The Status of the SNS

3rd SPL Collaboration Meeting
CERN
Nov. 11-13, 2009

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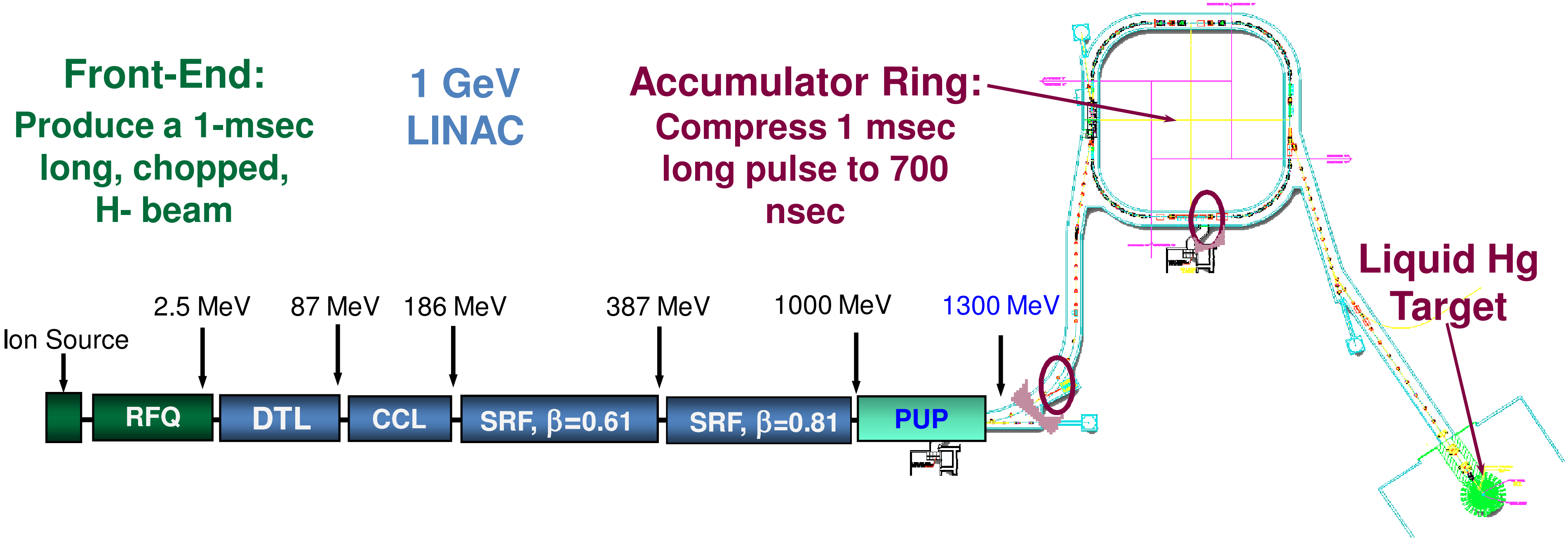
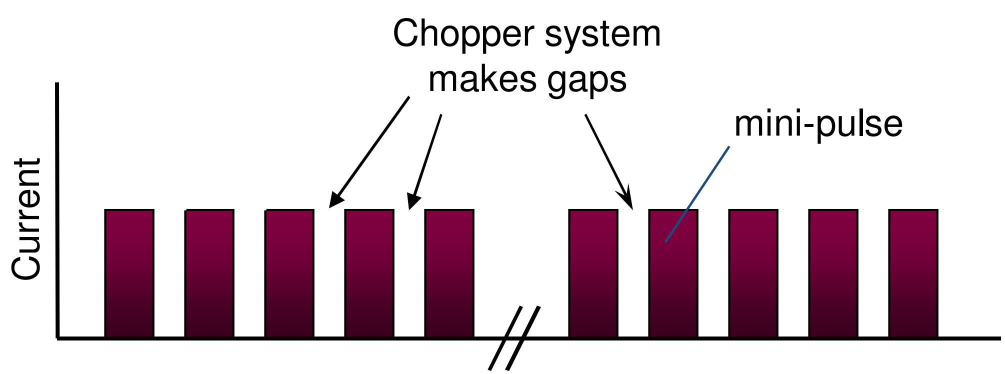
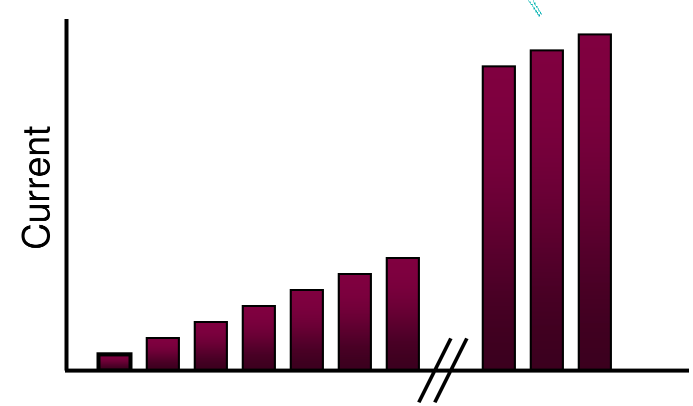
Outlines

- SNS operational status
- Technical Issues and status
  - RFQ
  - Foil
  - HVCM
  - Beam loss & Activation
  - SCL
- Power Upgrade; Impact on SCL
- Summary

SNS Accelerator Complex



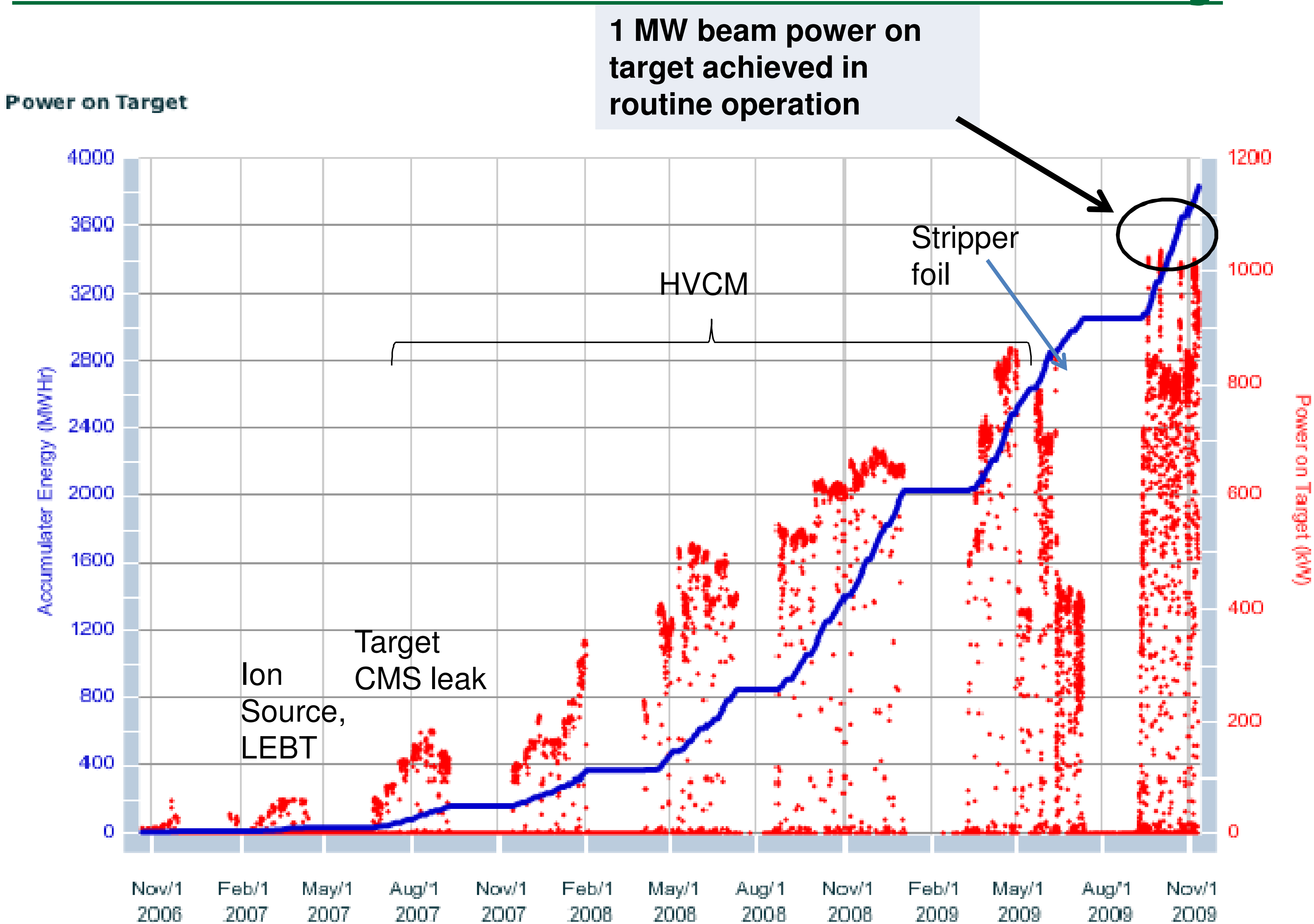




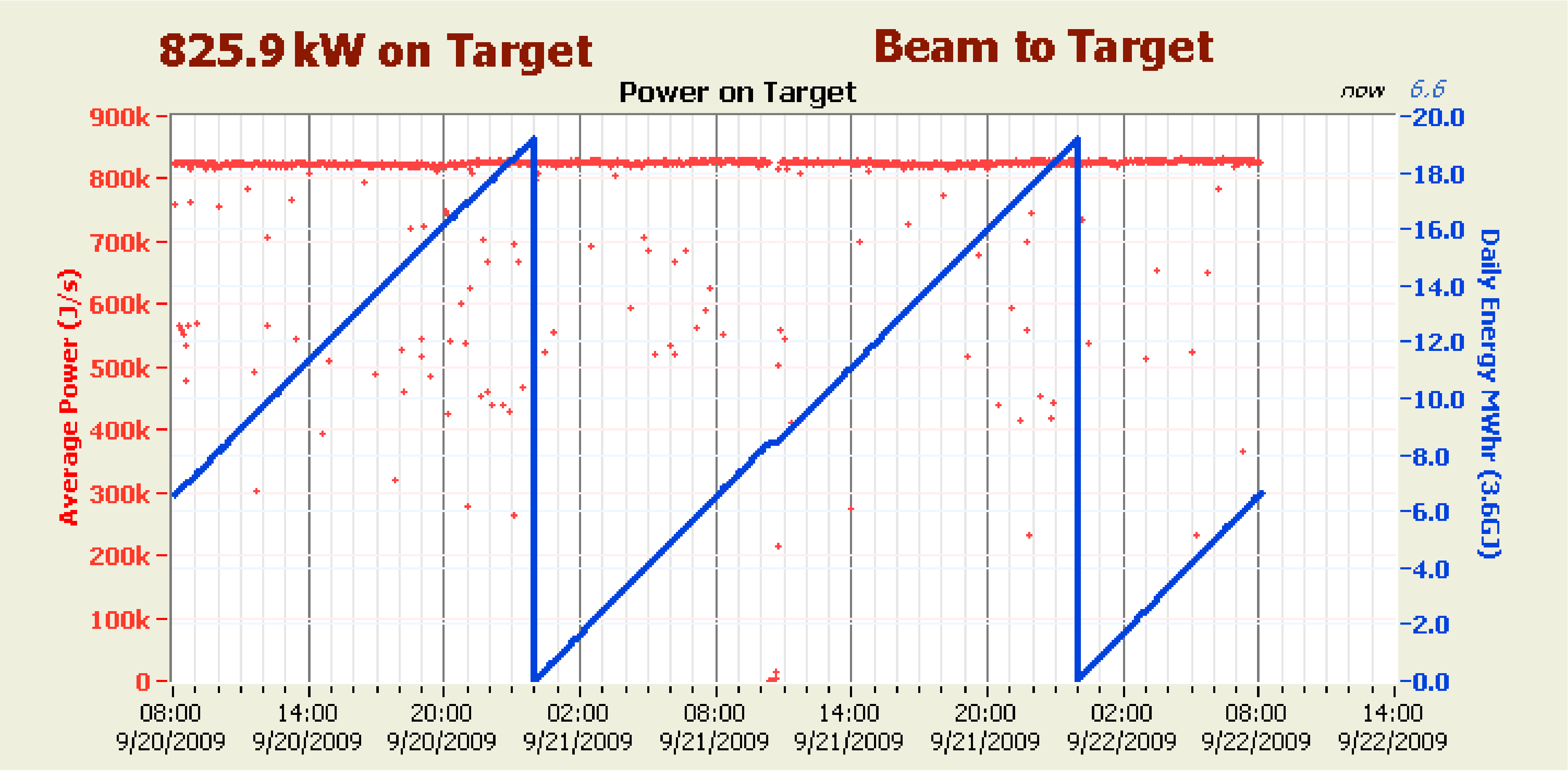
Major Parameters achieved vs. designed

Parameters	Design	Individually achieved	Highest production beam
Beam Energy (GeV)	1.0	1.01	0.93
Peak Beam current (mA)	38	40	36
Average Beam Current (mA)	26	26	24
Beam Pulse Length (μs)	1000	1000	825
Repetition Rate (Hz)	60	60	60
Beam Power on Target (kW)	1440	1030	1030
Linac Beam Duty Factor (%)	6.0	5.0	5.0
Beam intensity on Target (protons per pulse)	1.5×10^{14}	1.55×10^{14}	1.1×10^{14}
SCL Cavities in Service	81	80	80

