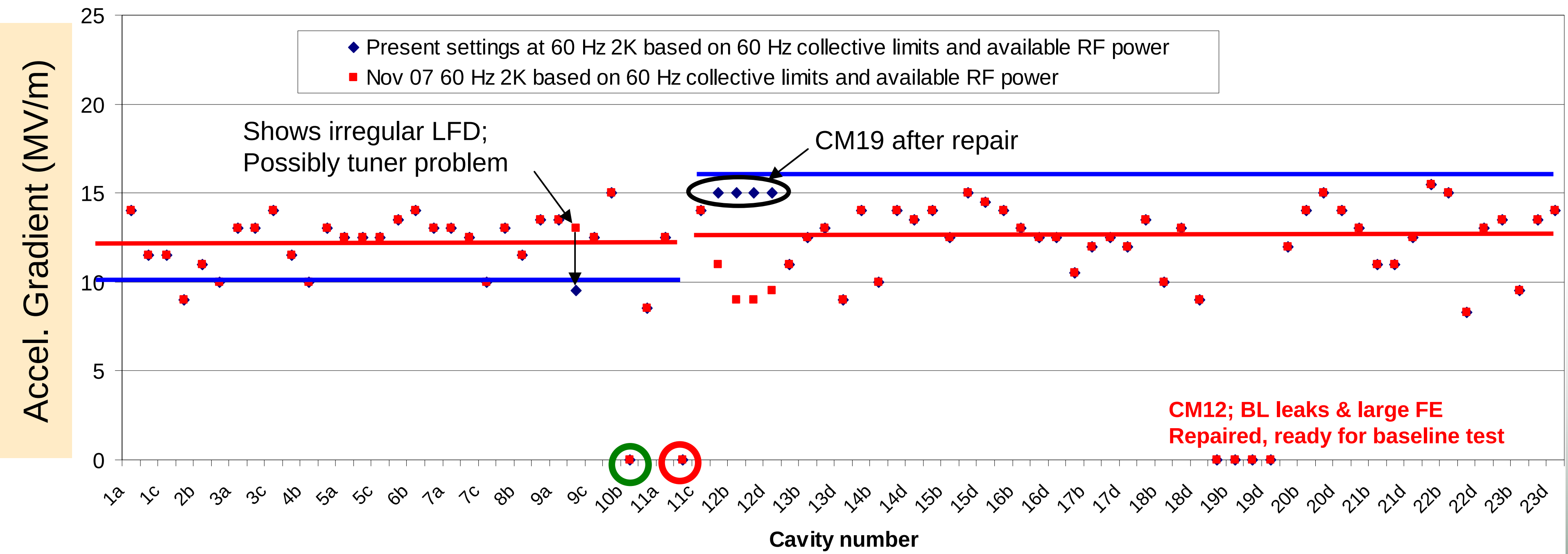
Courtesy J. Galambos



Courtesy Y. Zhang

Challenges: Superconducting Linac Performance Zhang (THPP044)

- **Linac operates at 890 MeV, with 75 of 81 cavities in-use (one CM has been removed)**
- **Operating gradients are shown; individual cavity limits are higher**
- **The inherent flexibility of individually powered cavities is used to “tune-around” an unpowered cavity.**
- **We are making use of our new SRF Facility for cryomodule repair and development of surface processing**



