UT-BATTELLE

SNS Commissioning and Upgrade Plans

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For the SNS Team

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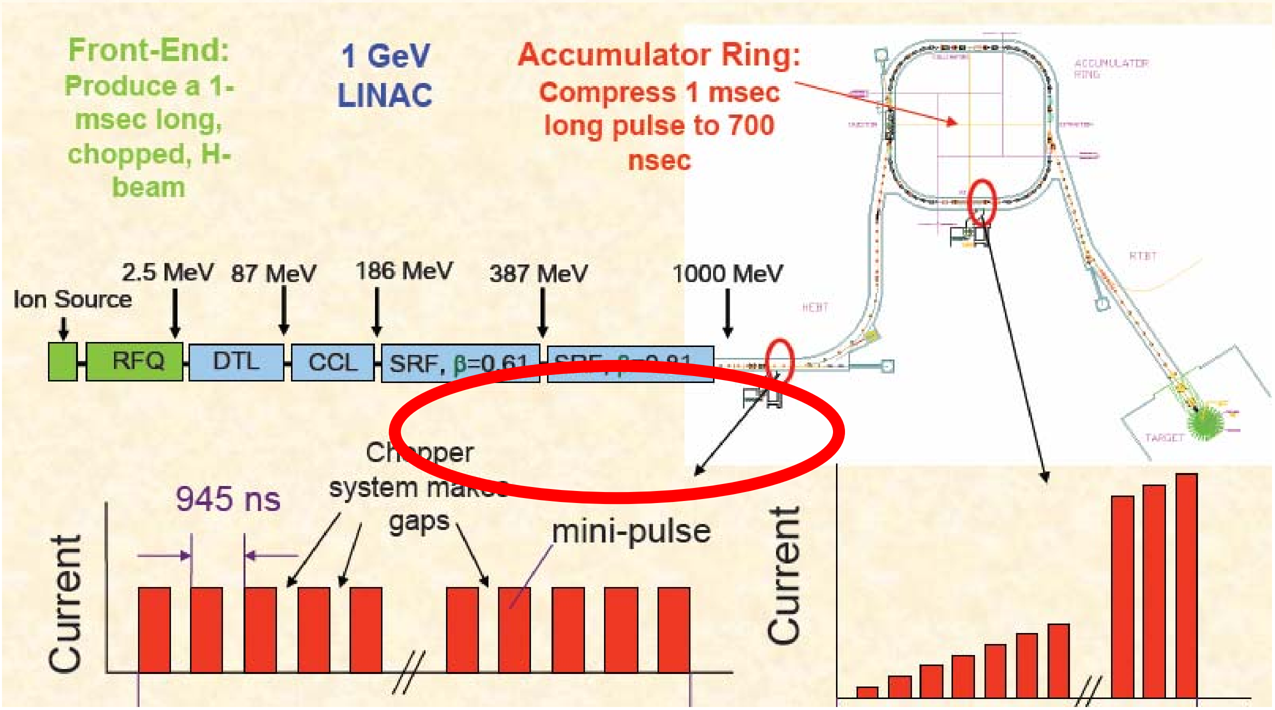
HFIR

SNS
SPALLATION NEUTRON SOURCE

Spallation Neutron Source

- The SNS is a short-pulse (700 ns) neutron source, driven by a 1.4 MW proton accelerator, becoming the world leading neutron scattering facility
- Construction project was a collaboration of six US DOE labs

SNS Accelerator

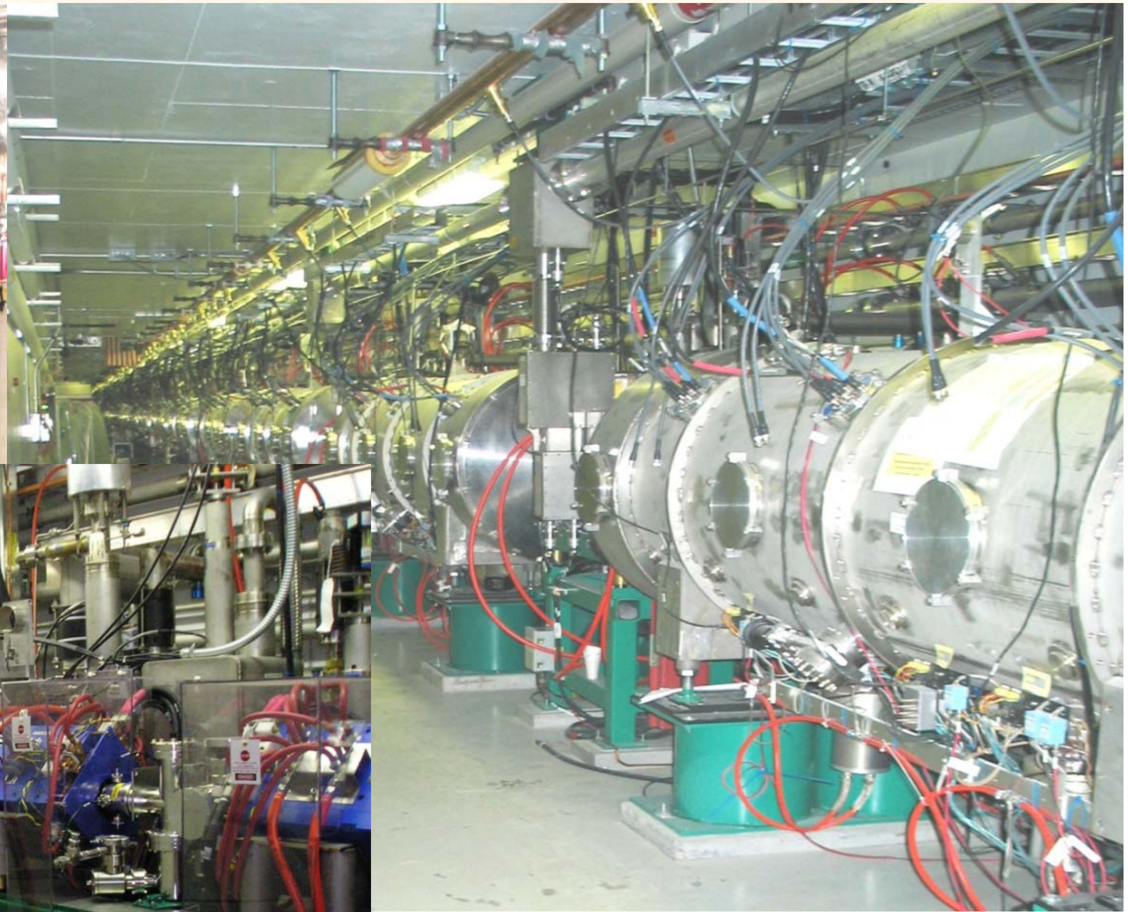


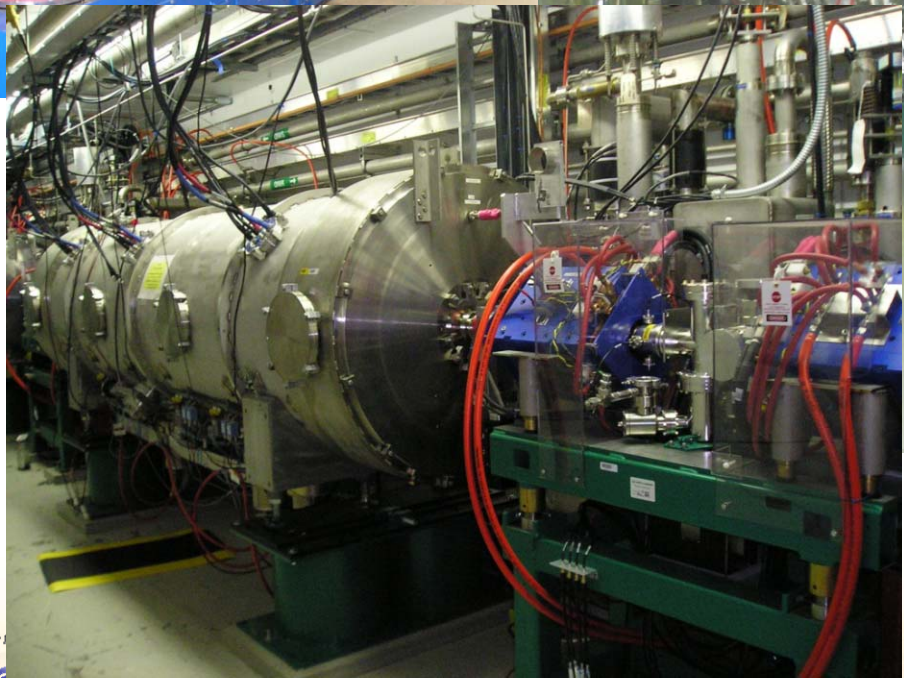
•Superconducting linac has 33 medium β cavities and 48 high β cavities.
•Designed for 2.1 K. Until recently ran at 4.5 K (lower repetition rates to decrease HV converted modulator failures and decrease load on cryogenic plant).
•Pulsed Superconducting RF operated at 805 MHz, 1.3 ms, 7.8% RF duty cycle

Status at the Cornell SRF Workshop, July 2005

- Completed installation of all 23 cryomodules
- Completed installation of all 32 warm sections
- Completed testing at 4.5 K of all cavities at 10 Hz
- Preparing for beam commissioning in August 2005