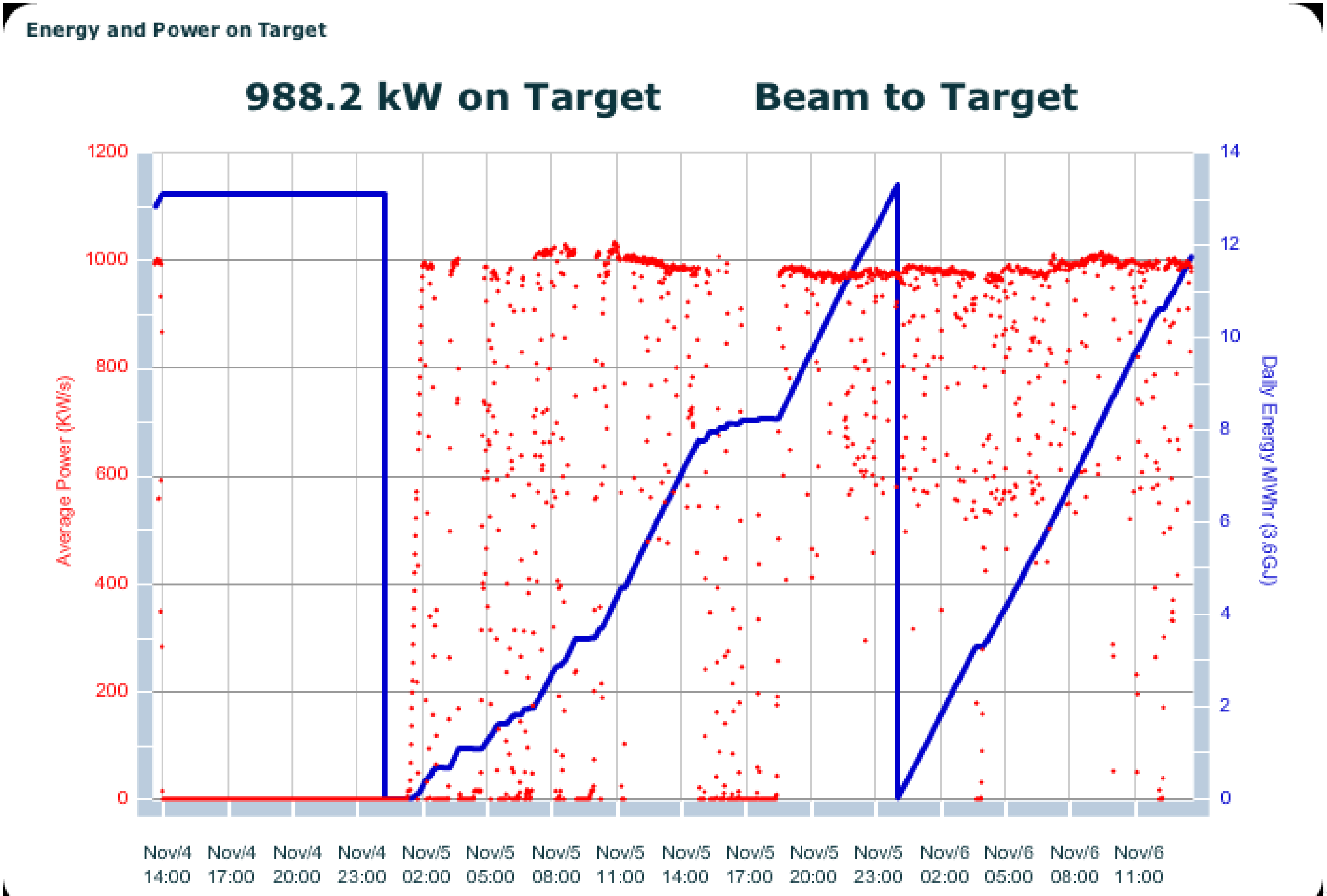
SNS Beam Power Performance History



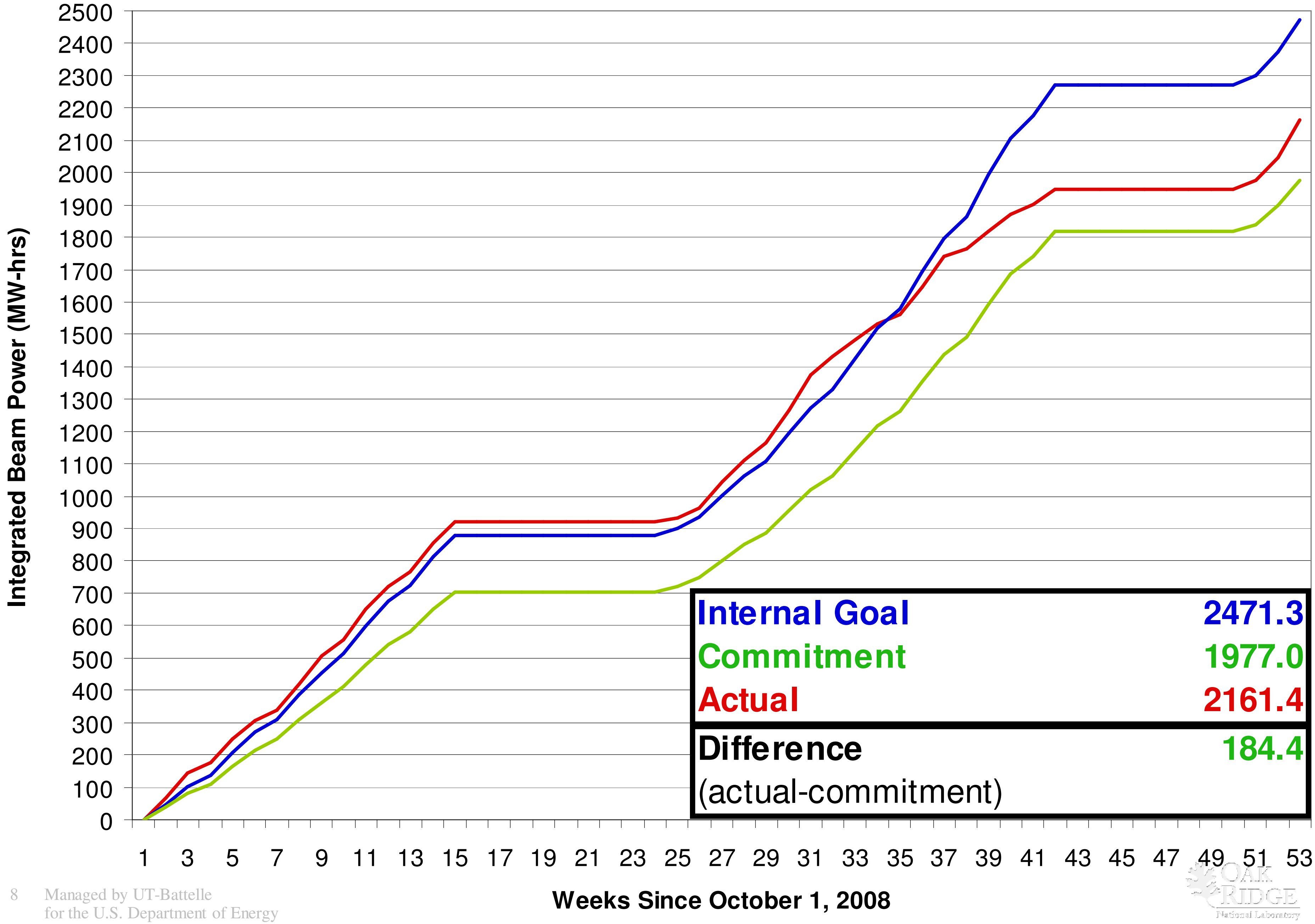
Smooth Running…



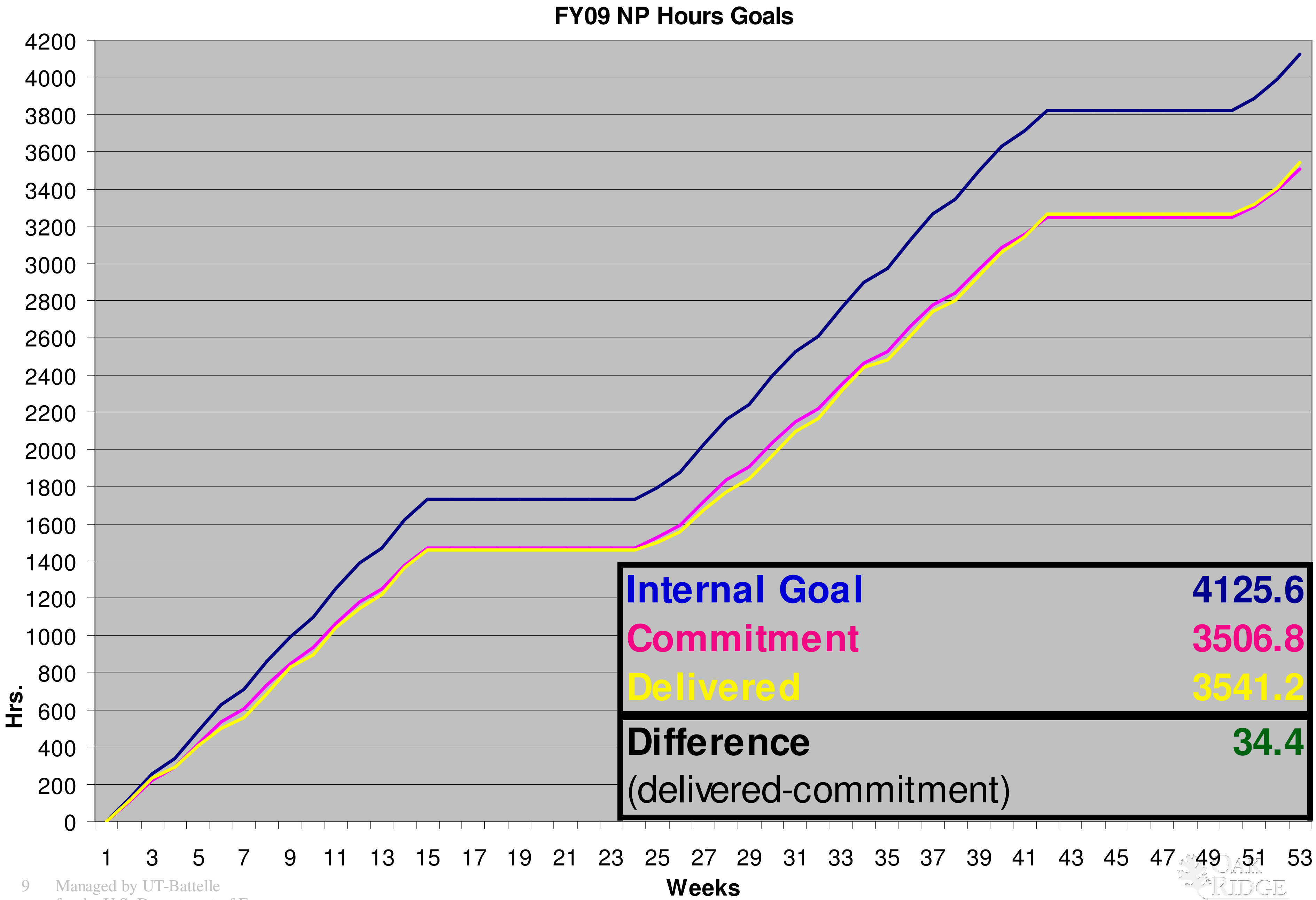
Sometimes not…



Power delivery goals for FY09

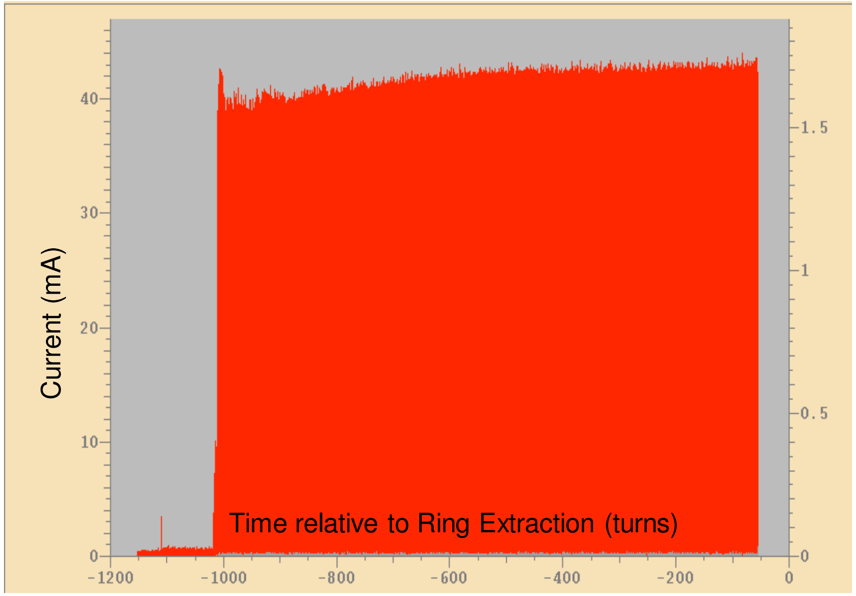


FY09 Neutron Production hours goals

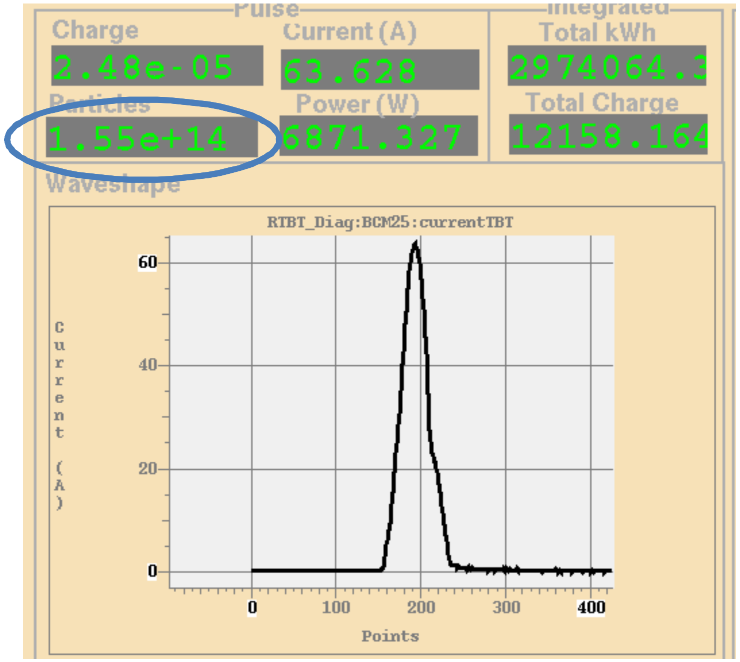


High Intensity Beam Studies – 7/11/2009
1 Hz beam

Linac Beam waveform:
- ~ 1 msec long
- produces the design intensity



Beam Pulse Extracted from the Ring:
- Full baseline design intensity stored and extracted
- No gross instability observed