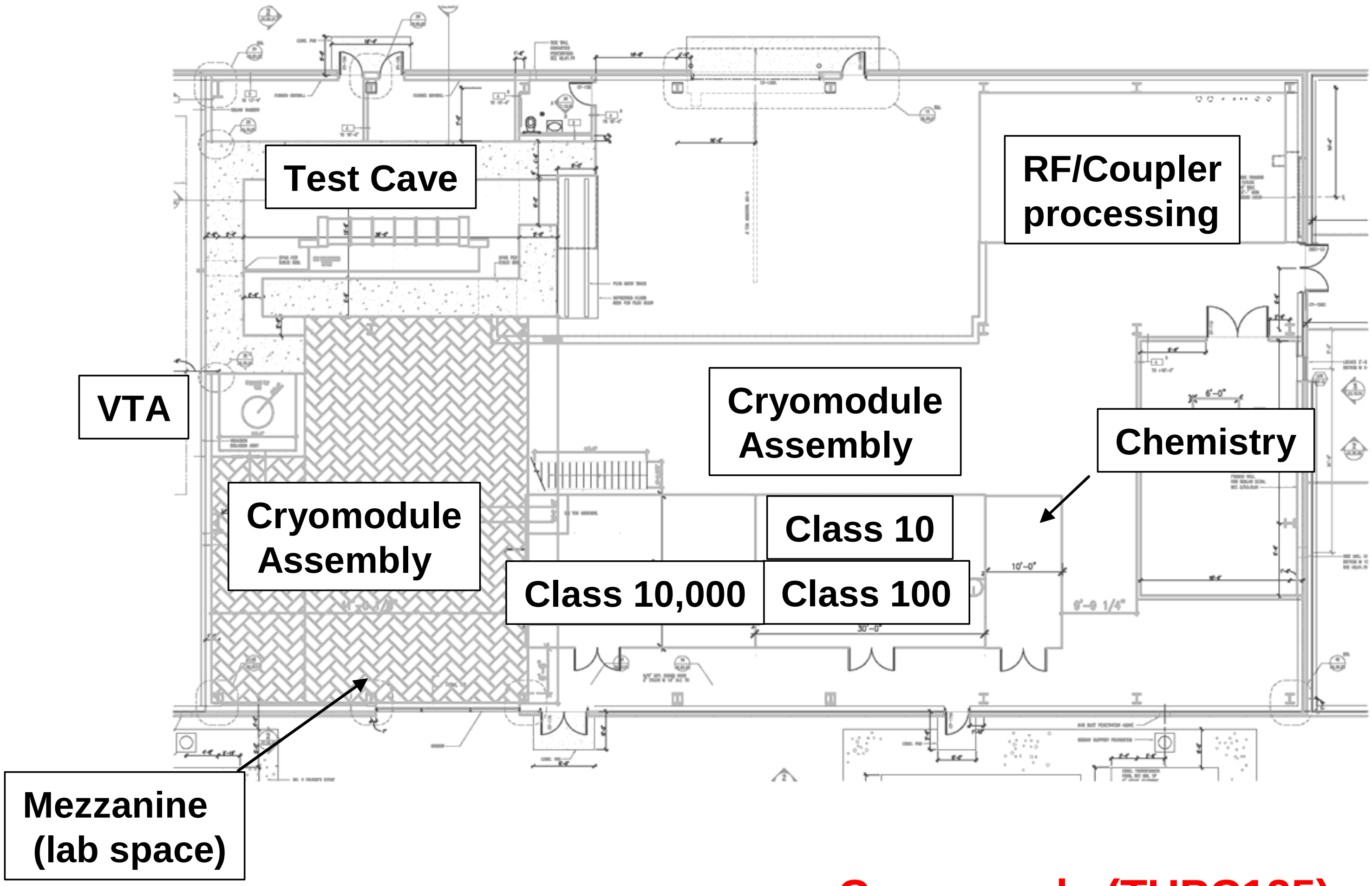
Design gradient

Average Operating gradient (exclude cavities not in service)

Large fundamental power through HOM coupler

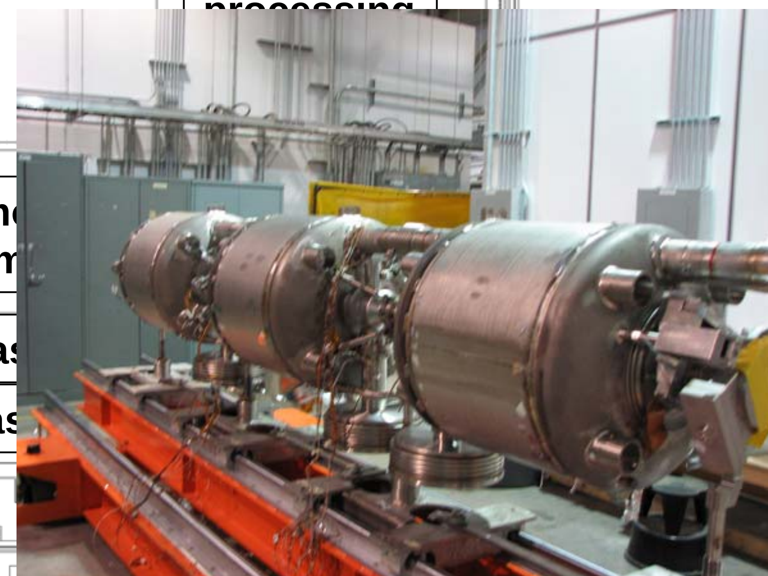
Field probe and/or internal cable (control is difficult at rep. rate >30 Hz)

SRF Test Facility



Casagrande (TUPC125)
Crofford (TUPC140)
Blokland (TUPC006)