SCL installation

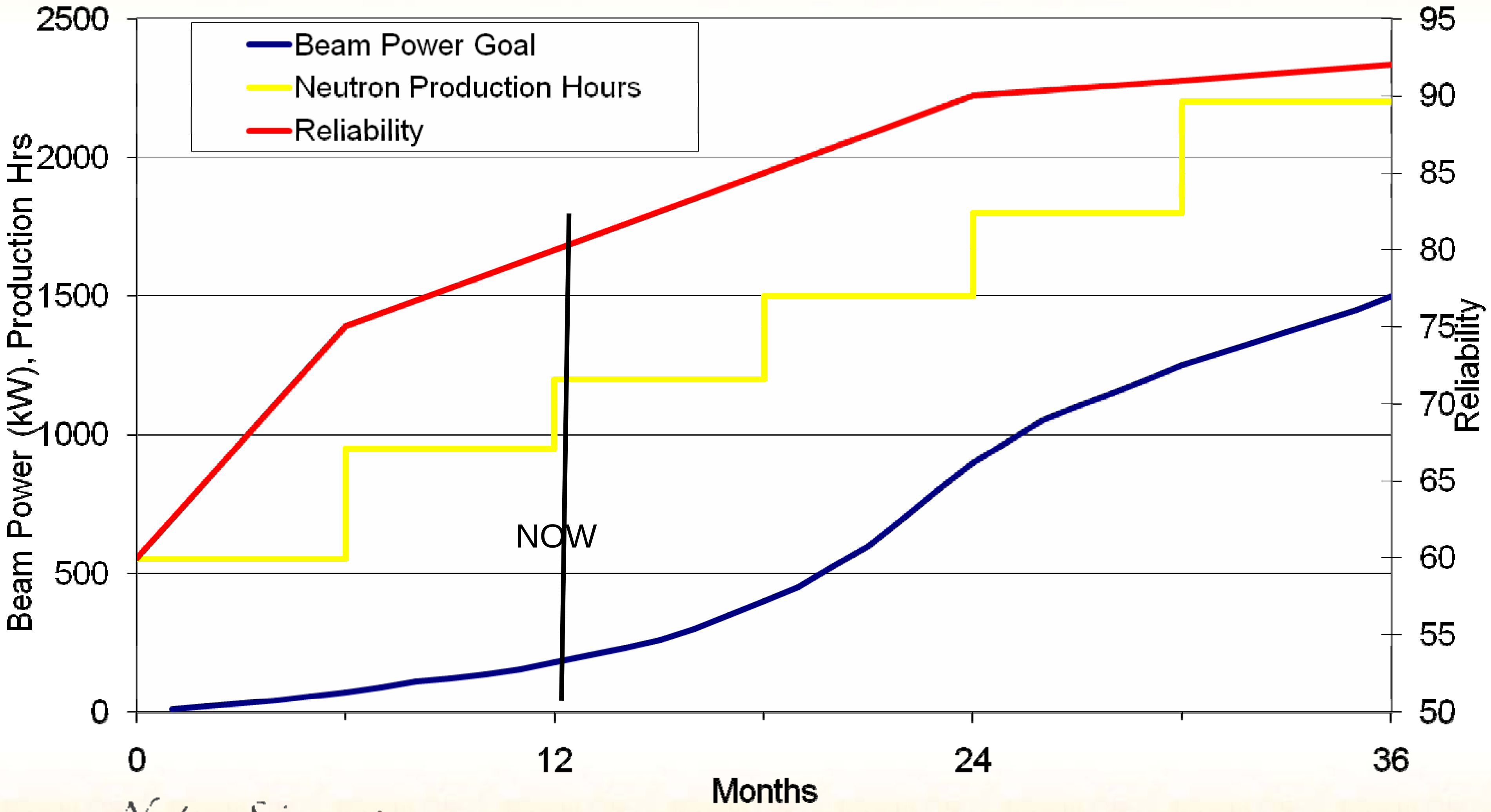




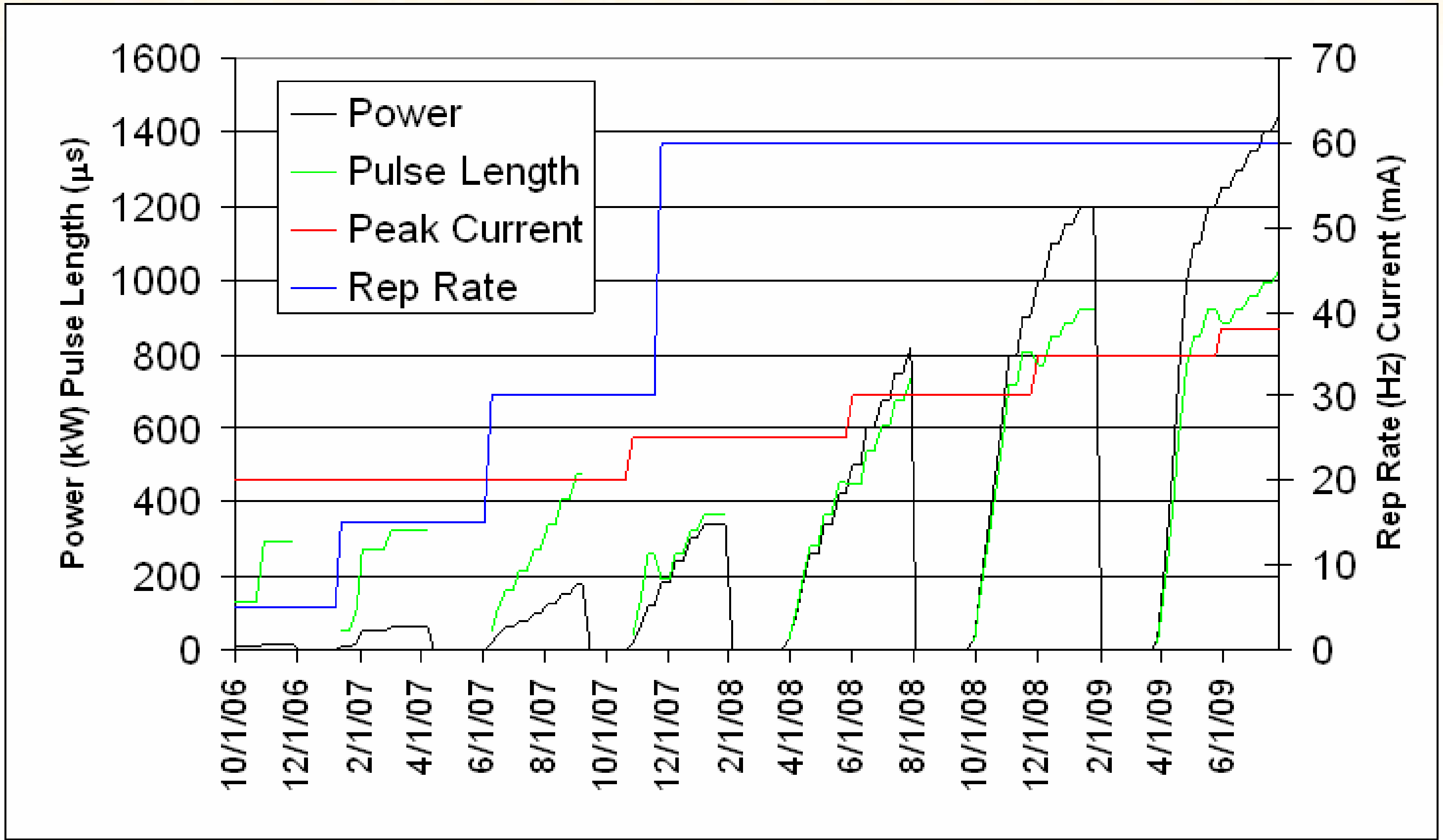
Major milestones since July 2005

- **August 2005: beam commissioning of Superconducting Linac at 550 MeV straight ahead (7.5 kW dump)**
- **February 2006: Ring Commissioning with full injection energy from the linac (above 850 MeV)**
- **28 April 2006: Beam on Target**
- **July 2006: Official start of Operations**
- **Goal of reaching full SNS design capability at the end of a three-year ramp-up period, which started October 1, 2006**
  - **1.4 MW beam power**
  - **5000 hours of operation per year**
  - **>90% availability (hours of neutron production delivered/hours scheduled)**

Performance Goals: Power, Hours and Reliability

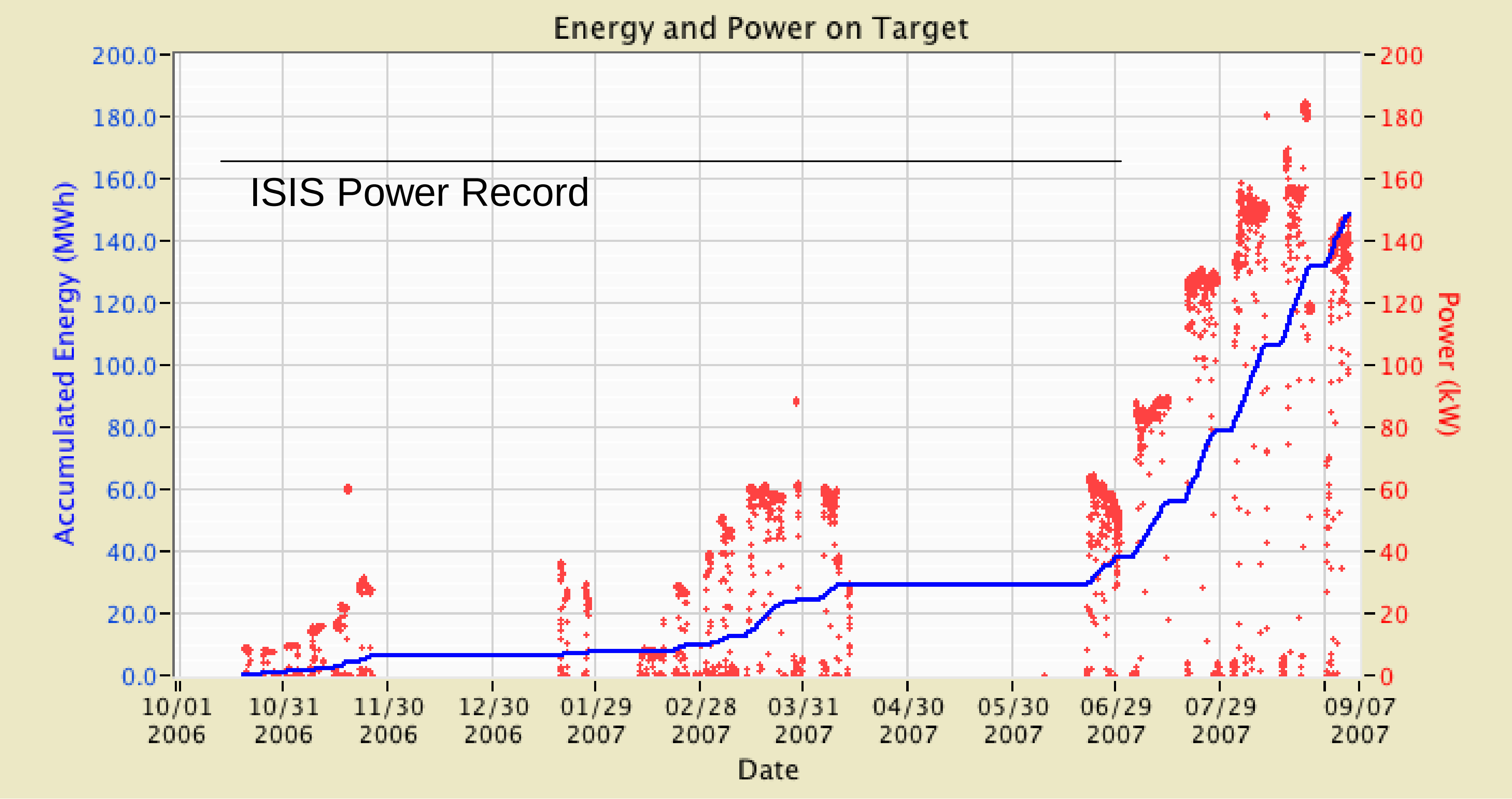


SNS power ramp up schedule



Since June 2007 we have been running at 30 Hz 2.1 K.
From November 1st on, always at 60 Hz (Target lifetime)

Power Ramp-up Progress in the Past Year



Presently SNS is the most powerful Spallation Source

180 kW run

Accumulated beam power (daily/monthly)

Some SNS Linac Beam Performance Measures *(through the entire linac)*

	Design	Highest Ever (Individual)	Highest Beam Power (Simultaneous)
Energy (GeV)	1.0	1.01	0.88
Rep Rate (Hz)	60	60	30
Pulse Length (mSec)	1	1	0.55
Beam Current * (mA)	26	20	13
Beam Power (MW)	1.5	0.18	0.18

* Time average including ~ 30% chopping

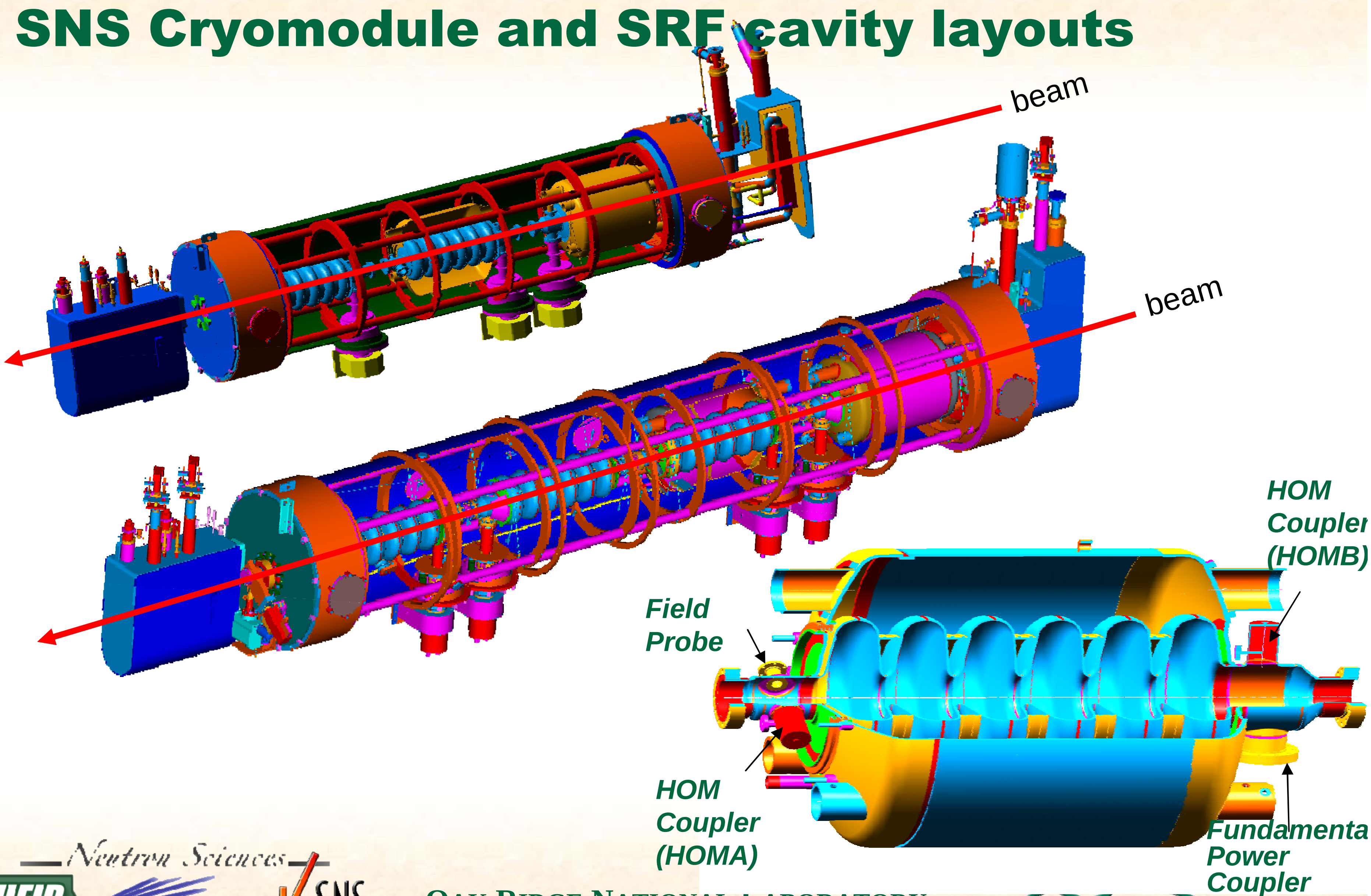
Superconducting Linac

- **Designed and built by Jefferson Laboratory**
- **SCL accelerates beam from 186 to 1000 MeV**
  - **Reached 1011 MeV**
  - **Run at 890 MeV most of the time**
- **81 Niobium cavities in 23 cryomodules (33 medium .61 beta, 48 high .81 beta)**
- **Cavities are now operated at 2.1 K**
- **Until Spring 2007 mostly run at 4.5 K (can run up to 30 Hz, 1.3 msec RF pulse width)**