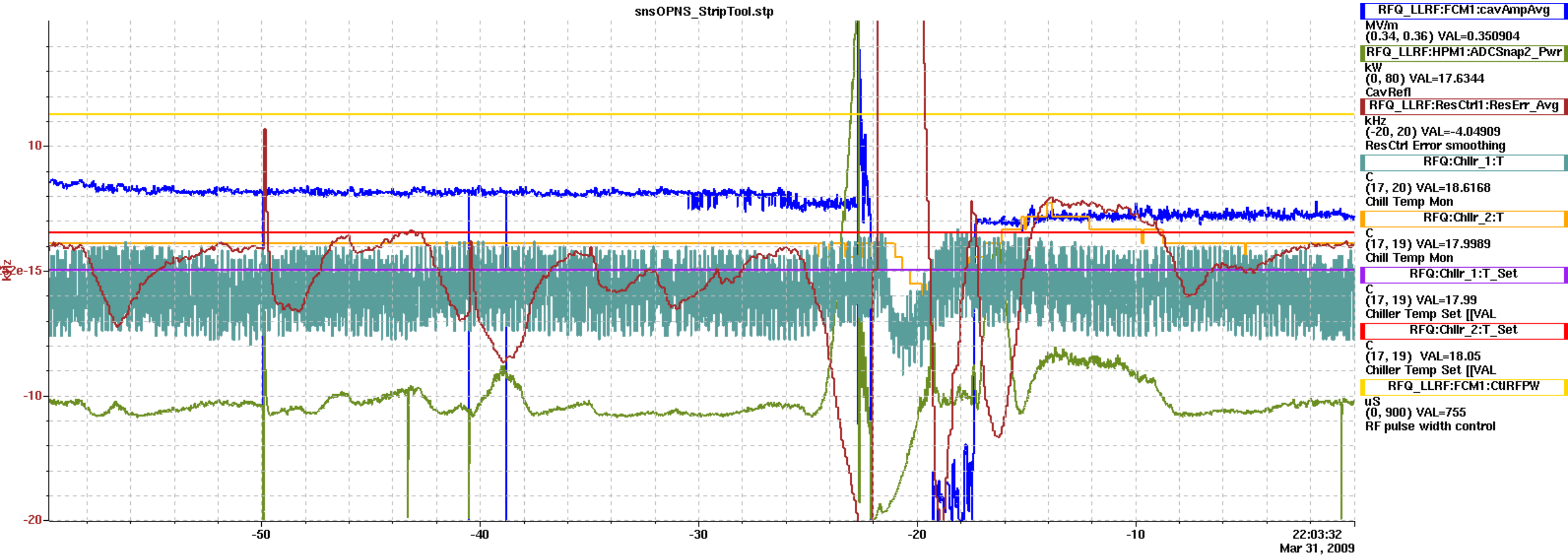


- **The linac delivered the full pulse length**
- **For the first time we verified the Ring can stably store and extract the design intensity of 1.5 x10^{14} ppp**

Technical Issues and Status

RFQ instability

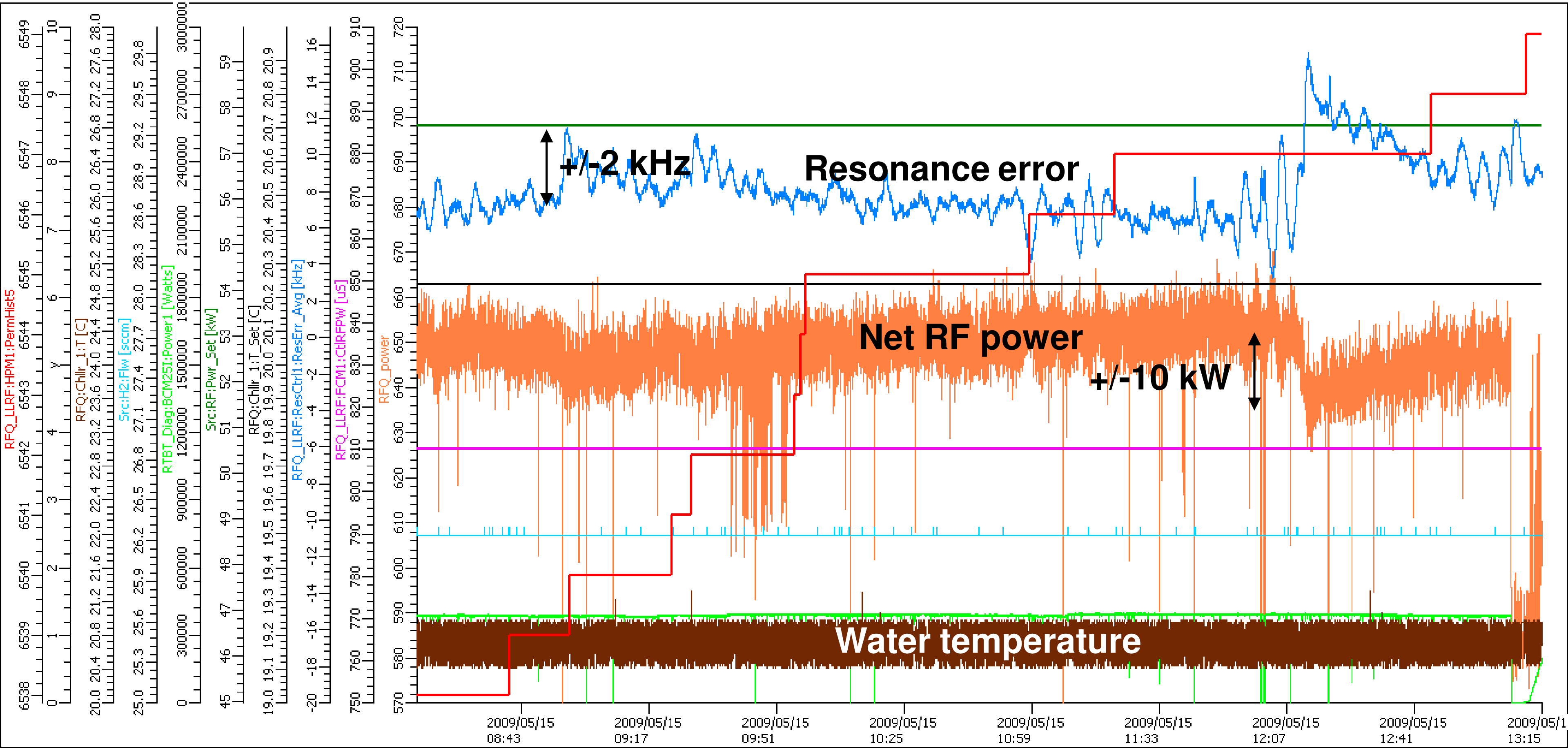
- It was difficult to get stable operation at 60 Hz, >700us
  - >30 min. down time in a day
  - Resonance error goes down → loosing closed loop



- One of limitations for 1 MW;
  - Since March 09; an extensive investigation
  - Why? What causes this instability? Limiting condition?
  - How can we improve the stability of operation?