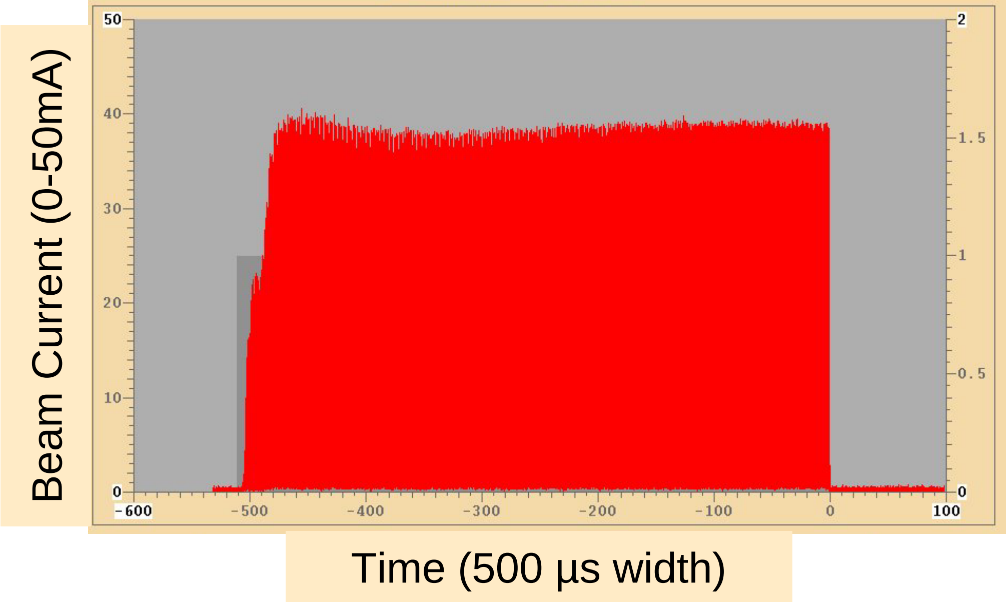
SRF Test Facility



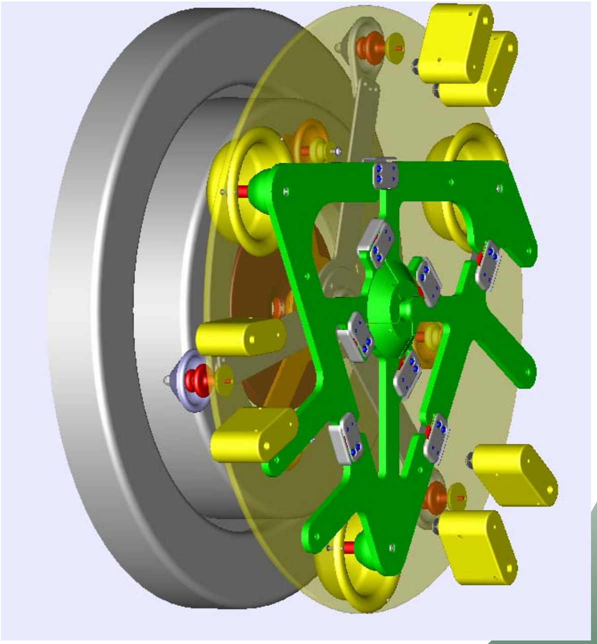
Casagrande (TUPC125)
Crofford (TUPC140)
Blokland (TUPC006)

Challenges: Ion Source and LEBT

- **Modified LBNL baseline source is the workhorse for operation**
  - **routinely delivers 30 mA of beam current at ~4% duty**
  - **Goal: 38mA at 7% needed for 1.4 MW.**