Medium beta cavity

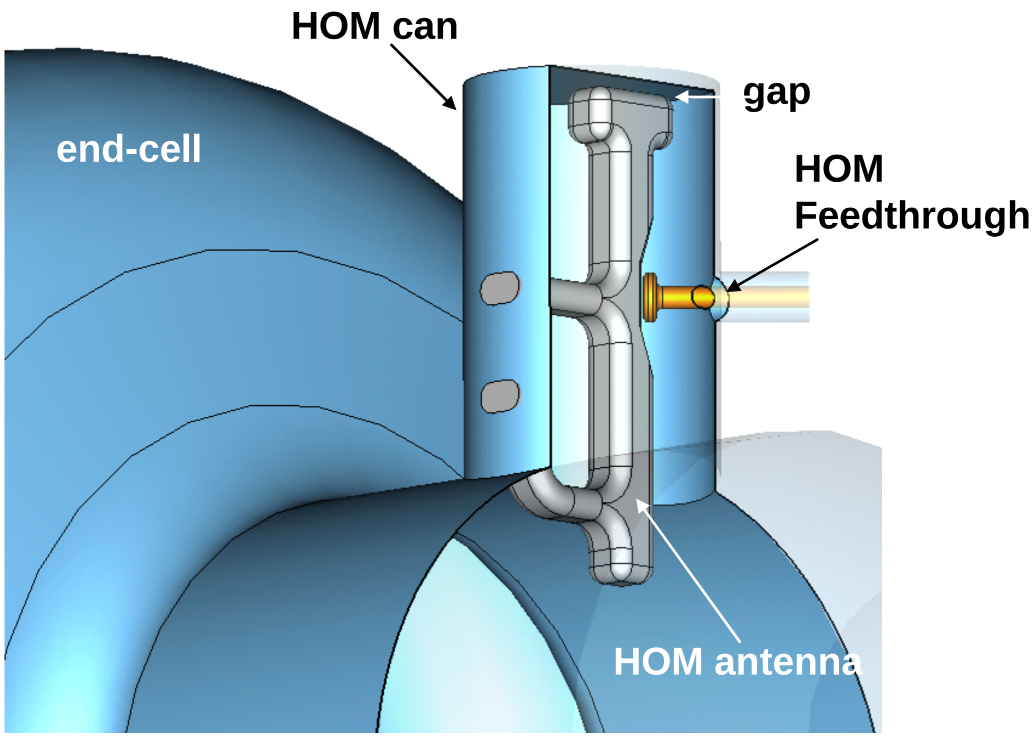
High beta cavity

SNS Cryomodule and SRF cavity layouts



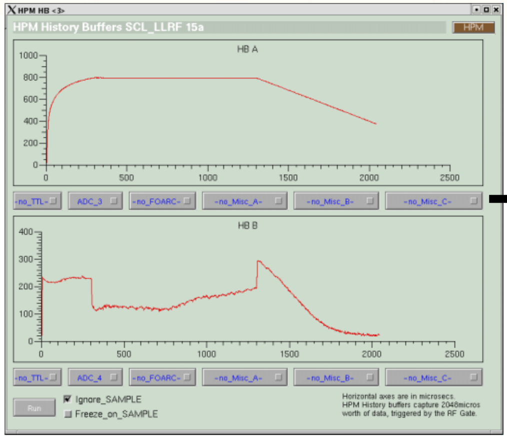
HOM Couplers

- HOM couplers added as extra safety against longitudinal instabilities
- Some HOM feed-throughs have been damaged or show abnormal transmission curves
- Exact cause of anomalies not completely known, but conservatively turned off of run at limited gradients

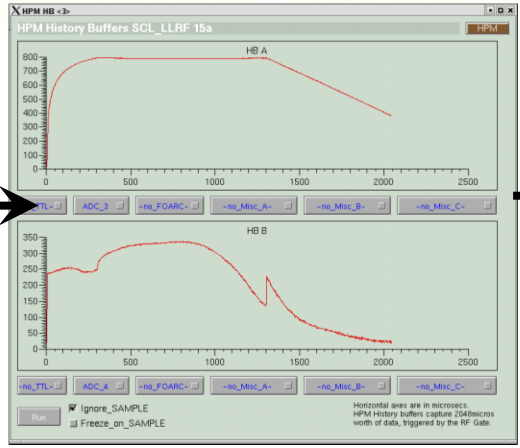


- Some cavities are limited by coupling of fundamental power via HOM filters (one is off, one is being repaired by blanking the HOM ports)

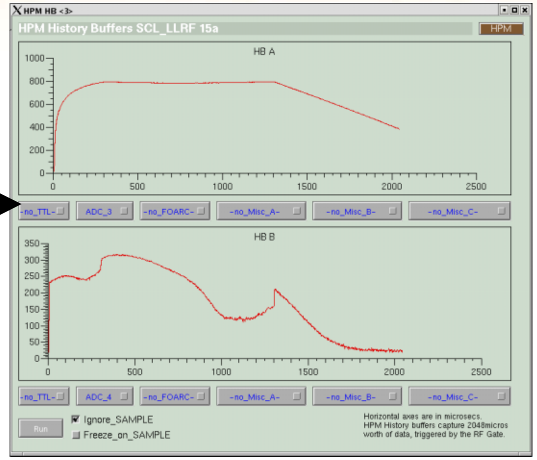
HOM Couplers behavior



1~5 Hz

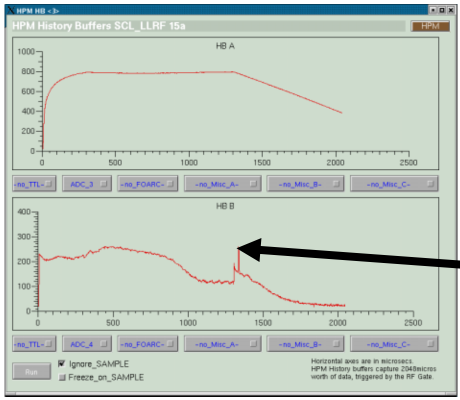


10 Hz



30 Hz

Ex. 15a Eacc=15.4 MV/m

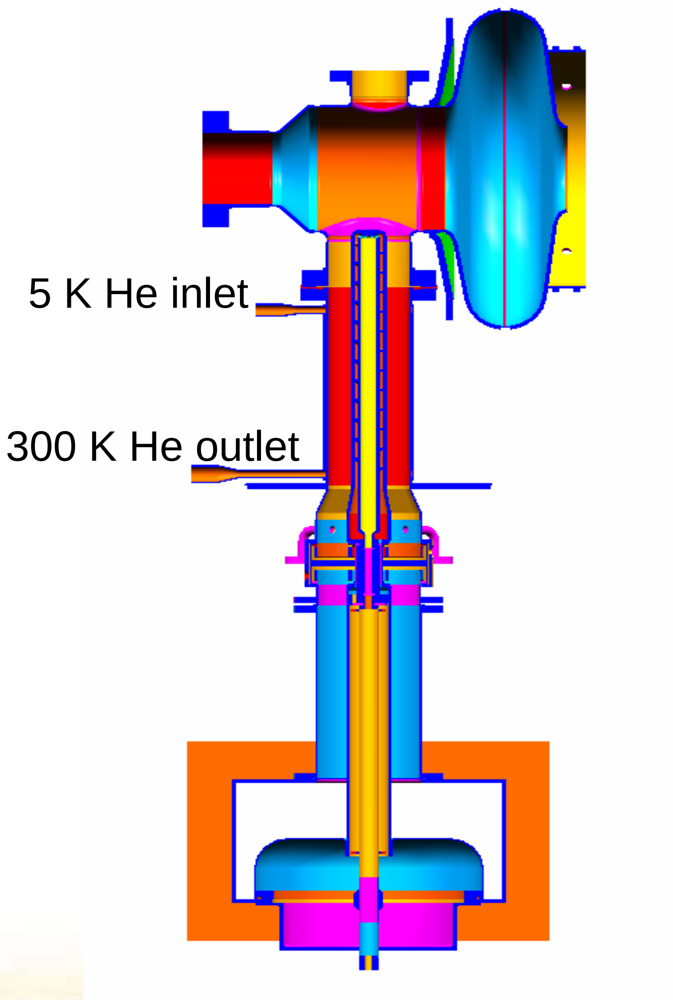


Sharp electron loading appeared

after ~20 min operation at 30 Hz

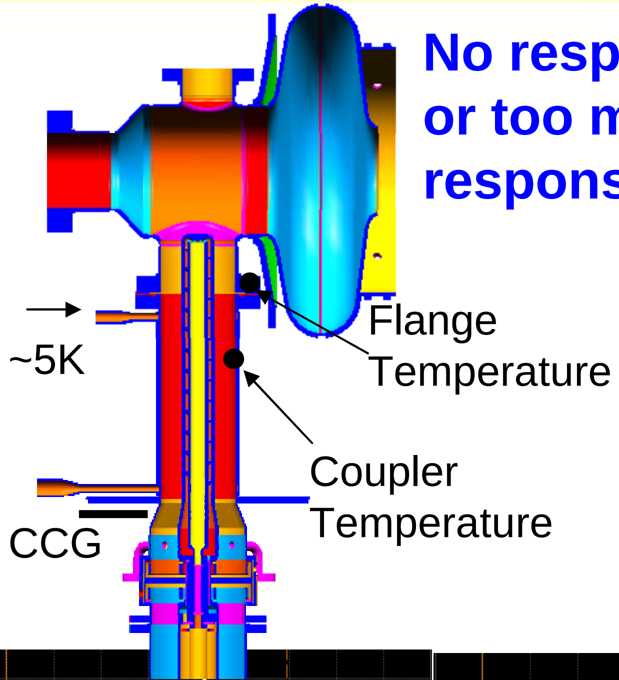
accompanied by vacuum excursions

FPC Vacuum interlocks

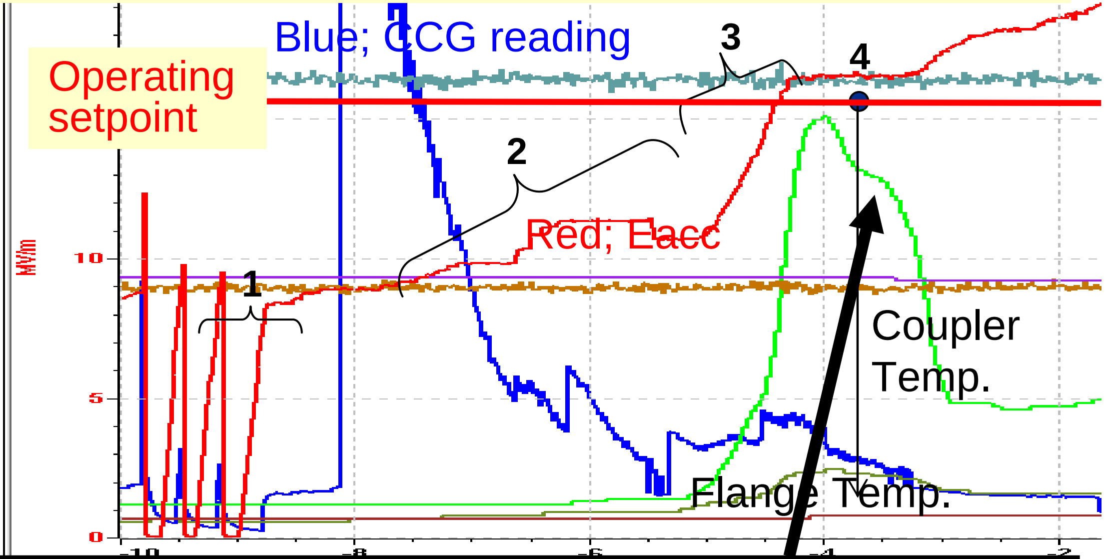


Window vacuum interlock

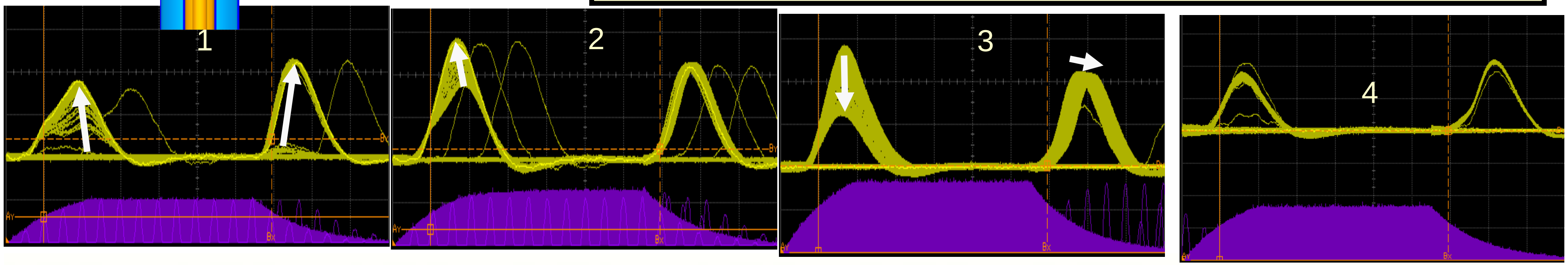
Very difficult turning on cavities during the first year of operation



No response or too much response!!