All stable except net RF power → resonance error fluctuation

- Resonance error; pure passive parameter
- Net RF power=forward power – reflected power



RFQ Instability; findings

- Direct correlation between Net RF power and res. Error
  - When Net power > +40 kW → RFQ becomes unstable
- Changes in resonance error
  - Vanes are getting hotter/colder at a constant field, water temperature
- Load changes are clearly observed when
  - Hydrogen flow rate is changed; slow response
  - (Source off) vs. (source on/beam off); fast response
  - (Source on/beam off) vs. (source on/beam on); fast response
- Theory
  - RFQ (especially vane) absorbs hydrogen from ion source
  - Hydrogen are desorbed by ion beam bombardments
  - Local vacuum goes up (gauge reading at the wall may not see any changes)
  - Local discharge (very mild) starts; discharge conditions changes
  - Vane temperature changes→ resonance error changes
  - When discharge reaches a runaway condition → instability

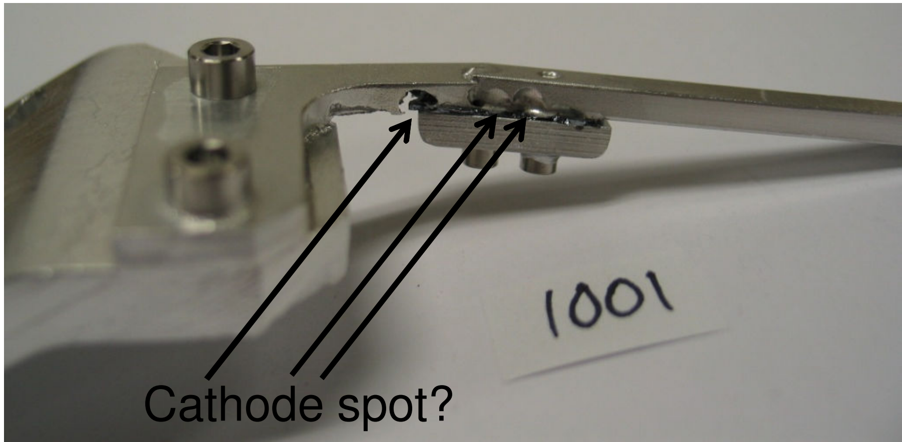
RFQ operation improvements

- Minimize H_2 flow rate in Ion Source (minimize H_2 absorption)
- Better source alignment (minimum, uniform desorption)
- Operate chiller in a good regulation region
- Run the gradient at a lower end
  - No affection in transmission, beam loss, beam quality
- Run at positive resonance error (around 12 kHz ± 5kHz)
  - Colder vane
- New auto tuning mechanism (LLRF)
  - Fine tuning; pulse width adjustment (+/- 30 us)
  - Coarse tuning; chiller temperature at 0.1 C step

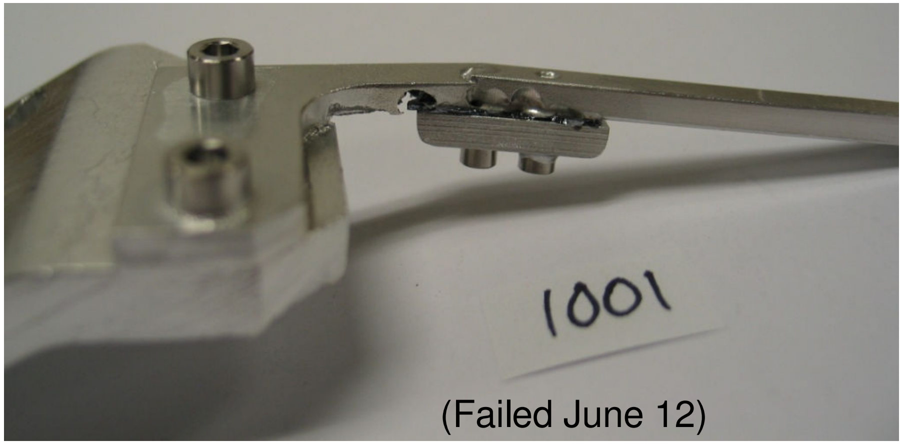
→ **No trip due to instability at 60 Hz, 900 us (limited by HVCM pulse width) during this operation period started on 8/29/09**

Foil issues

- **May 09 ~ June 09; foil failures at >700 kW run**
- **June 09~July 09; ~ 400 kW**
- **Causes?**
  - Best foil failure theory to date is that one of the primary causes is vacuum breakdown (arcing) caused by charge build up on the stripper foils, caused by SEM and maybe thermionic electron emission
  - Another primary cause is reflected convoy electrons and possibly also electrons from trailing edge multipacting
  - Some of our foil failures also involved convoy electrons hitting the foil bracket

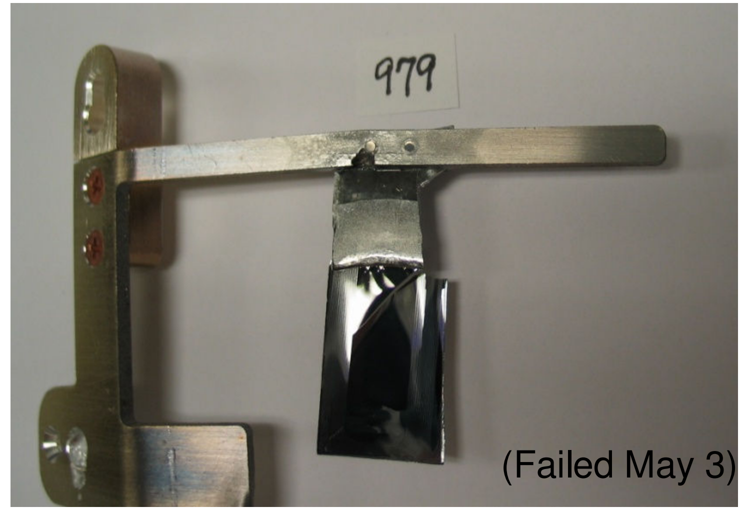


Foil failures

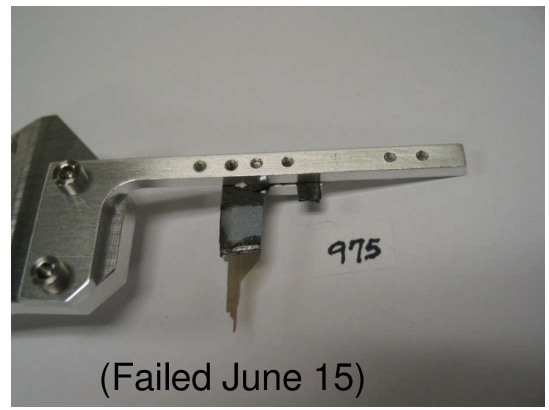


(Failed June 12)

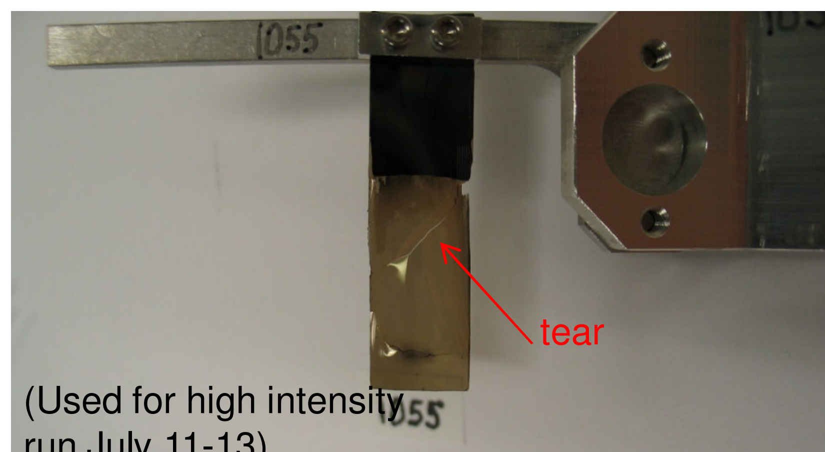
(Failed May 3)



(Failed May 3)



(Failed June 15)



(Used for high intensity run July 11-13)

Foil Fluttering & Glowing Edge/Spot

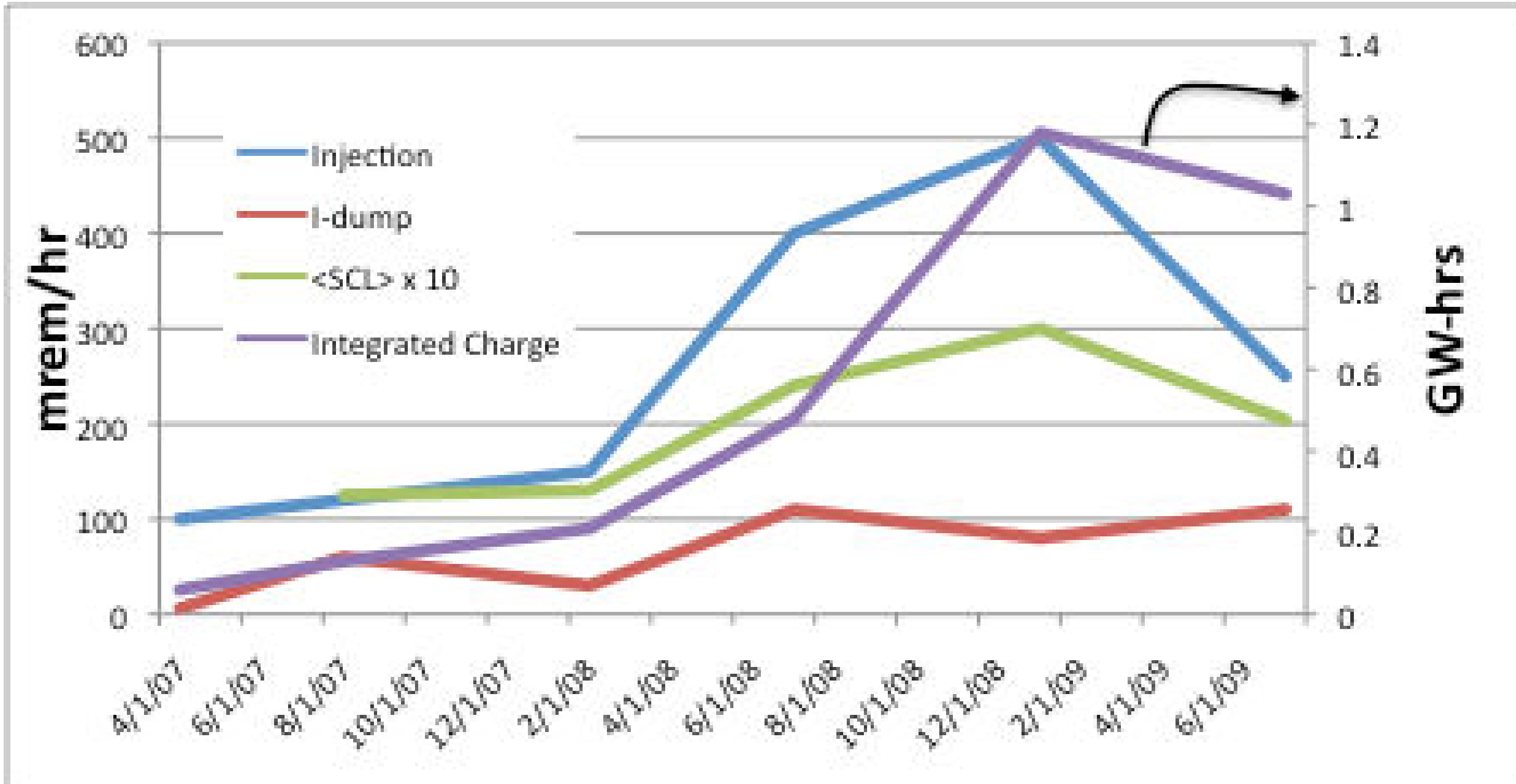
Foil Status

- Our best guess to date is that we have **multiple foil failure mechanisms,** and the biggest ones are vacuum breakdown, reflected convoy electrons, and trailing edge multipacting
- The Sep – Dec run has new Ti brackets, new foil mounting method, and diamond foils with a longer free length
- Also an HBC foil, and a diamond foil mounted at an angle
- The new instrumentation (foil camera, temperature measurement, clearing electrode, faster vacuum update rates) should help us to understand what is going on
- **No foil failure since September and till now in November**
  - **But still need more understandings**