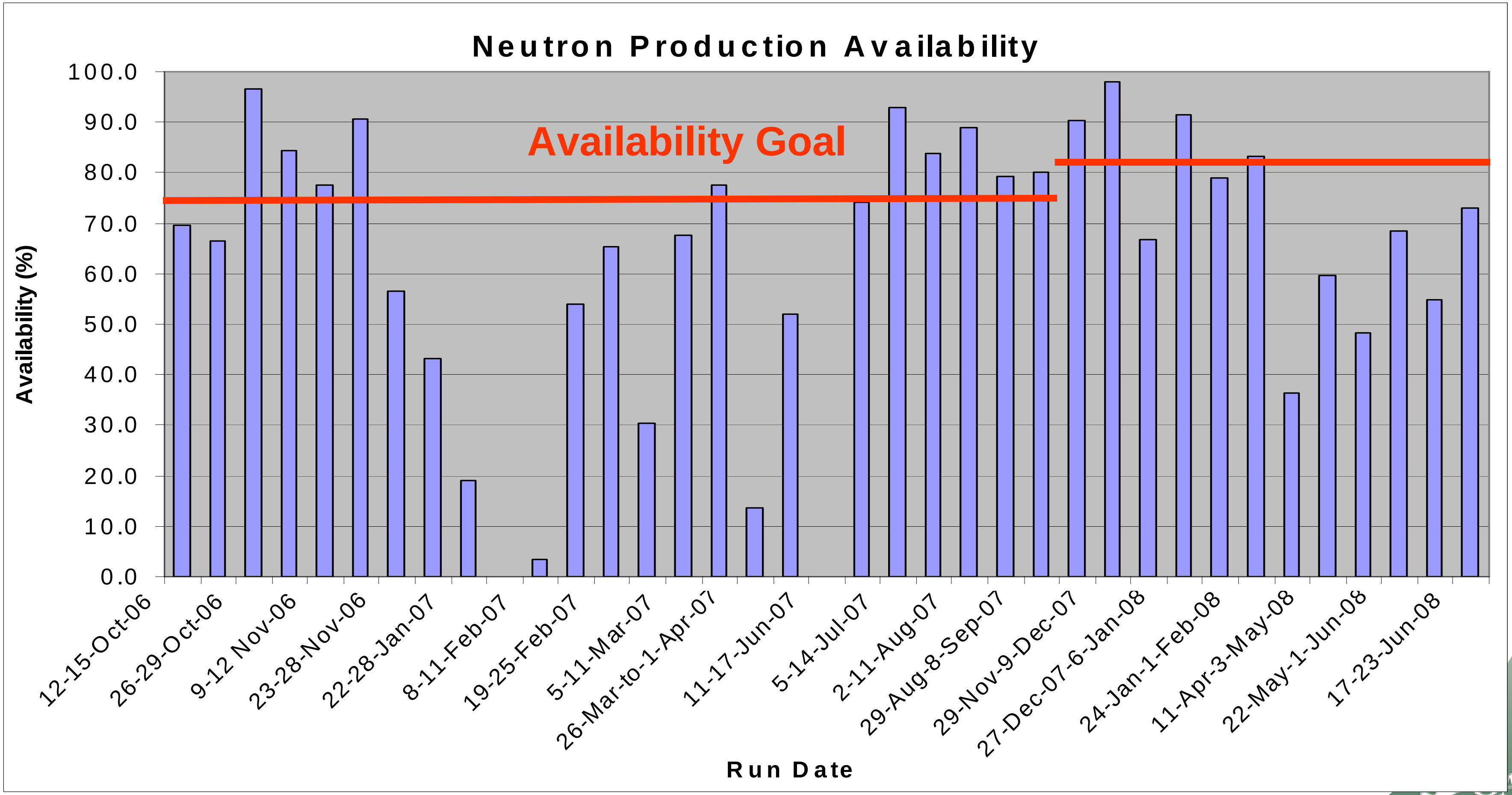


- **Very active source development program for higher currents and longer lifetime**
  - **ORNL developed AlN External antenna source – delivers higher currents at full duty on the test stand when used with elemental Cs system and plasma gun**
- **Due to excessive arcing and subsequent chopper failures, the LEBT has been redesigned for better voltage standoff and reduced arcing**



Challenges: Beam Availability

- **Recent downtime dominated by Modulators, issues related to Low-energy Beam Transport and choppers, several long MTTR failures in Cryogenic Moderator System, Vacuum leak, …**
- **Availability year-to-date is 73%**
- **Several improvement programs in place to address limitations**