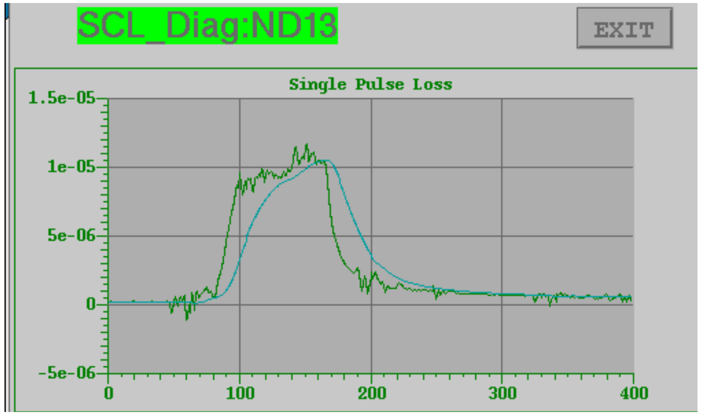
Difficult to find a proper coupler cooling rate



Will switch to current monitor for window interlocks

Radiation patterns

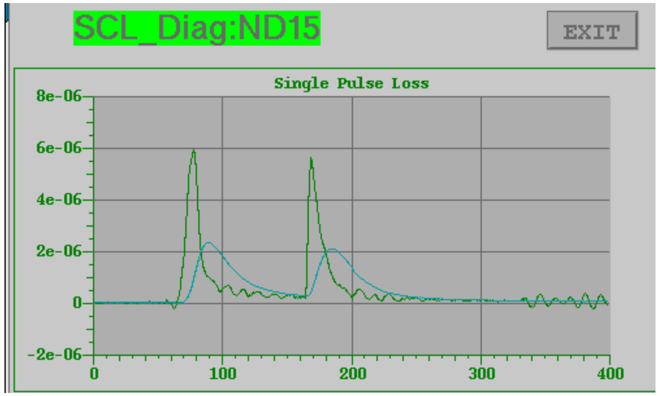
Pulsed Field Emission Radiation



Microseconds/10

Radiation correlated with cavity fields (most cavities)

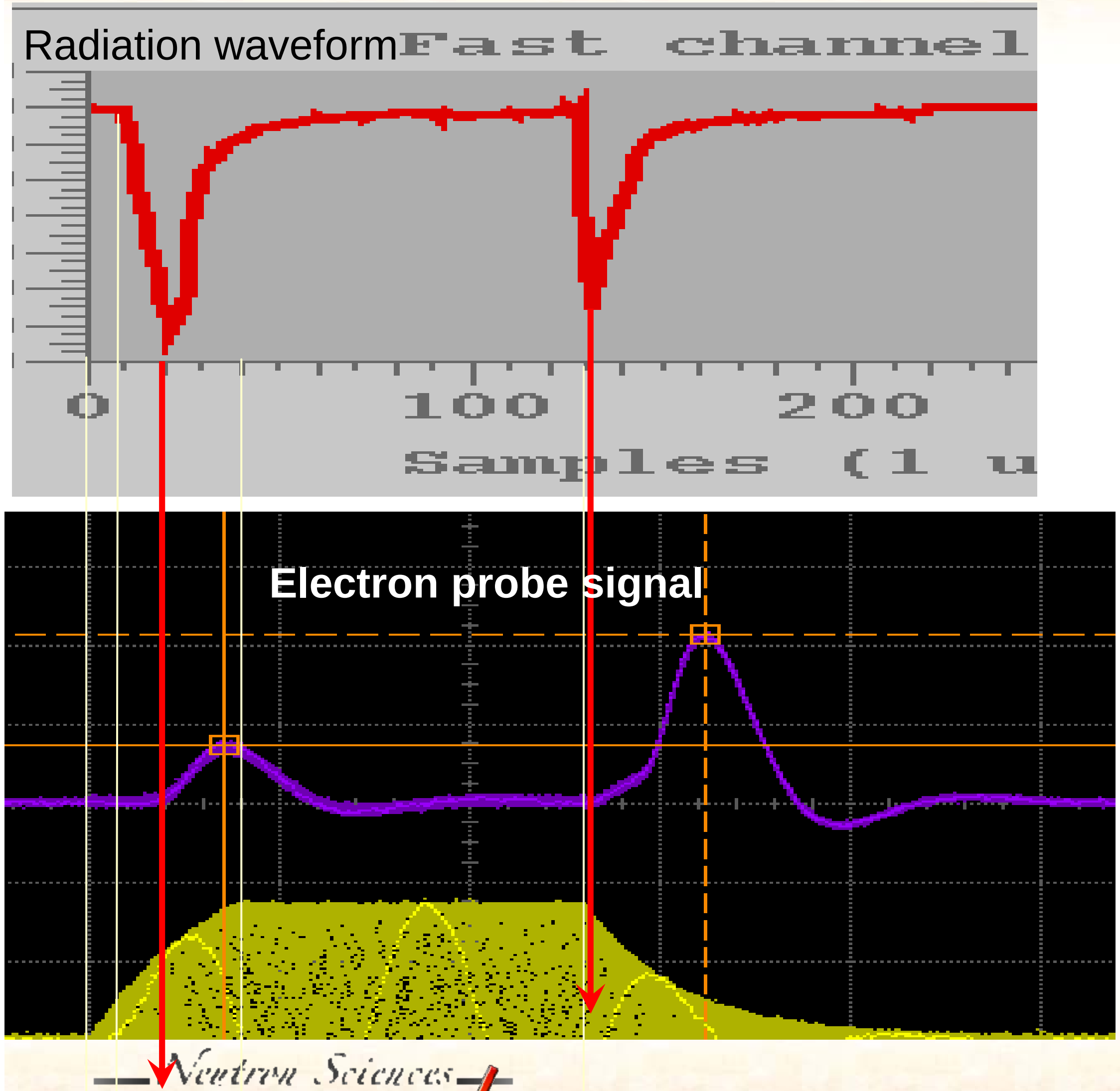
Traces are fast and filtered detector responses

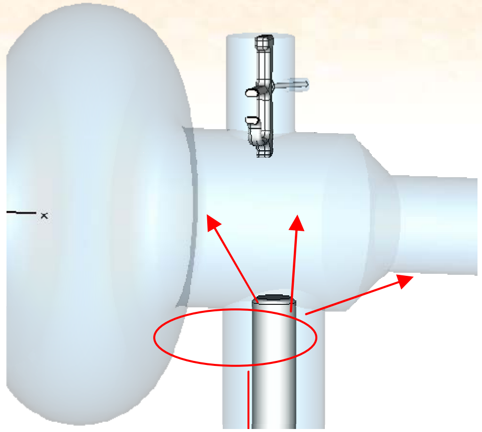


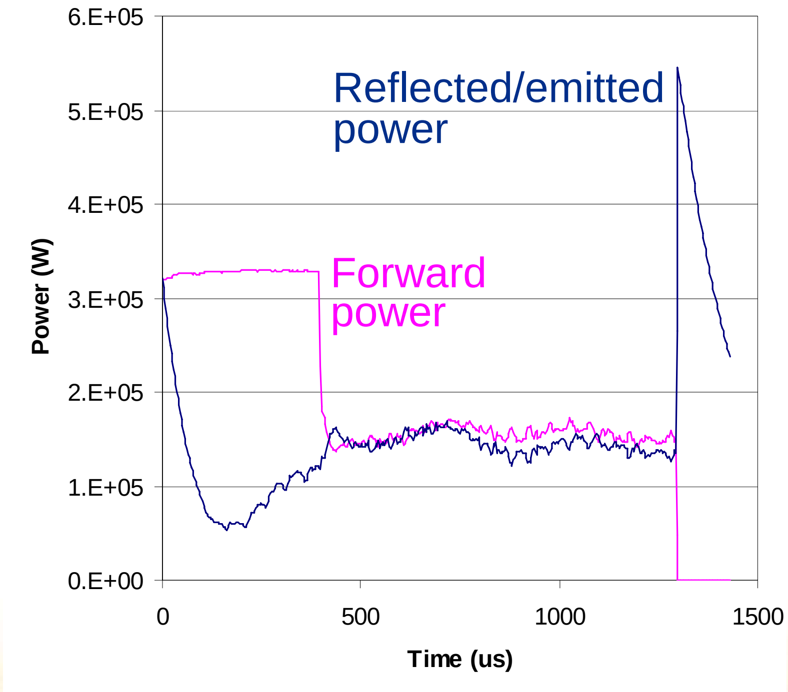
Microseconds/10

Radiation correlated with traveling waves in the coupler (about 10 cavities)