HVCM Improvement

- New capacitors
- New IGBTs, physical configuration changes, etc
- Running at about 82 % of design duty
- This run (since September 1, 09~)
  - Much less down time due to smoke alarm related
  - Still major down time in SNS

Activation Buildup Trends
3 Month Run Cycle Interval

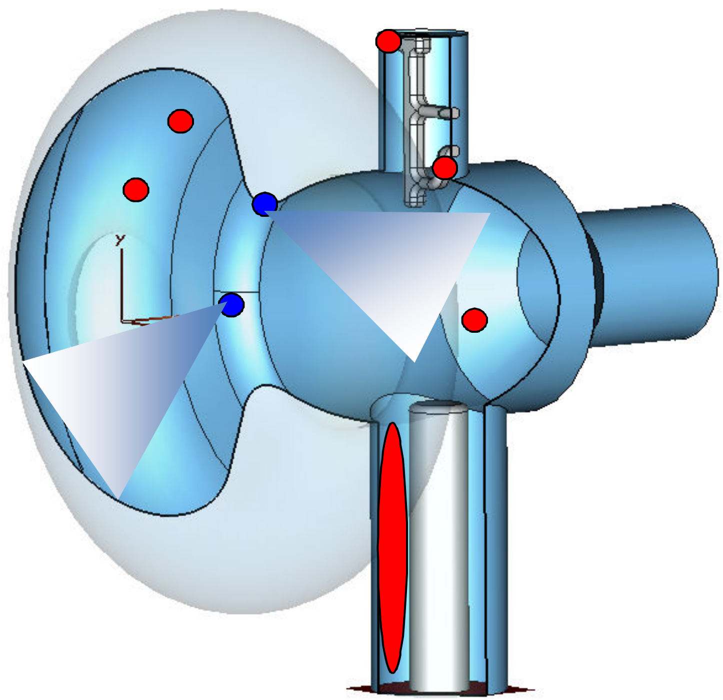


- Finishing the run at lower power helps reduce the residual activation
- SCL is also lower because of reduced loss/C
- SNS is not limited by beam loss

SNS SCL, Operations and Performance

- **The first high-energy SC linac for protons, and the first pulsed operational machine at a relatively high duty**
- **We have learned a lot in the last 5 years about operation of pulsed SC linacs:**
  - Operating temperature, Heating by electron loadings (cavity, FPC, beam pipes), Multipacting & Turn-on difficulties, HOM coupler issues, RF Control, Tuner issues, Beam loss, interlocks, alarms, monitoring, …
- **Current operating parameters are providing very stable and reliable SCL operation**
  - Less than one trip of the SCL per day mainly by errant beam or control noise
- **Proactive maintenance strategy (fix annoyances/problems before they limit performance)**
- **Beam energy (930 MeV) is lower than design (1000 MeV) due to high-beta cavity gradient limitations (mainly limited by field emission)**
- **No cavity performance degradation has occurred to Oct. 09**
  - Field emission very stable
  - Recently Nov. 09; One cavity has been showing performance degradation
- **Several cryomodules were successfully repaired without disassembly**
  - Multiple beam-line repairs were successfully performed

Electron Loading and Heating (Due to Field Emission and Multipacting)

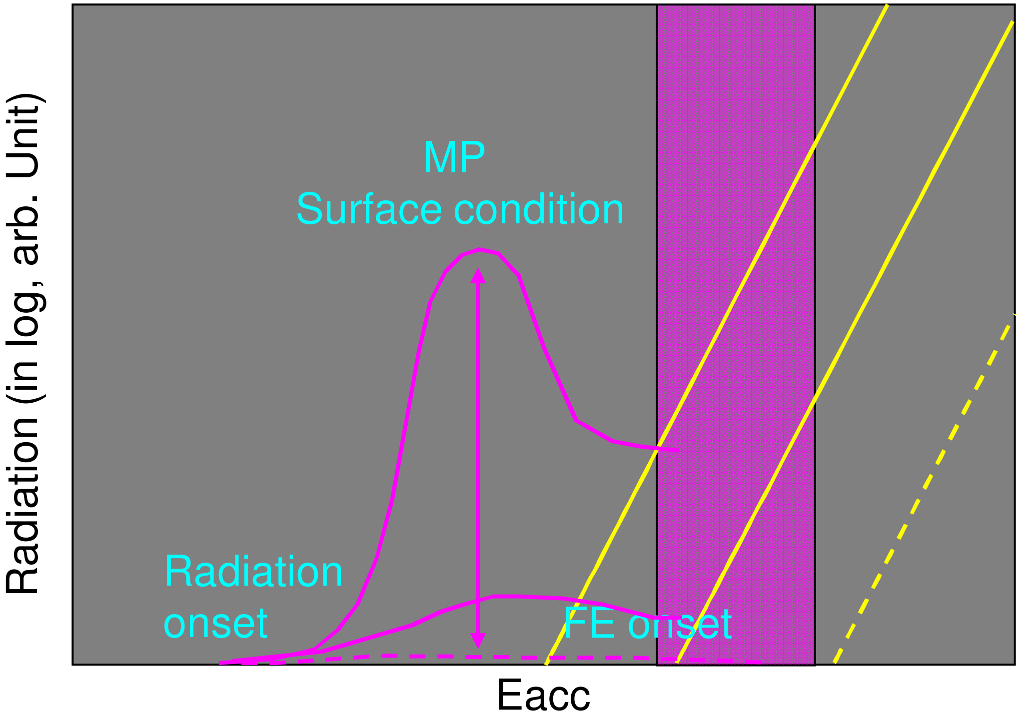


- Field Emission due to high surface electric field
- Multipacting; secondary emission
  - At resonant condition (geometry, RF field)
  - At sweeping region; many combinations are possible for MP
    - Temporally; filling, decay time
    - Spatially; tapered region
    - Non-resonant electrons→ accelerated → radiation/heating
  - Mild contamination → easily Processible
  - But bad surface → processing is very difficult in a cryomodule (operational)

Initial VTA or CM HP tests could have a significant conditioning effects for both. But most dangerous moment !

Electron loading usually results in end group heating/beam pipe heating + quenching/gas burst

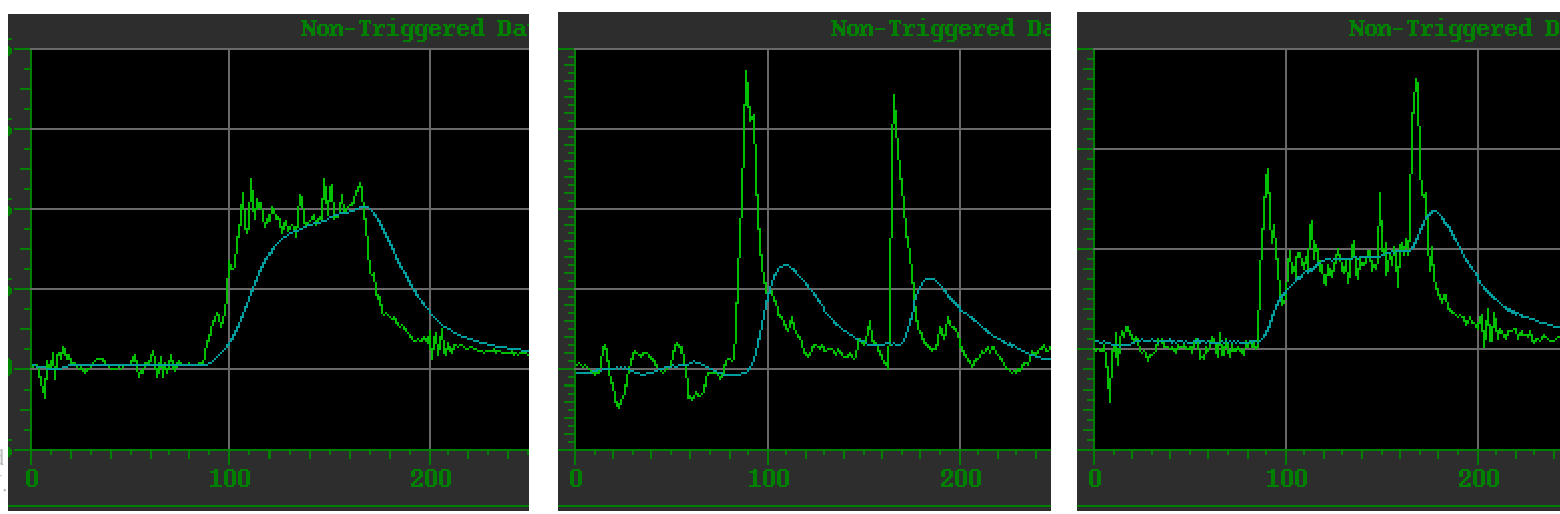
SNS Cavity Operating Regime



After initial commissioning and conditioning
→surface conditions are quite stable

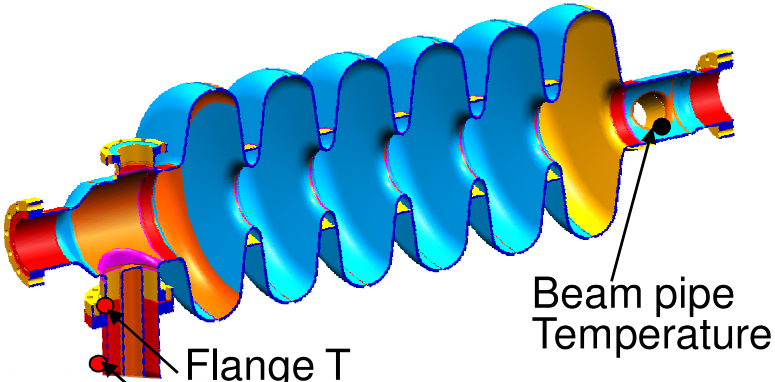
re-distribution of gases (slow & fast)
→processible

Gradient settings in SNS SCL;
Not uniform gradients as designed
But as high as individually achievable

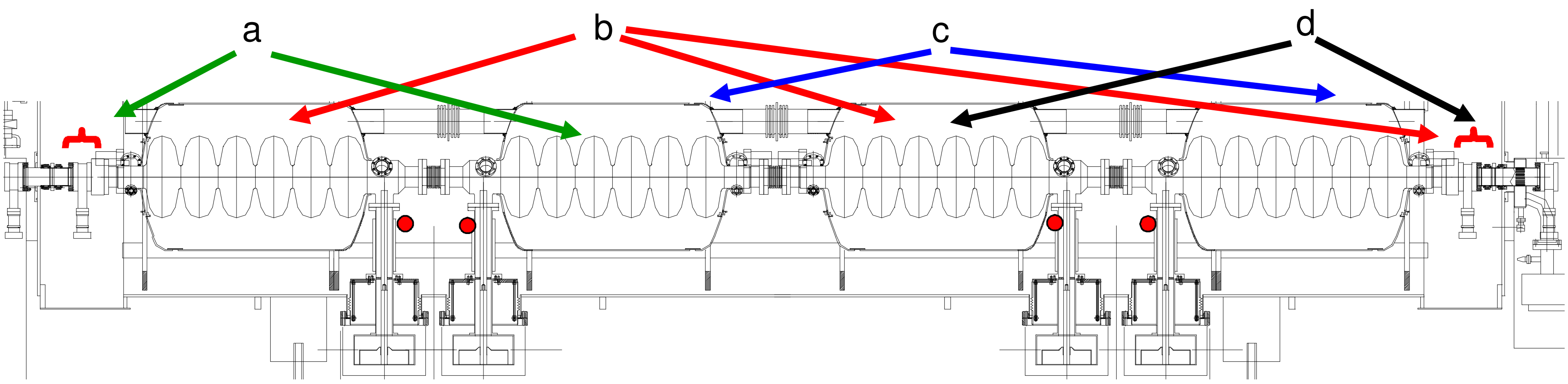


Gradient Limitations from “Collective Effects”

- **Electrons from Field Emission and Multipacting**
  - Steady state electron activity and sudden bursts affects other cavities
- **Electron impact location depends on relative phase and amplitude of adjacent cavities**