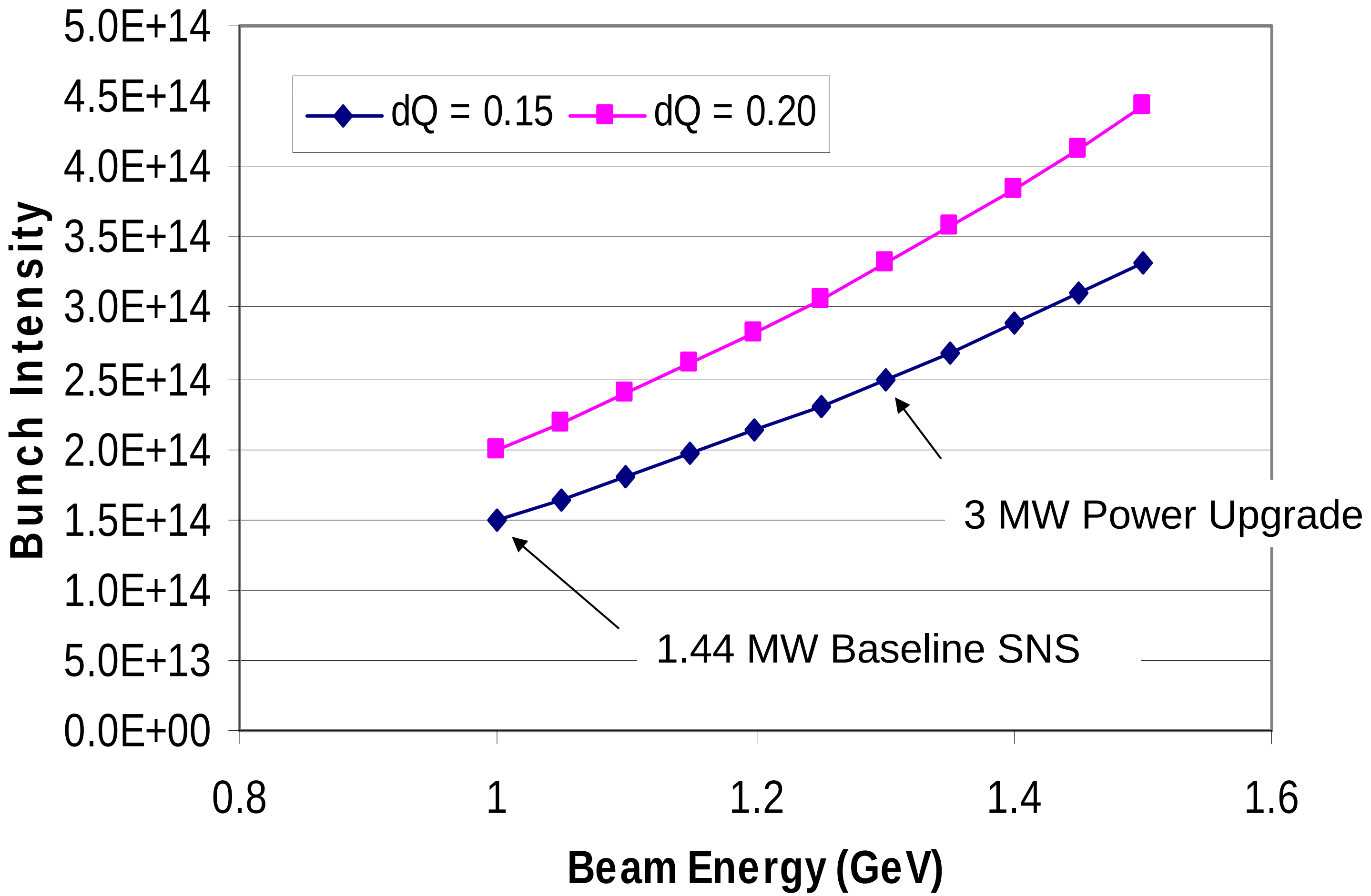
SNS Power Upgrade Project

- We plan to double the SNS beam power by
  - Increasing beam energy by installing 9 additional cryomodules
  - Increasing peak current from the source
  - modifying injection and extraction regions to accommodate higher beam energy (all other power supplies support 1.3 GeV operation)
- Seeking "CD-1" Approval (Cost Range); Construction Timeline 2011-2016
- Active R&D: Laser-stripping (Danilov, THPPGM02) , target cavitation damage mitigation, e-p damping, source development, …

	Baseline	Upgrade
Kinetic Energy	1.0 GeV	1.3 GeV
Beam Power	1.44 MW	3.0 MW
Linac Beam Duty Factor	6%	6%
Peak Linac Current	38 mA	59 mA
SRF Cavities	81	117
Ring Bunch Intensity	1.5×10^{14}	2.5×10^{14}
Ring Space Charge Tune Spread	0.15	0.15

Space-Charge Tuneshift Scaling

- **Two curves of constant space charge tuneshift ($N/\beta^2\gamma^3$)**
- **The 3MW upgrade is a straightforward extension of the baseline ring, at least as regards space-charge effects.**



Second Target Station

- **Higher beam power will enable operation of two target stations, which in turn doubles the scientific productivity of the facility**
- **Reference concept calls for "pulse-stealing" operating mode:**
  - **40 short pulses/second to Target Station One (~2 MW)**
  - **20 long pulses/second to Target Station Two (no ring accumulation)**
- **Project is seeking "CD-0" (Mission Need Approval)**

Summary

- **SNS is steadily "ramping-up" towards full design capability**
- **Routine operation at 0.5 MW beam power makes the SNS the world's most powerful pulsed spallation neutron source**
- **Two upgrades are in the approval process to further increase the scientific capabilities of the SNS**
- **Our success is due to the talent, hard work and dedication of the SNS staff, and the partner laboratories!**

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