Cavity-coupler interaction

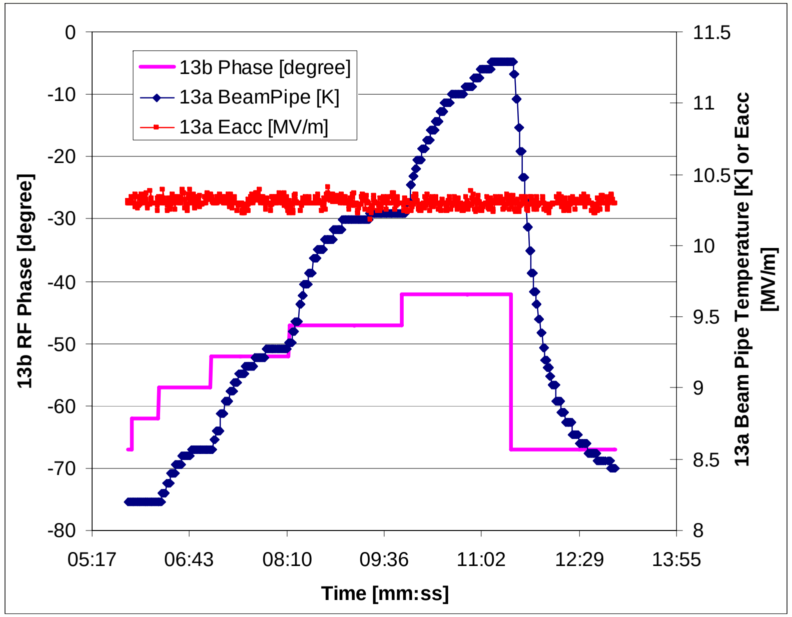




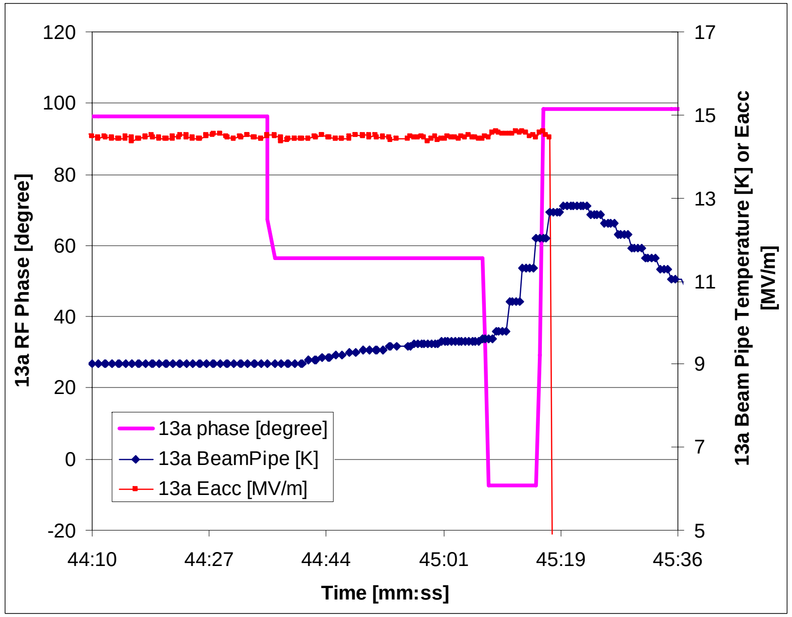


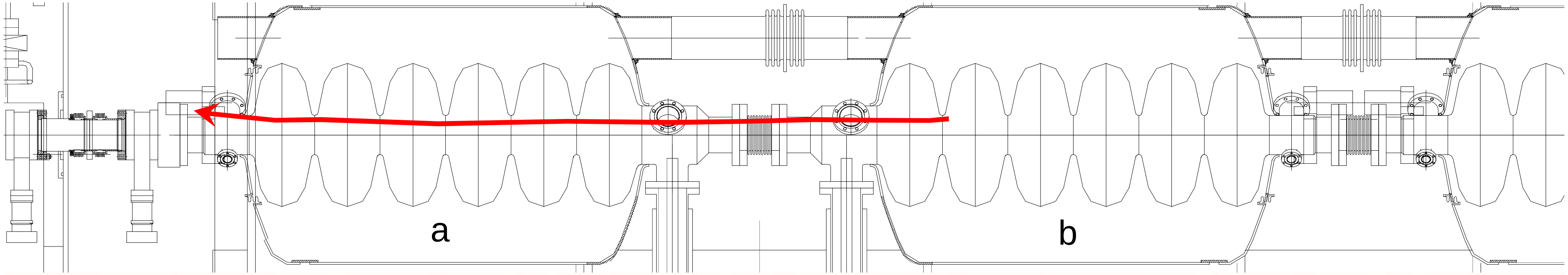
Field Emission Heating Across Cavities

b cavity phase → a cavity beam pipe



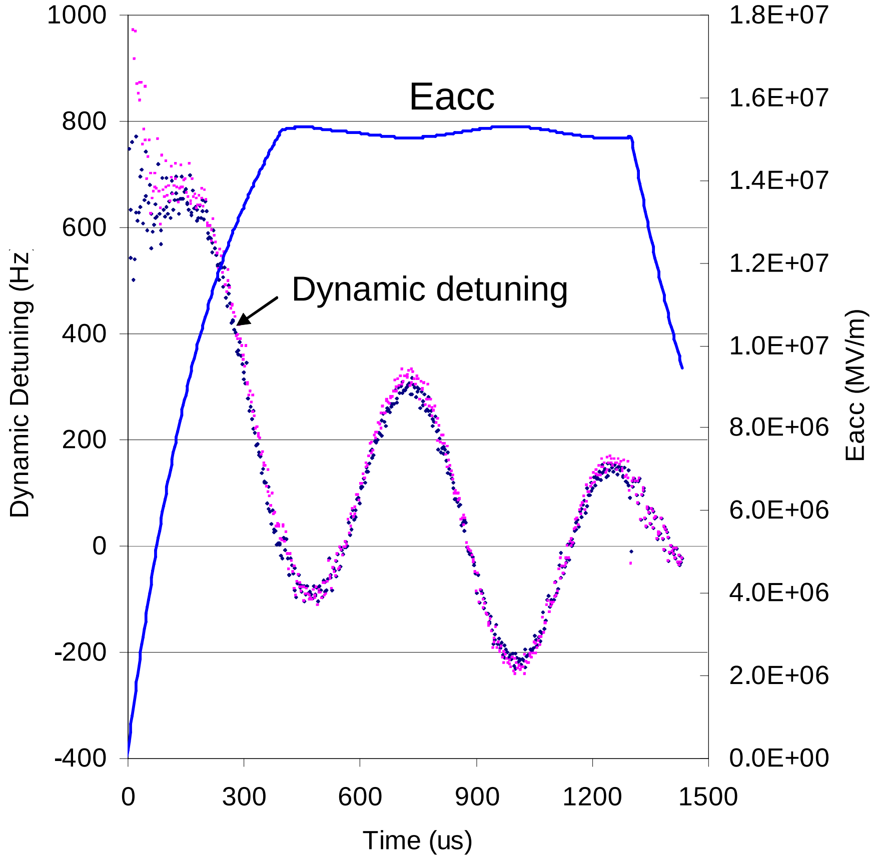
a cavity phase → a cavity beam pipe

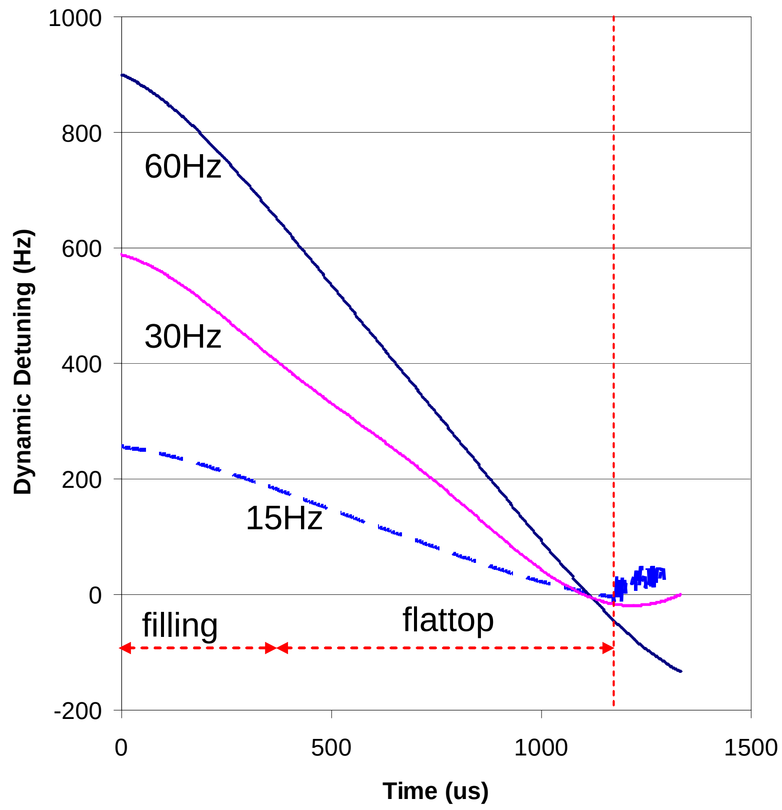




Lorentz force detuning

Dynamic detuning as expected (K_{LFD}→3-4:medium; 1-2:high)
Some cavities show resonance phenomena at higher repetition rates

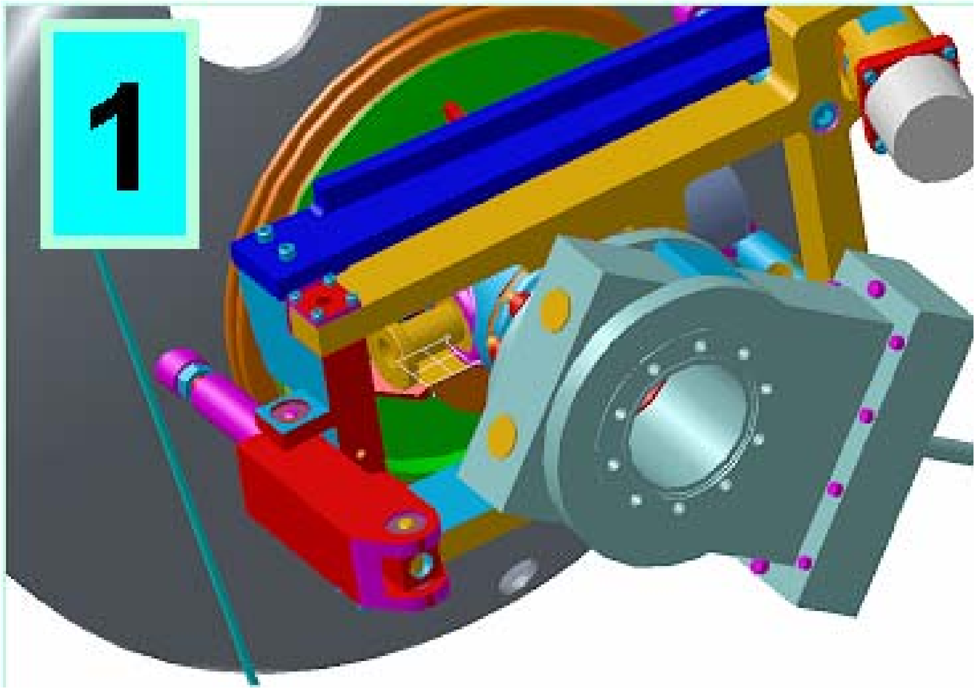




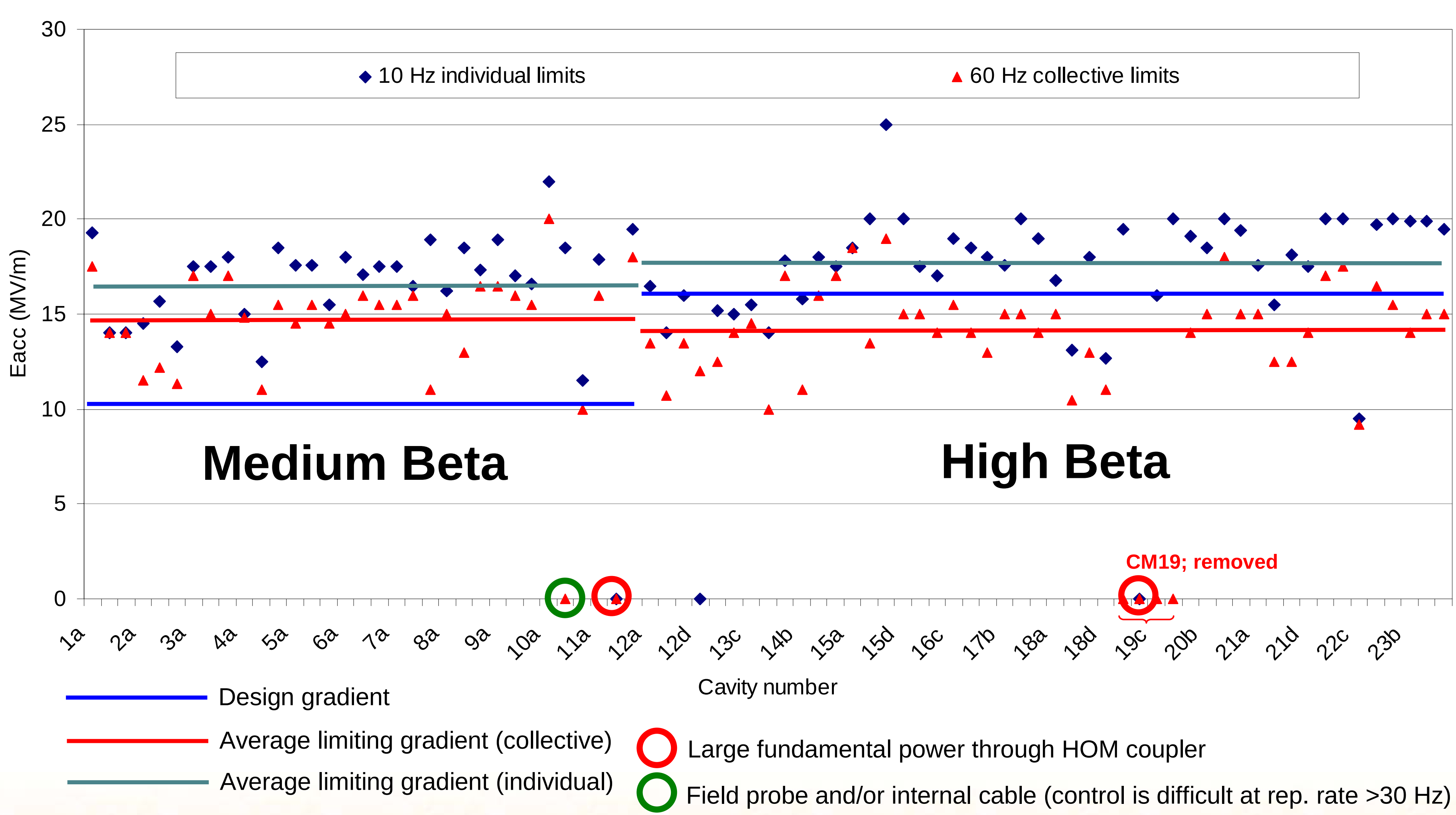
The 2 kHz components shows resonances at higher repetition rate in some of medium beta cavities.

SCL Subsystems– Piezo Tuner

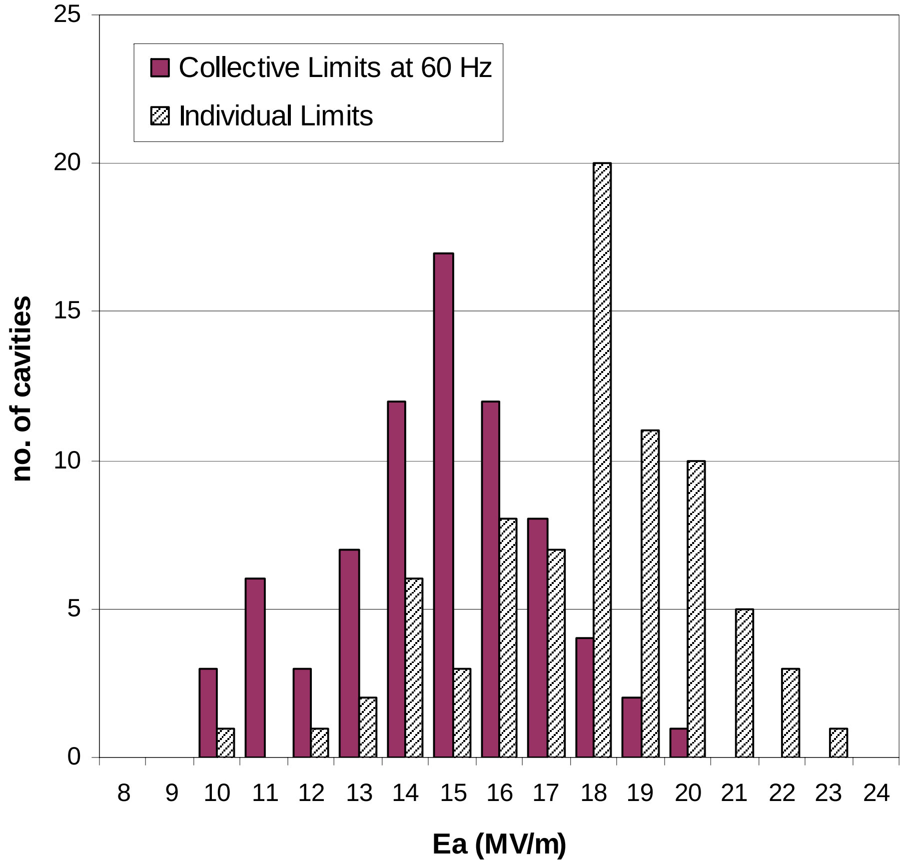
- Piezo tuners installed compensate for the Lorentz detuning
- Not yet used in operations
- If piezo stack fails, the cavity cannot be operated (real event in February 2007)
- May be activated on selected cavities if necessary