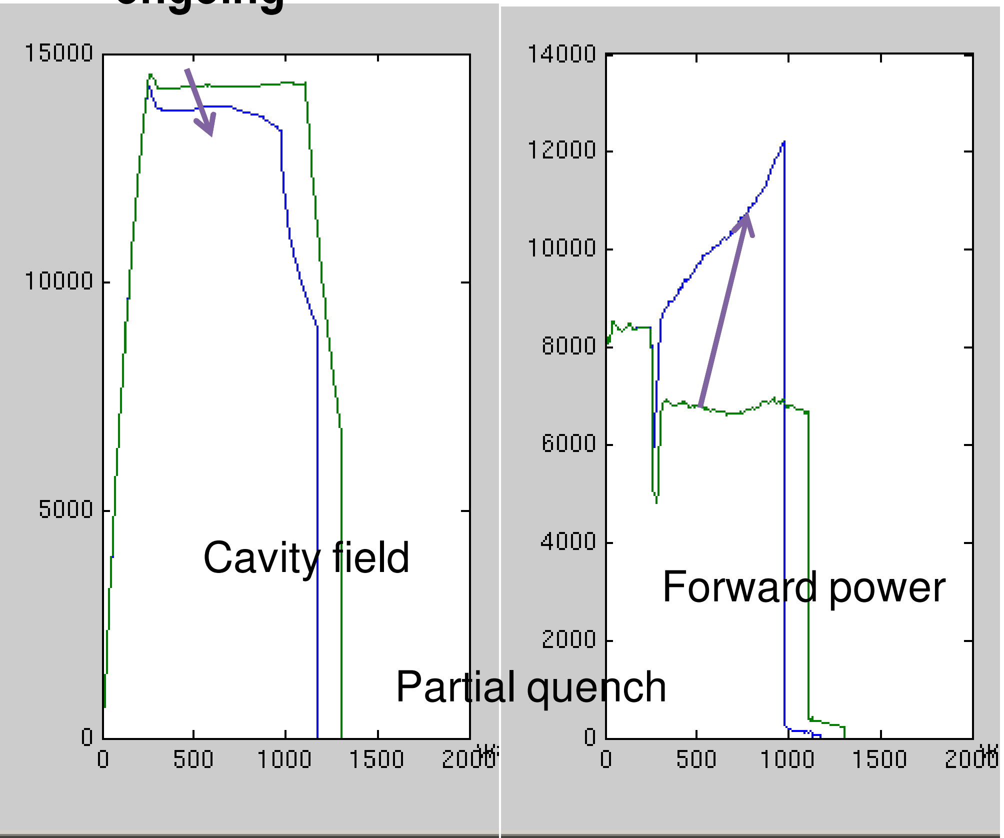


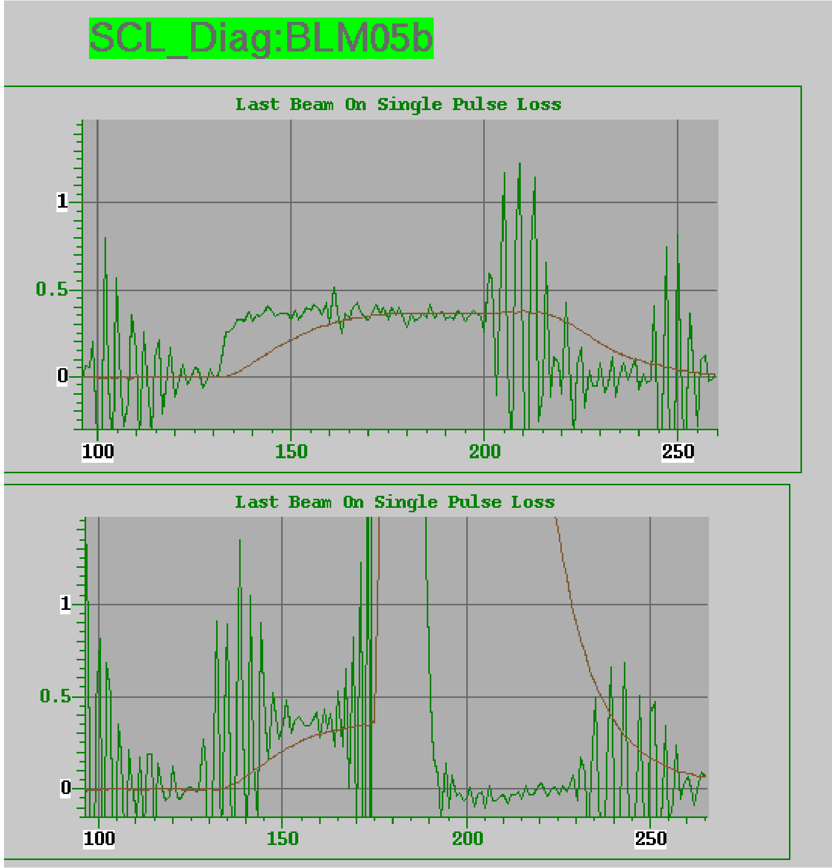
- **Leads to gas activity and heating with subsequent end-group quench and/or reaches intermediate temperature region (5-20k); H_2 evaporation and redistribution of gas which changes cavity and coupler conditions**
- **Example for CM13:** individual limits; 19.5, 15, 17, 14.5 MV/m
  collective limits; 14.5, 15, 15, 10.5 MV/m



Performance degradation

- First time in 4-years operation + commissioning
- Limiting gradient of 5a; 14.5 MV/m due to FE → Partial quench at 9 MV/m
- Beam between MPS trigger and beam truncation → off-energy beam → much bigger beam loss at further down-stream → gas burst → redistribution of gas/particulate → changes in performance/condition
- Random, statistical events; made HOM coupler around FPC worse
- As beam power goes higher, things could be worse → re-verification of MPS is ongoing



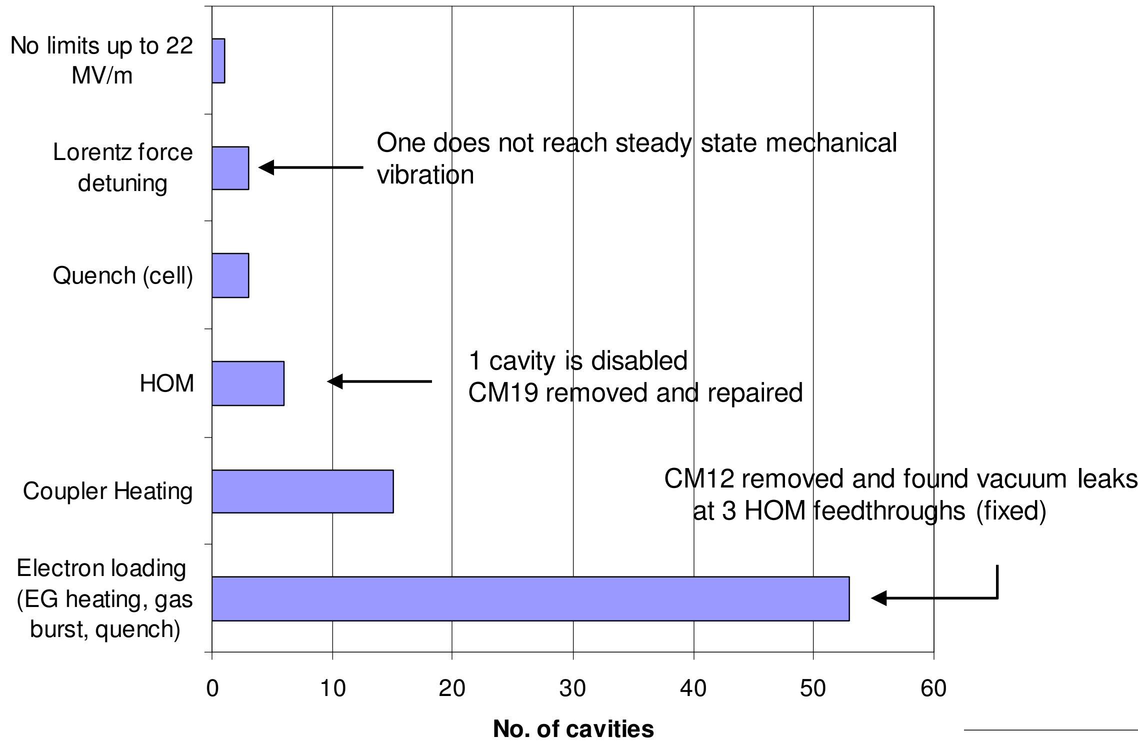


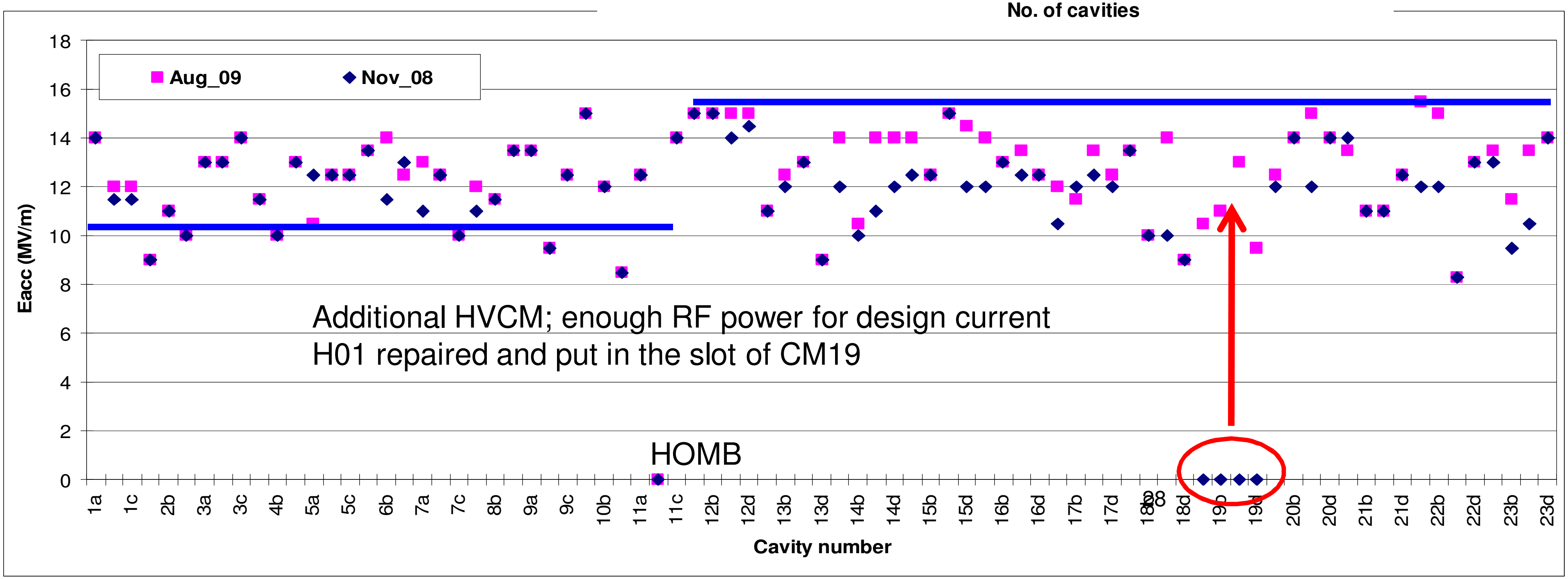
Increasing the Beam Energy

- Repaired ~10 cryomodules to regain operation of 80 out of 81 cavities
  - CM19 removed: had one inoperable cavity (excessive power through HOM); removed both HOM feedthroughs
  - CM12 removed: removed 4 HOM feedthroughs on 2 cavities
  - Tuner repairs performed on ~7 CMs
  - We have warmed up, individually, ~10 CMs in the past 4 years
  - Individual cryomodules may be warmed up and accessed due to cryogenic feed via transfer line.
- Installed an additional modulator and re-worked klystron topology in order to provide higher klystron voltage (for beam loading and faster cavity filling)
- Further increases in beam energy require increasing the installed cavity gradients to design values

SCL energy

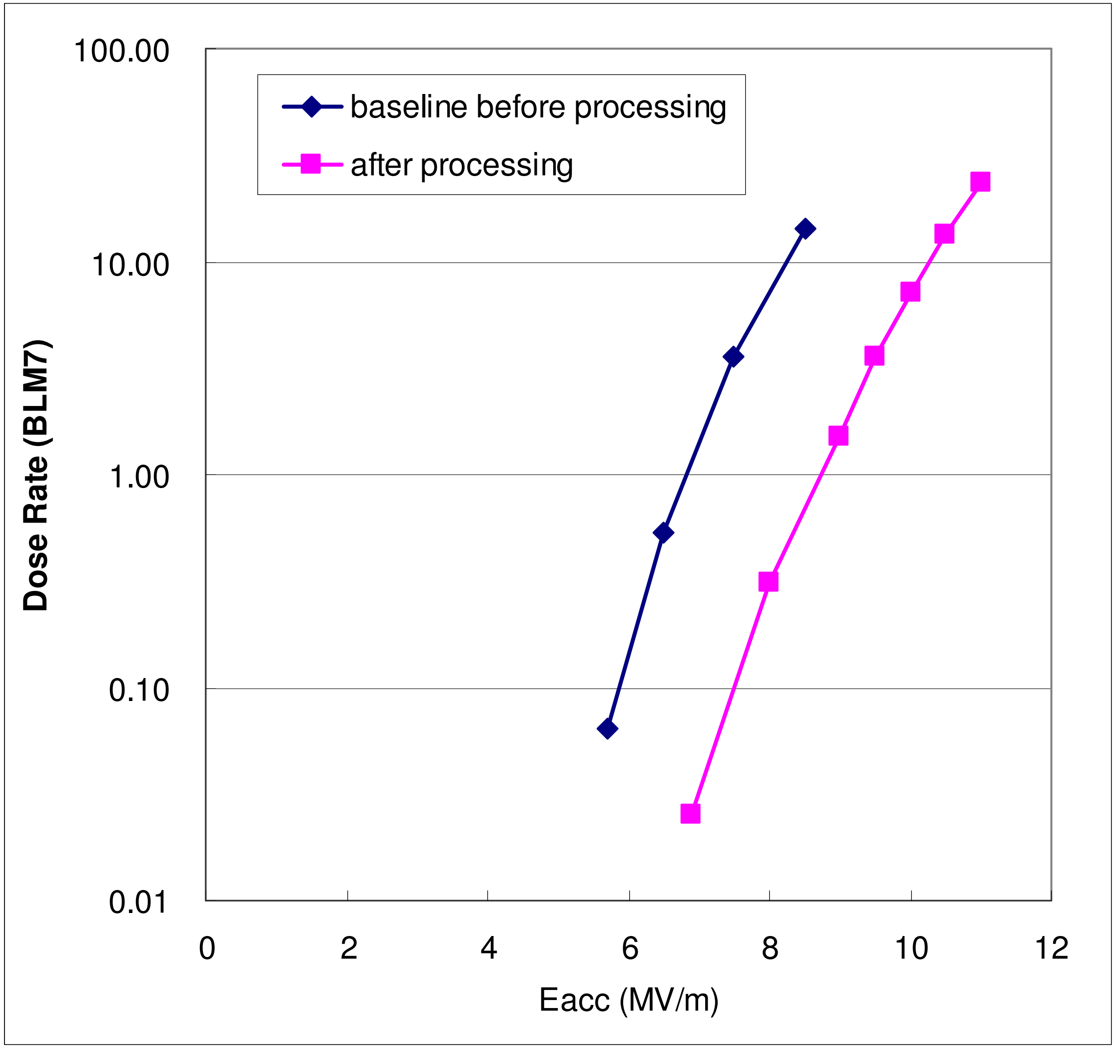
- **Limiting factors; mainly field emission**
- **80 out of 81 cavities; 930 MeV +10 MeV**



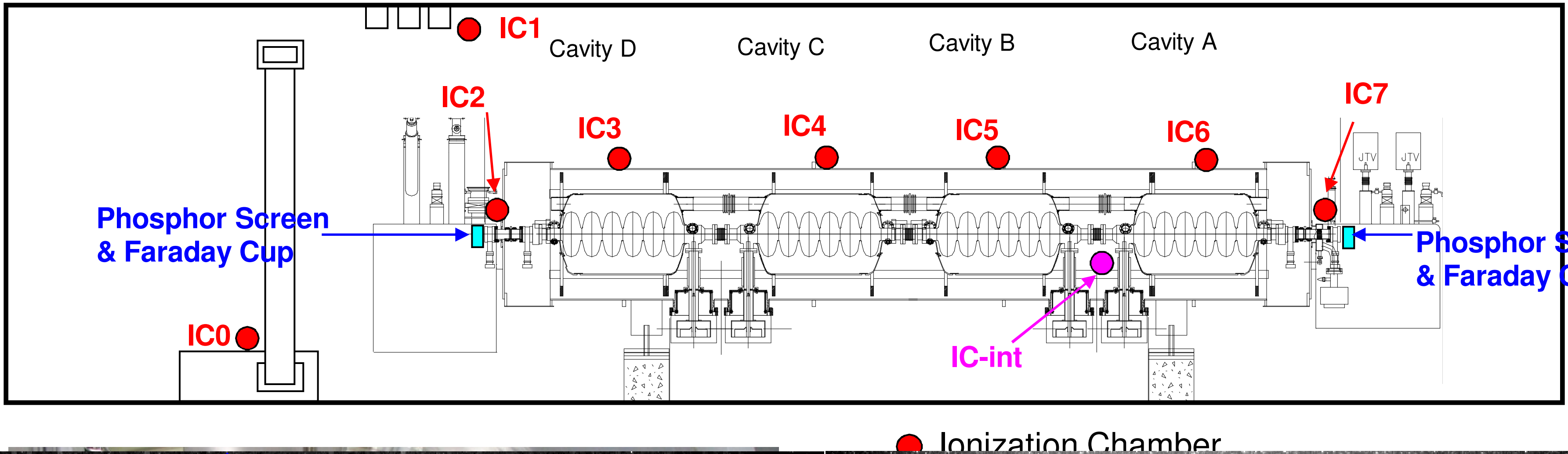


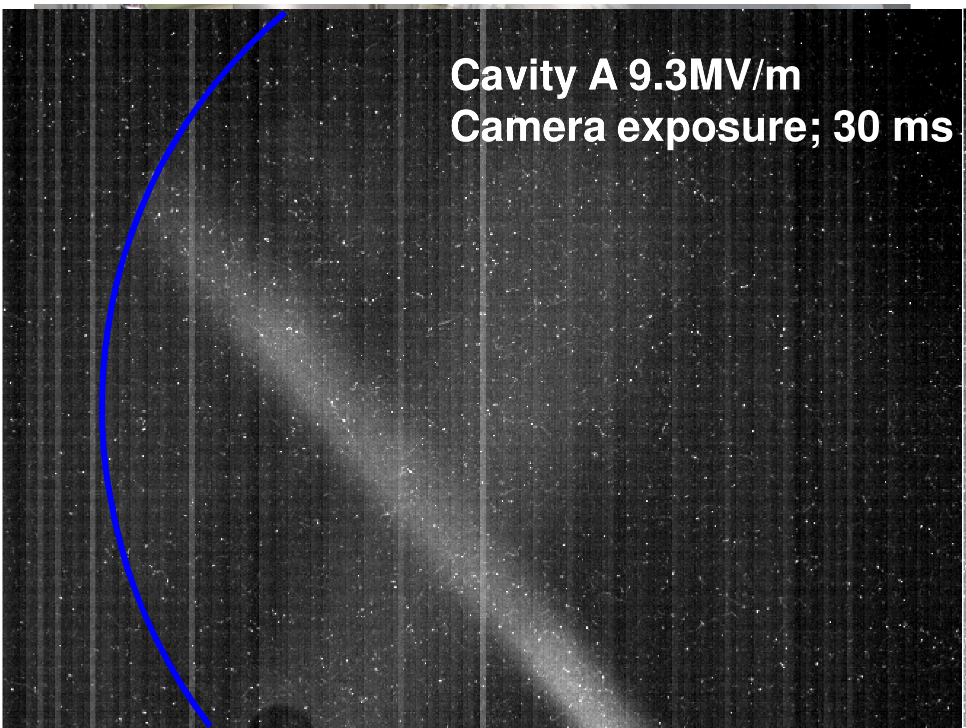
Plasma Processing Development

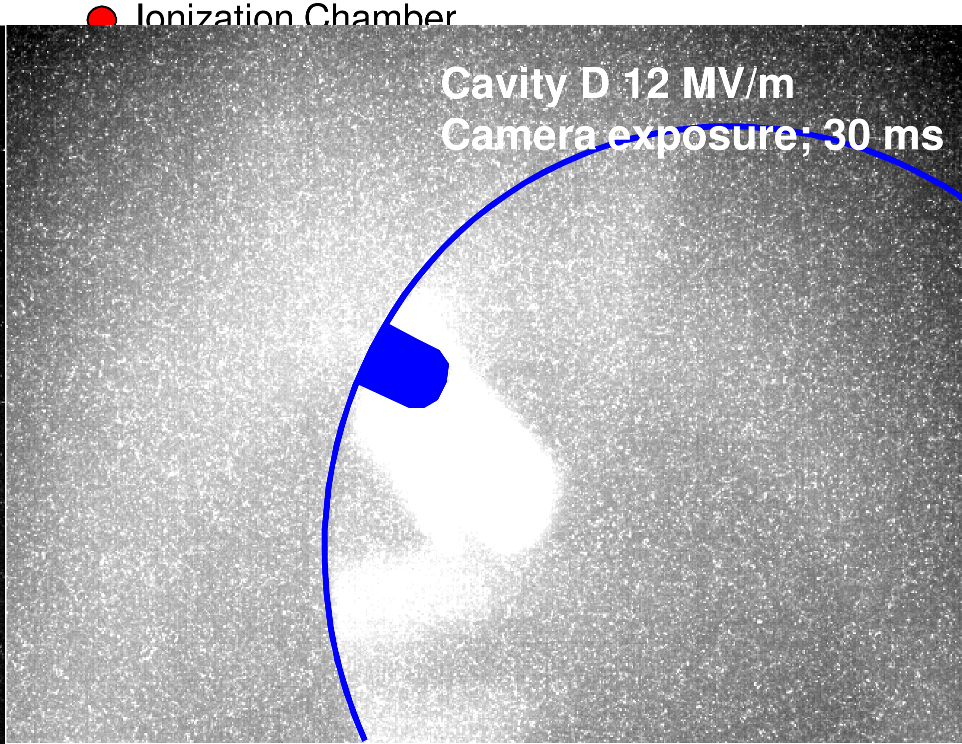
- A program is underway to develop and apply plasma cleaning methods to installed accelerator RF components
  - If successful this should significantly reduce field emission, mulitpacting and increase operating stability of RF structures
- First test on SNS cavity allows 2 MV/m increase for same radiation levels
- Experimental Program Includes
  - Witness samples from standard processes
  - TM020 test cavity
  - And full RF structures (3-cell test cavity) for procedure development