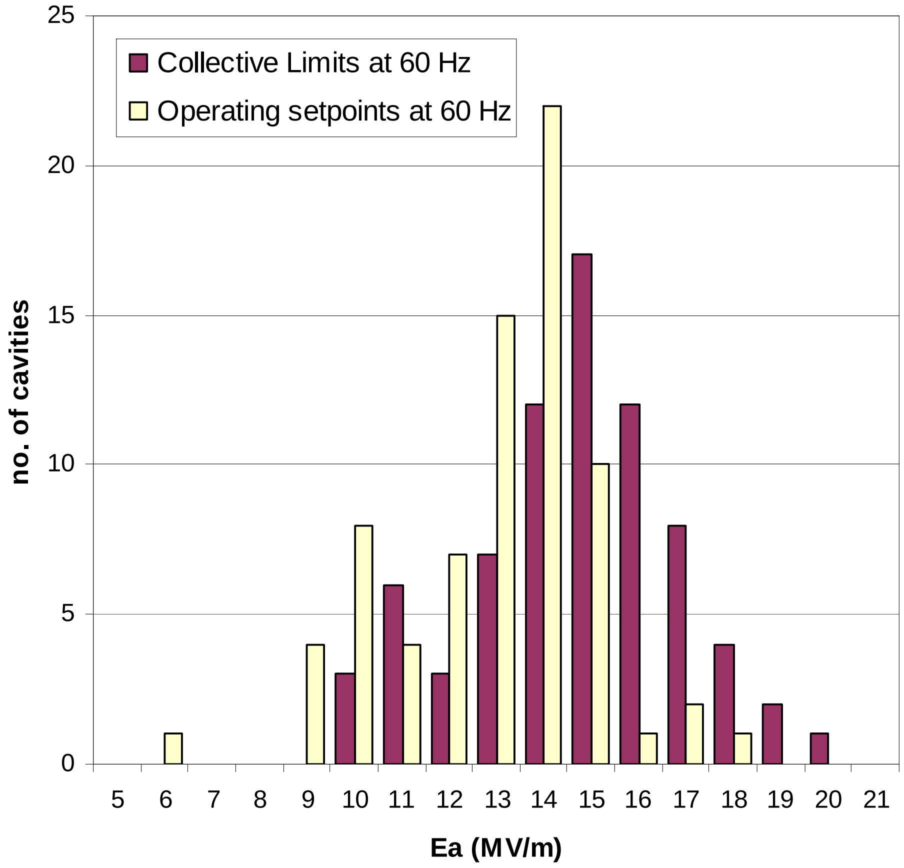


Accelerating gradients and statistics

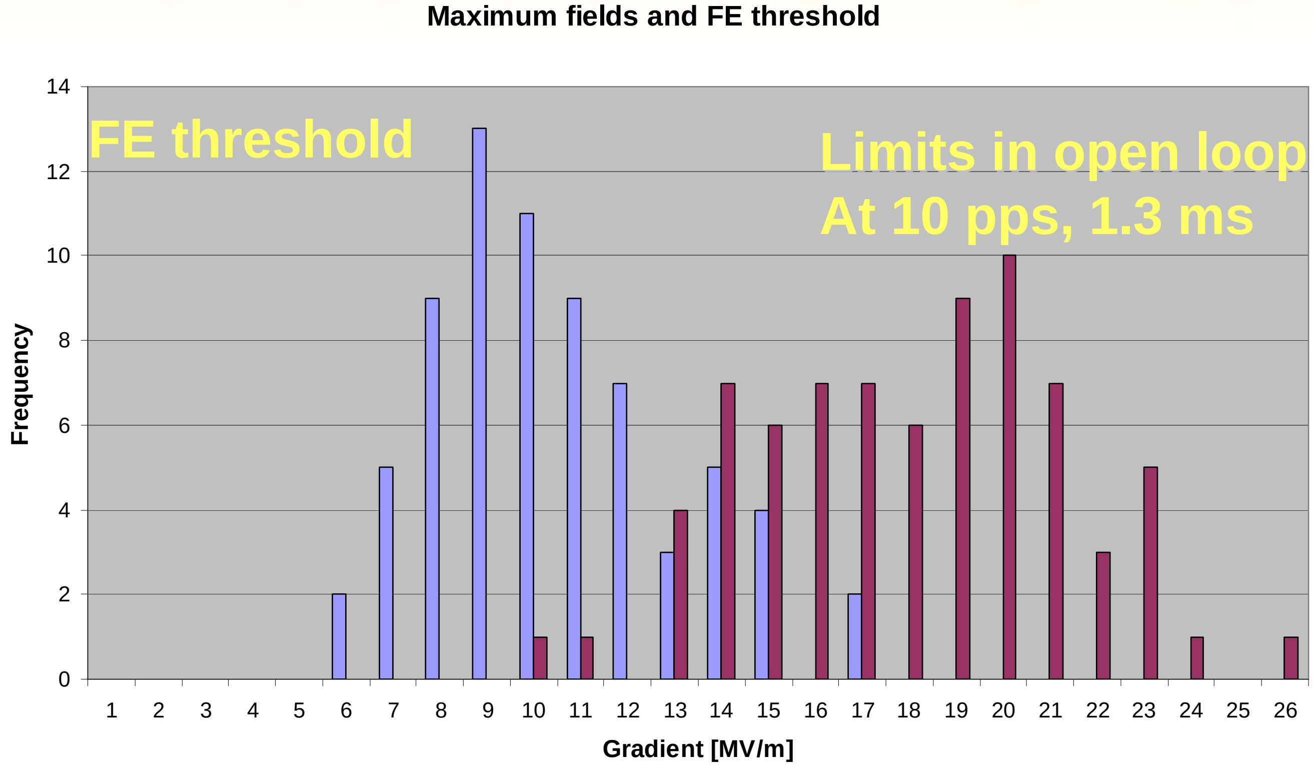


Accelerating gradients distributions





Field emission threshold

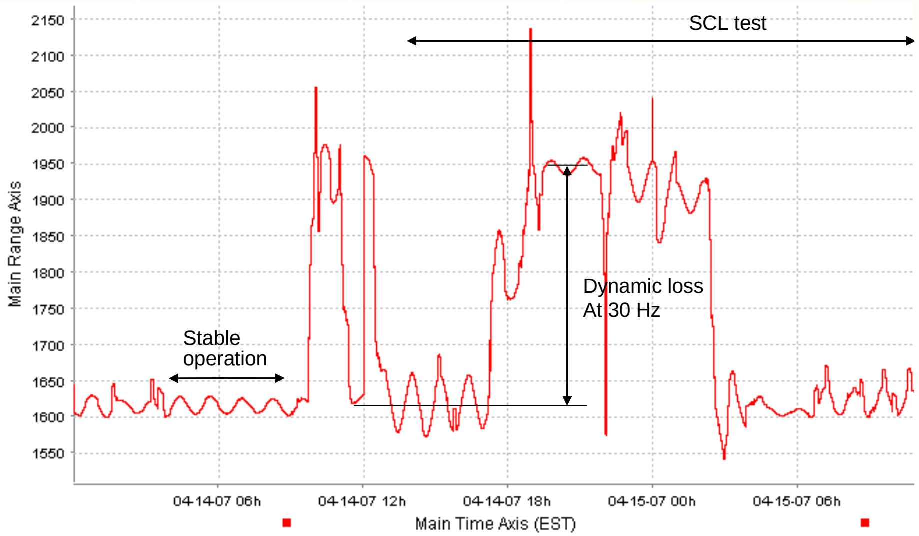


Average maximum gradient (31 MB and 44 HB): 17.6 MV/m

Average FE threshold: 10.0 MV/m

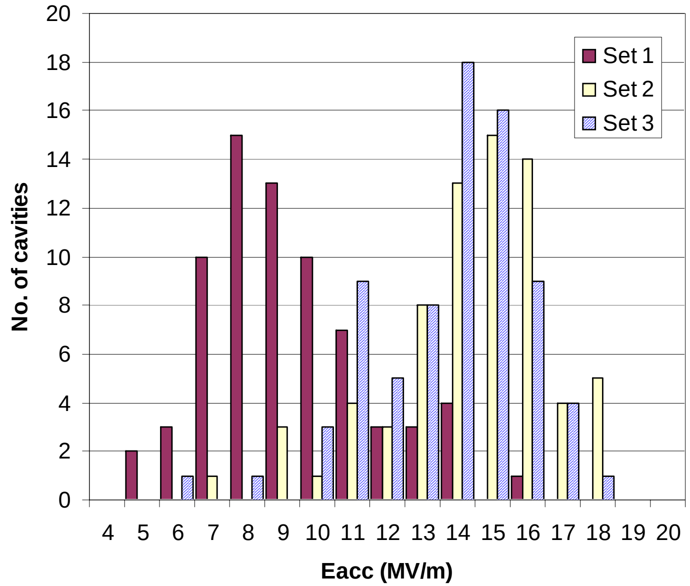
Operating gradients are kept somewhere between the FE threshold and 90% of the maximum value

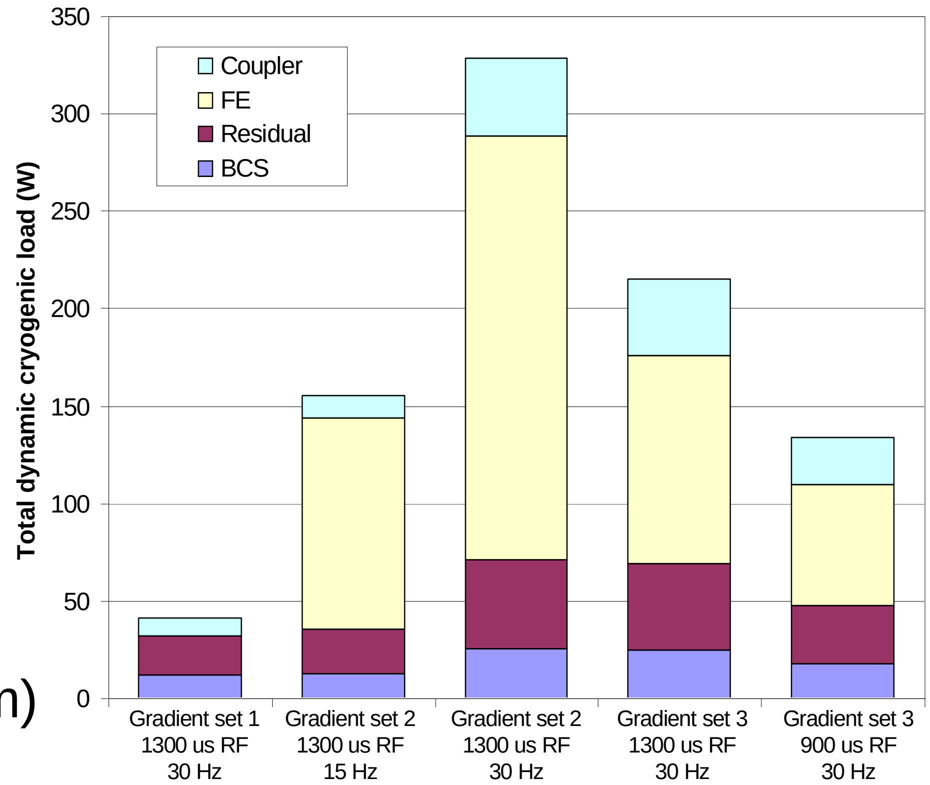
Dynamic heat load at 2.1 K



Heater compensation at 2.1 K for all operating cavities.
A few cavities, operated into heavy field emission, contributed almost half of the dynamic load.
At 4.5 K the field emission loading is negligible compared to the BCS losses.

Cryogenic loads at 2.1 K





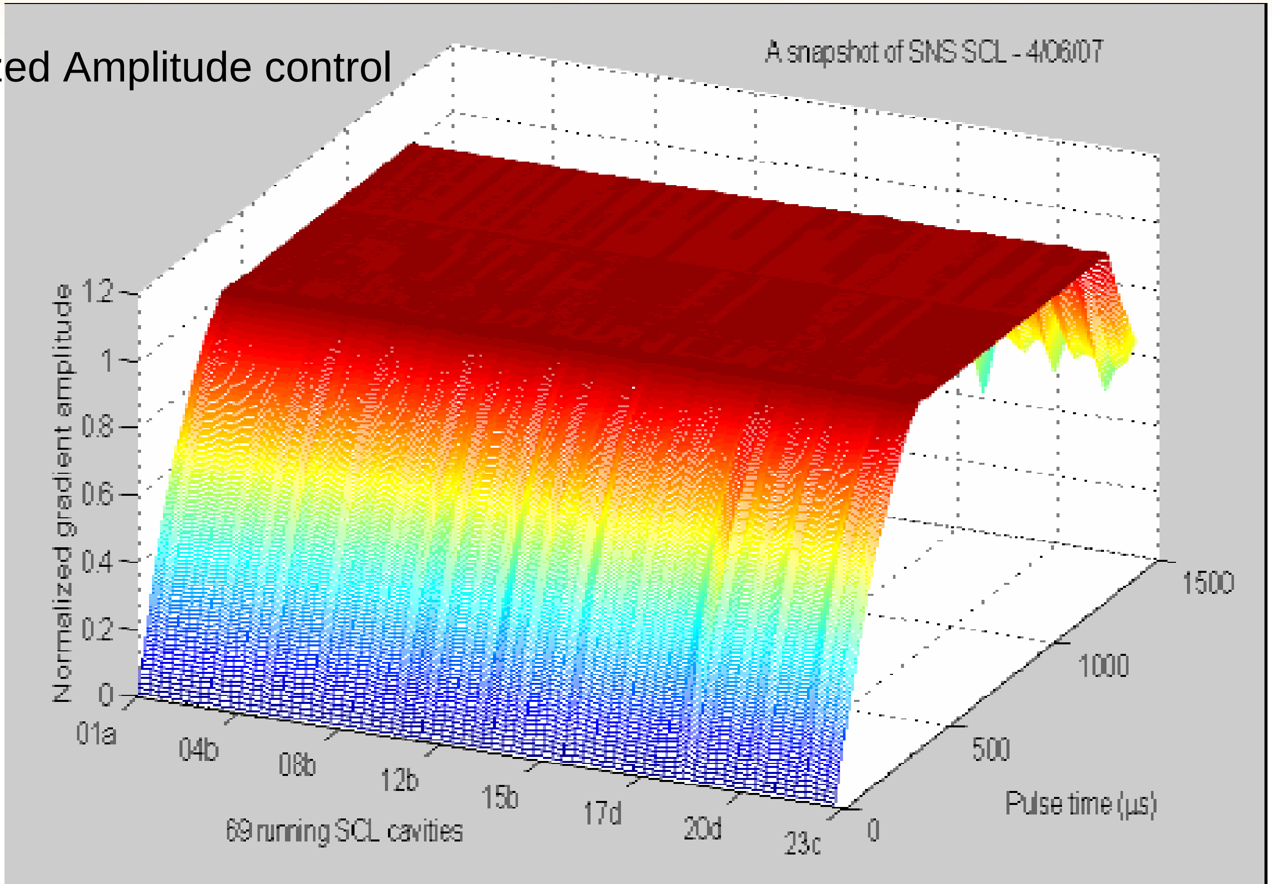
Set 1; Below FE threshold (~9MV/m)
Set 2; 80 % of individual limits
Set 3; 88 % of collective limits

Avg(set2)-Avg(set3)~1MV/m

Total dynamic heat loads due to different sources

RF control stability for SCL

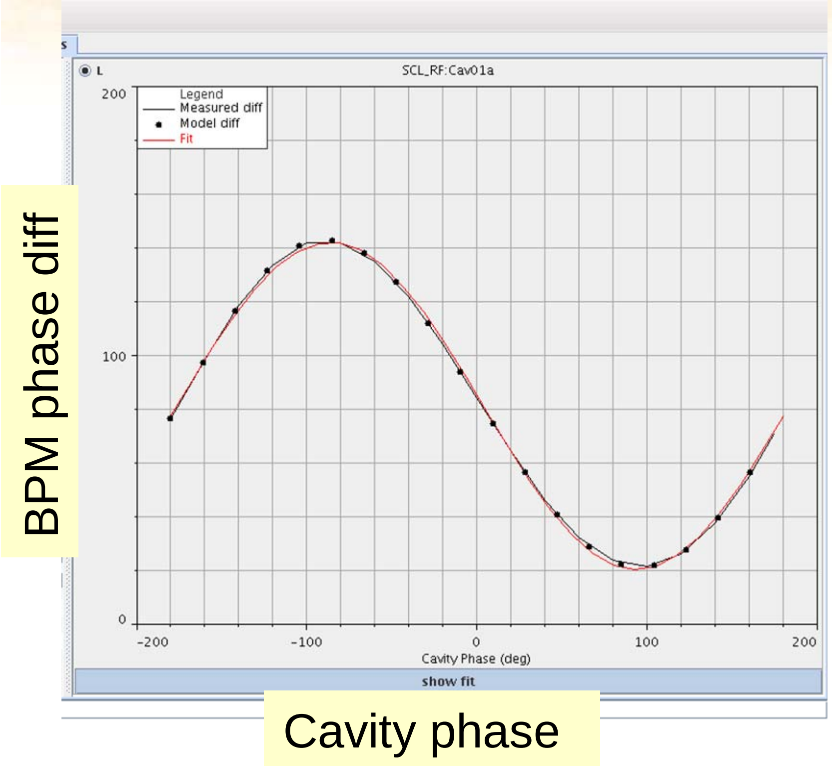
Normalized Amplitude control



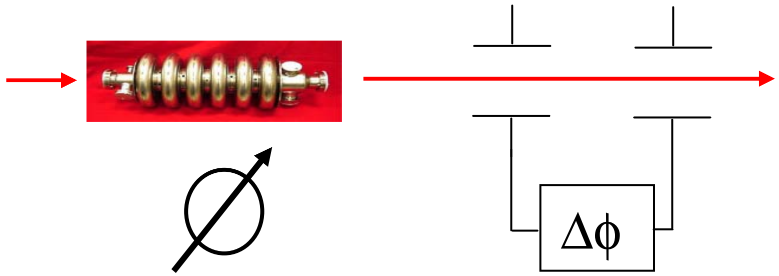
The RF Control System provides excellent amplitudes and phase stability for all operating cavities

Next week LLRF Workshop in Knoxville

Energy gain: SCL Phase Scan using BPMs



SCL phase scan for first cavity
Solid = measured BPM phase diff
Dot = simulated BPM phase diff
Red = cosine fit

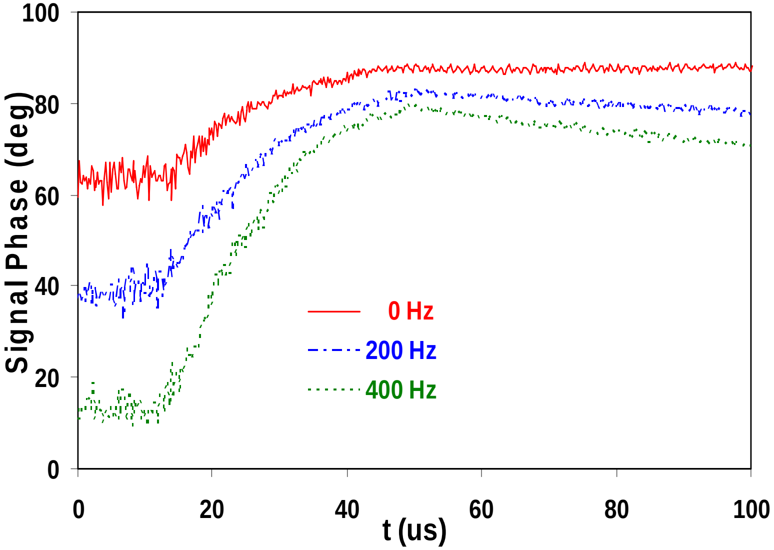


- **Relies on absolute BPM calibration**

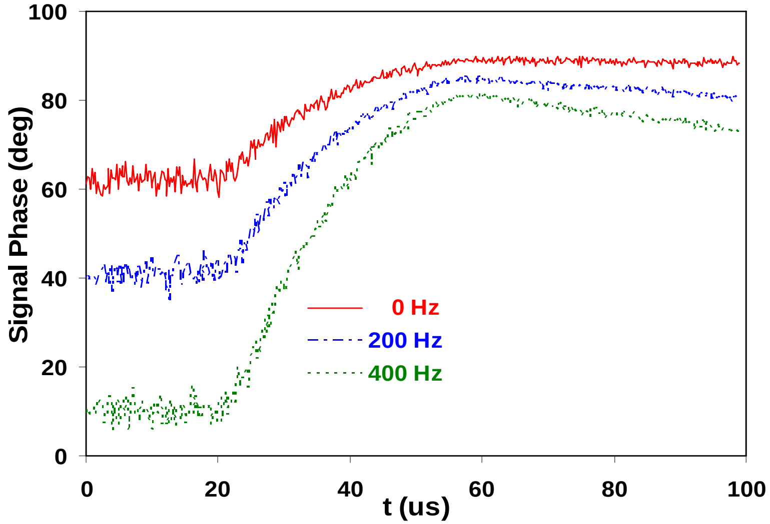
Drifting Beam Method to Determine Cavity Phase and Amplitude Setpoints

proton beam 422MeV, 15mA, 40us

signals measured with/without cavity detuning



simulations from the model with superimposed measured noise

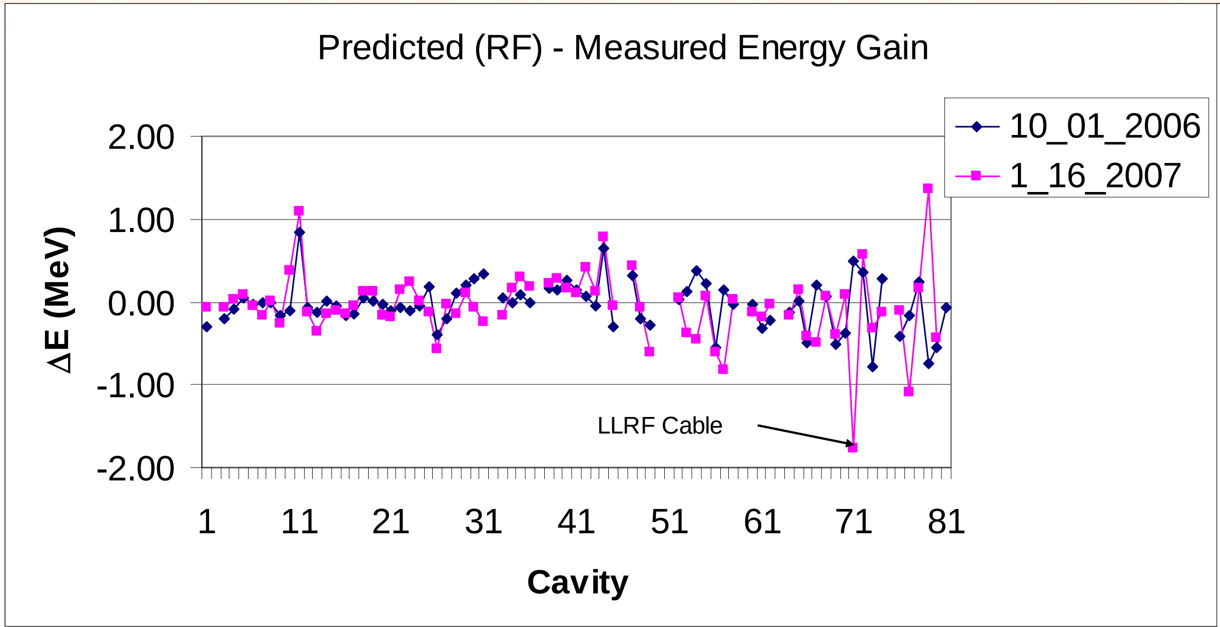


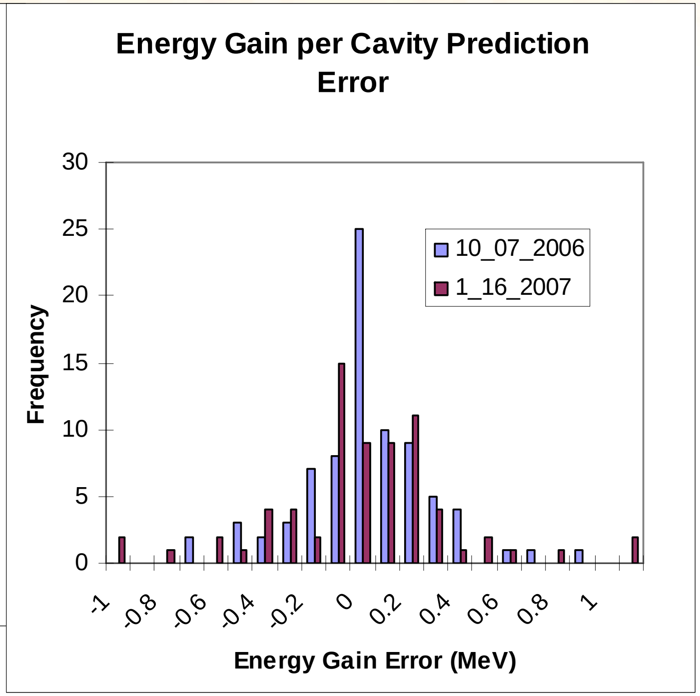
- **Drifting beam excites the cavity fields.**
- **Comparison to model allows calibration of the phase and amplitude**
- **Phase prediction ~ 1 degree, amplitude ~ 4% compared to phase scan technique**

Operations constraints

- **Drastically improved trip rates by better understanding of:**
  - underlying physical phenomena (outgassing, arcs, discharges, radiation, field emission, beam strike, dark current etc.)
  - components response (arc detectors, HOM couplers, Cold cathode gauges, Coupler cooling, end group heating)
  - controls (LLRF logic, programming, choice of limits and stability parameters)
- **Continue to improve performance and ultimate beam power by:**
  - Optimizing gradients, modulator voltages, matching of klystrons to cavities, circulator settings, available forward power for beam loading etc.

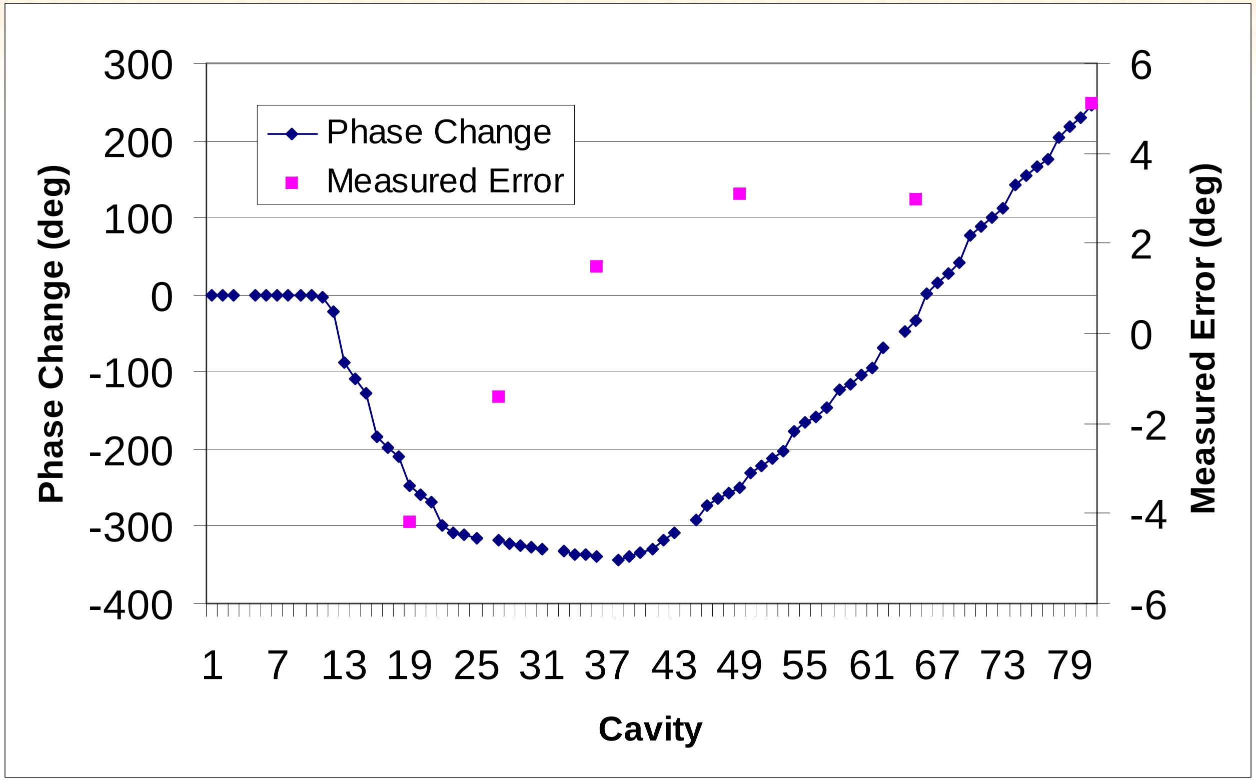
SCL Tune-up – Linac Energy Gain





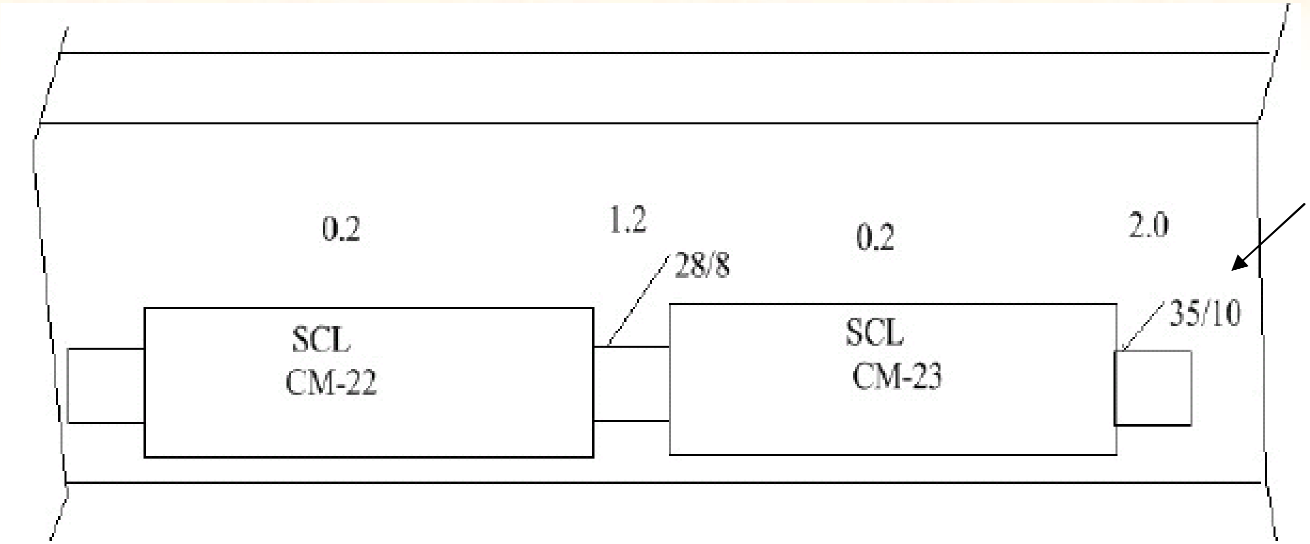
- **Energy gain per cavity is predictable to a few 100 keV and distributed about 0.**
- **Final energy is predictable to within a few MeV**
- **This leads to shorter and shorter setup times and rapid fault recovery, even for many "missing cavites" (operational availability)**

Cavity Fault Recovery Application



- **In the spring 2006, 11 cavities had to be either turned off or have their amplitudes reduced for safe operation, 1 cavity was returned to operation**
- **The fault recovery scheme was applied "all at once"**
- **Phase scan spot checks indicate the scaling was within 4 degrees**
- **No detectable change in beam loss**

Beam Loss / Activation



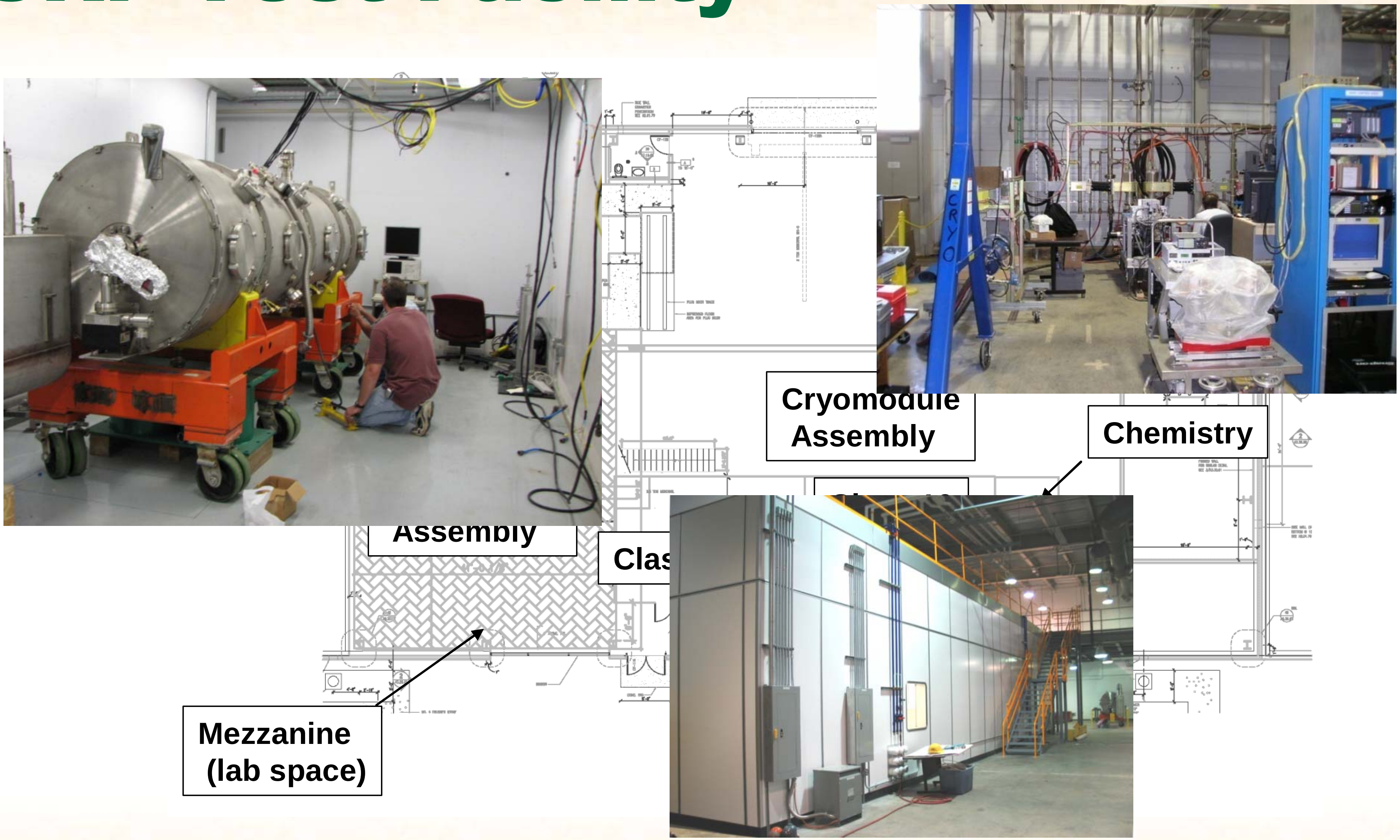
Contact / 30 cm dose in mRem/hr

- **Ultimately the <u>beam loss</u> and <u>components' activation</u> dictate the machine setup**
- **Components internal to Cryomodule become activated and planning for repairs becomes more complicated**

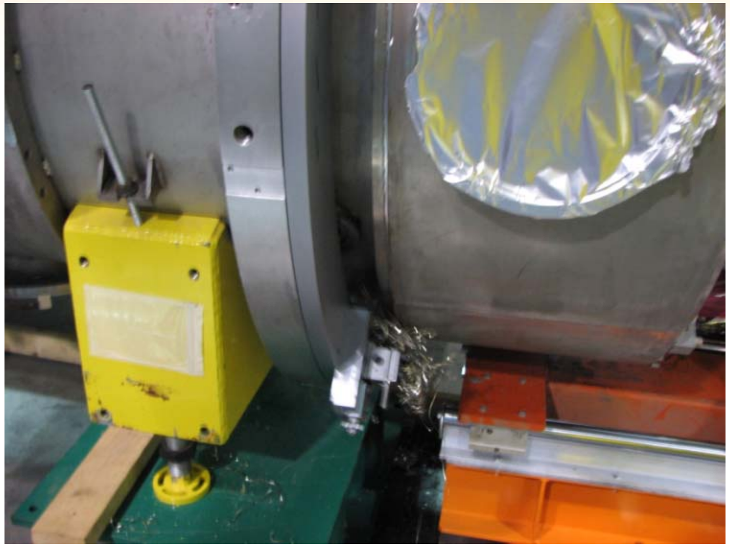
SCL Summary

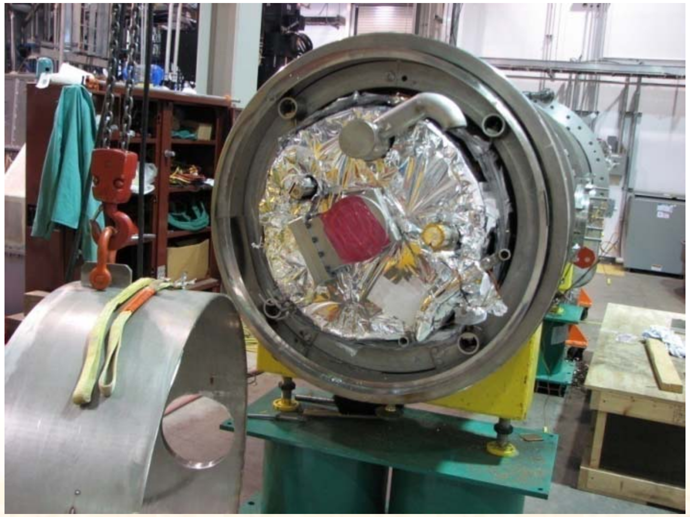
- Extensive studies of cavities, components and cryomodules have been performed
- 1 GeV demonstration at 15 Hz, 4.4 K (79 cavities) to linac dump
- 60 Hz demo at 860 MeV, 2.1 K (75 cavities) with beam to target
- Supporting beam power ramp up
- SCL is now providing stable/reliable acceleration for Neutron Production
- Repairs and spare acquisition plans being evaluated (Pressure Vessel Code requirements)

SRF Test Facility



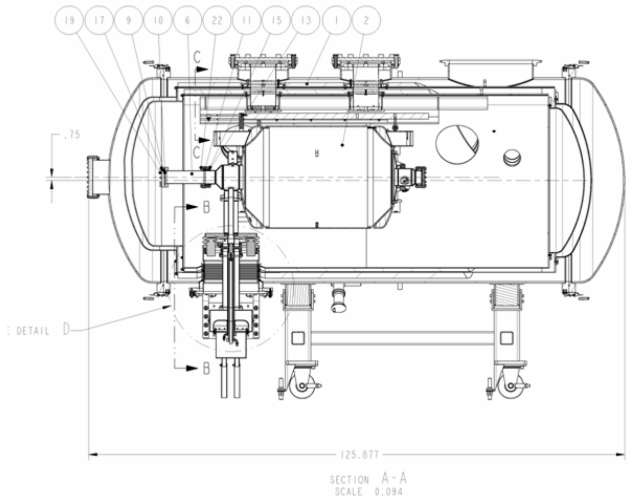
Rebuild (medium beta prototype)

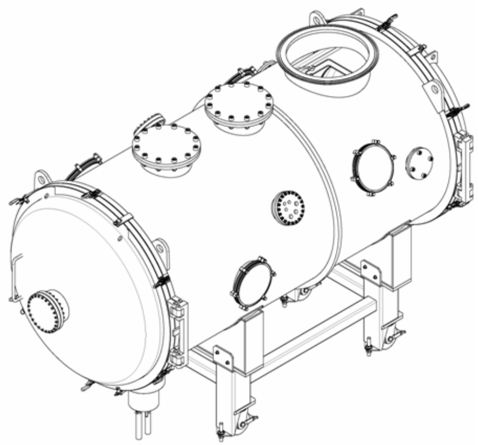




Horizontal Test Apparatus

To be used for cavity qualification before string assembly, for tests of cavity/end group cooling and for High Peak Power Pulse Processing up to 5 MW, 1 ms.





Mechanical components ready for assembly

Power (Energy) Upgrade Project

- **Increase in beam power is achieved by a combination of beam current (26 to 42 mA) and beam energy (1.0 to 1.3 GeV) increase.**
- **All of the energy increase will be accomplished in the superconducting linac by:**
  - **Acquiring, installing and commissioning 9 additional high beta cryomodules, which include:**
    - **36 high beta cavities**
    - **36 fundamental power couplers**
    - **36 Low level RF control systems**
    - **36 high power klystrons (750 kW) and related RF components**
    - **36 tuners**
  - **Modifications/improvements will be included into the CM**

CD 1 approved the ENERGY increase

This part would be completed by 2013

Summary

- SNS is now an fully operating facility providing proton beam for neutron production to users
- Achieved all of the design parameters separately
- Provides highest beam power of any spallation source
- Provides highest beam energy of any “proton” linac
- The SCL is gaining full operational experience on pulsed RF superconductivity
- Facilities are being put in place to make SNS a fully functional SRF Accelerator and Laboratory