Radiation/electron activity diagnostics in the Test Cave

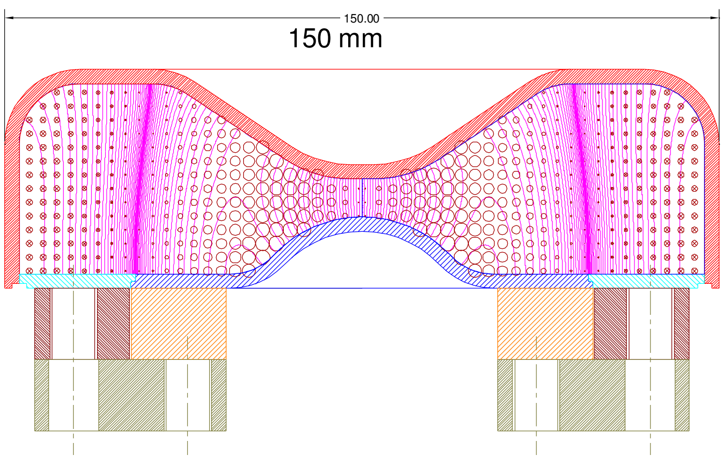




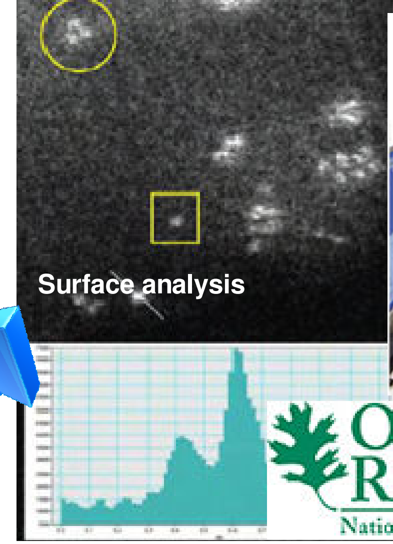


Test Cavity

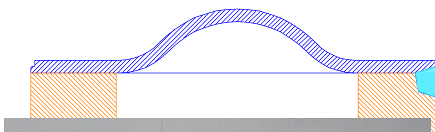
3.3 GHz, TM020 mode
Ep/Bp=1.12 (MV/m)/mT
Ex. Ep=50 MV/m, Bp=56 mT
P_{diss}=36 W at 4.2 K



-Cold test
w/ dual mode (CW or pulse)
-Plasma processing

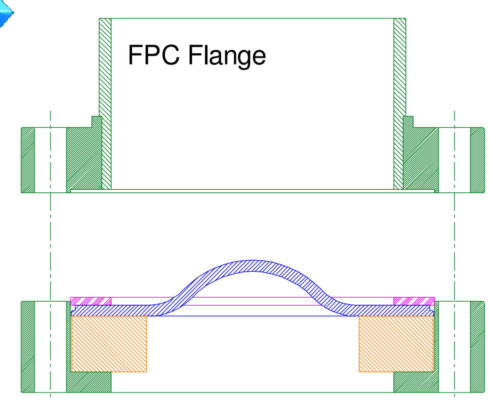


Demountable witness plate

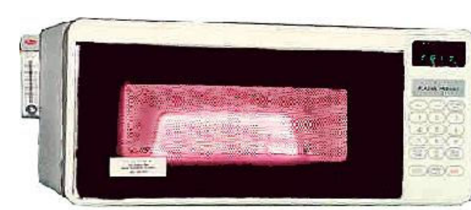


3–cell cavity For R&D

Witness Sample for Chemistry



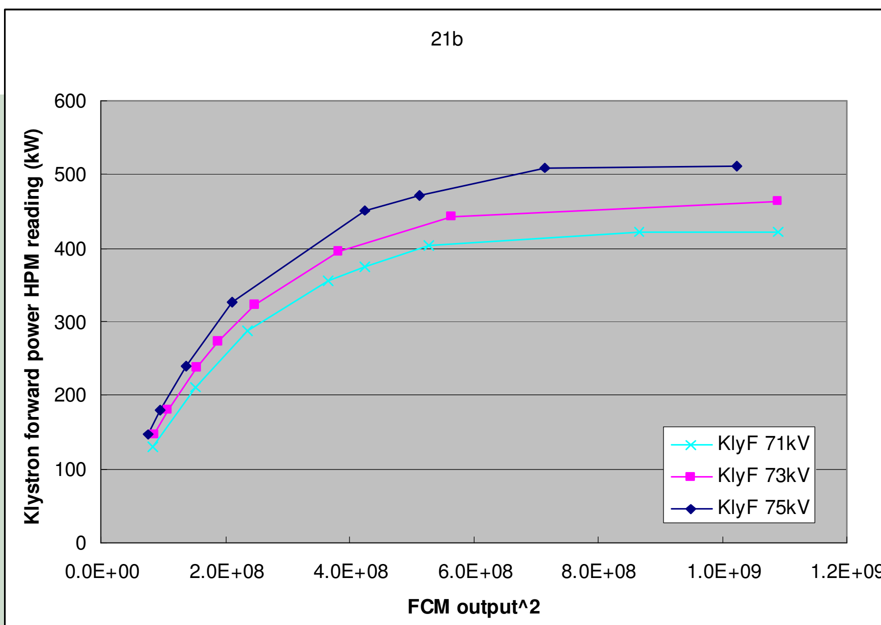
Microwave
Plasma processor

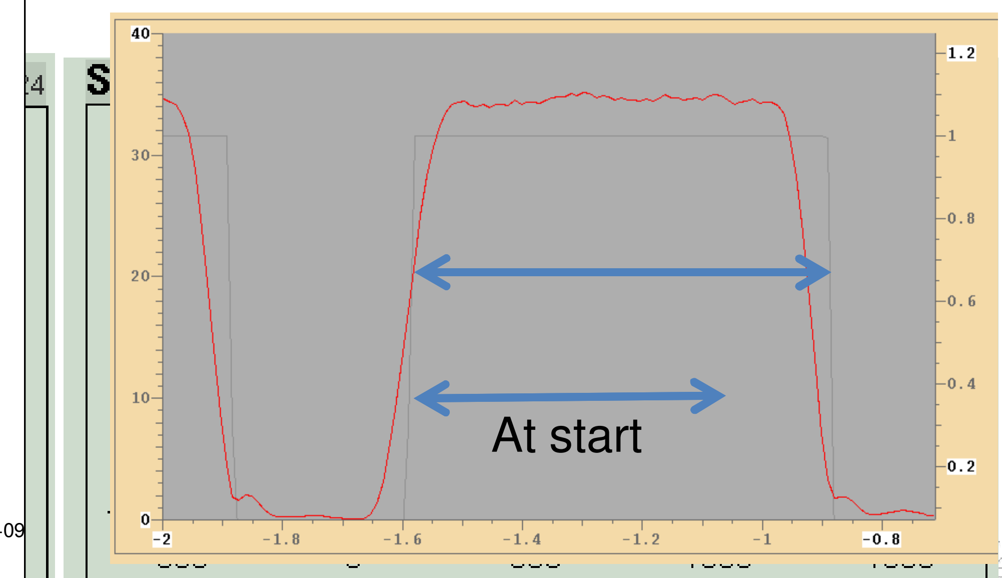


AFF & Beam ramp-up

- When beam current is bigger than ~18 mA average
  - field regulations go beyond the threshold → RF truncation → AFF can not learn
  - BLM trips → AFF can not learn
- Klystron power is usually those at saturation
  - Non-linear
- We use PW (chopping pattern; ratio between midi-pulse and gap)
  - Starting around <18 mA $I_{b,avg}$ → after AFF learned → increase $I_{b,avg}$

Overall gain measurement
(from FCM digital output to Klystron forward power)

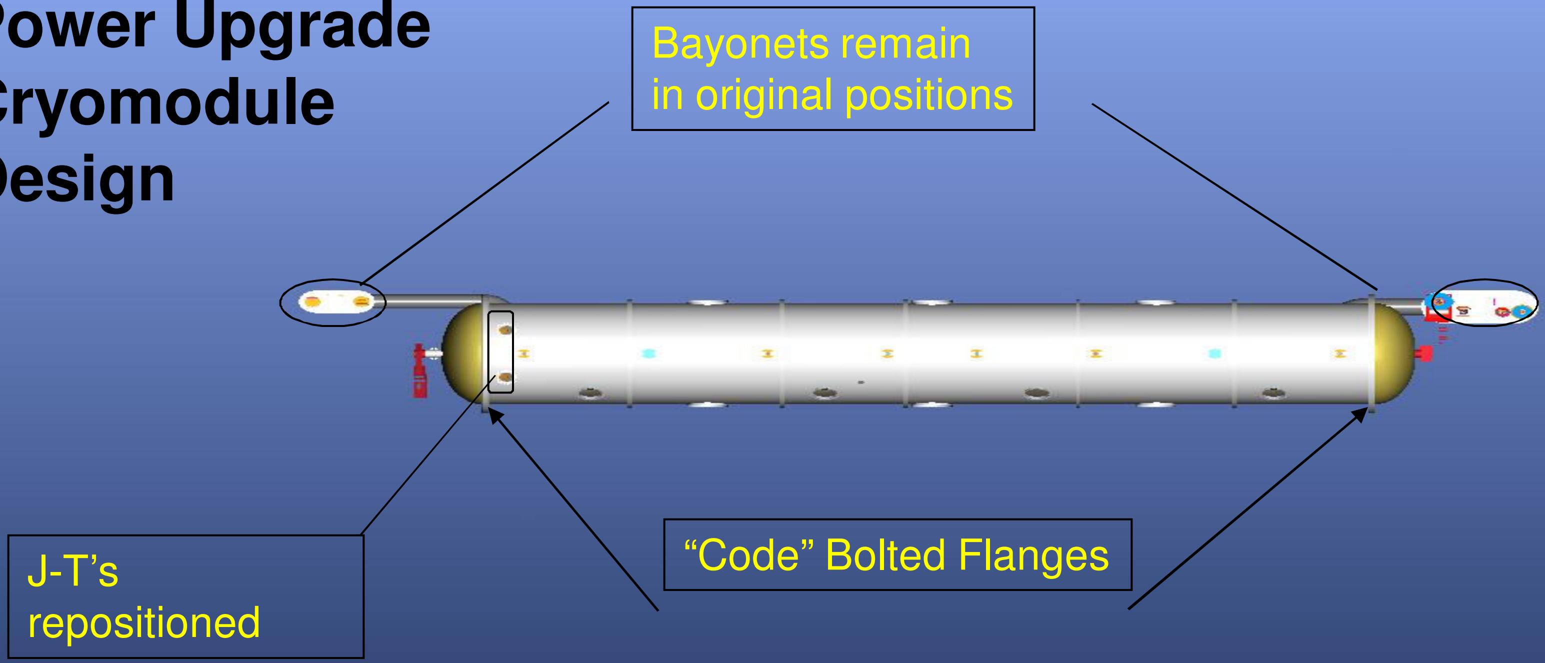


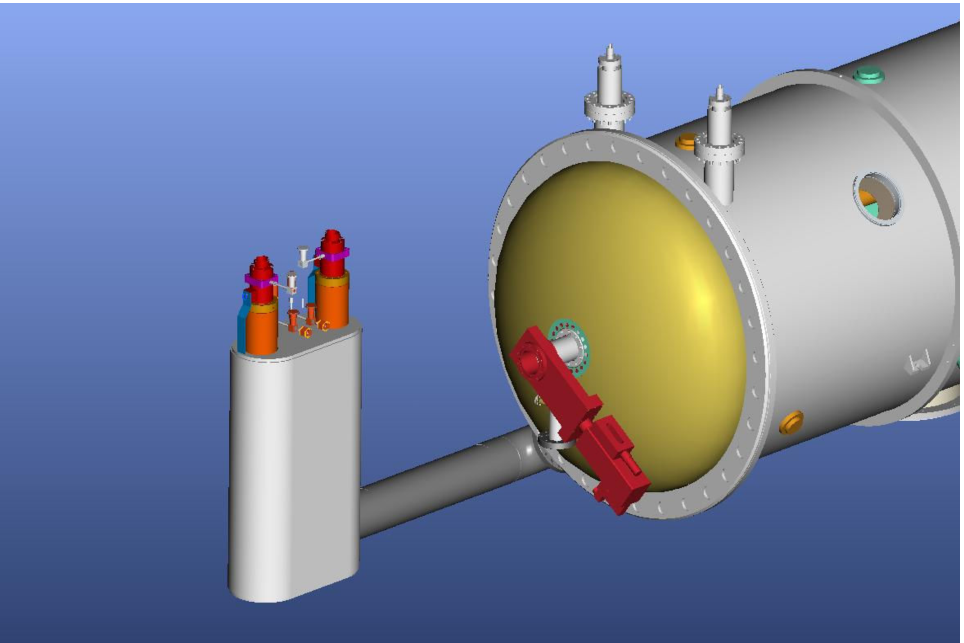


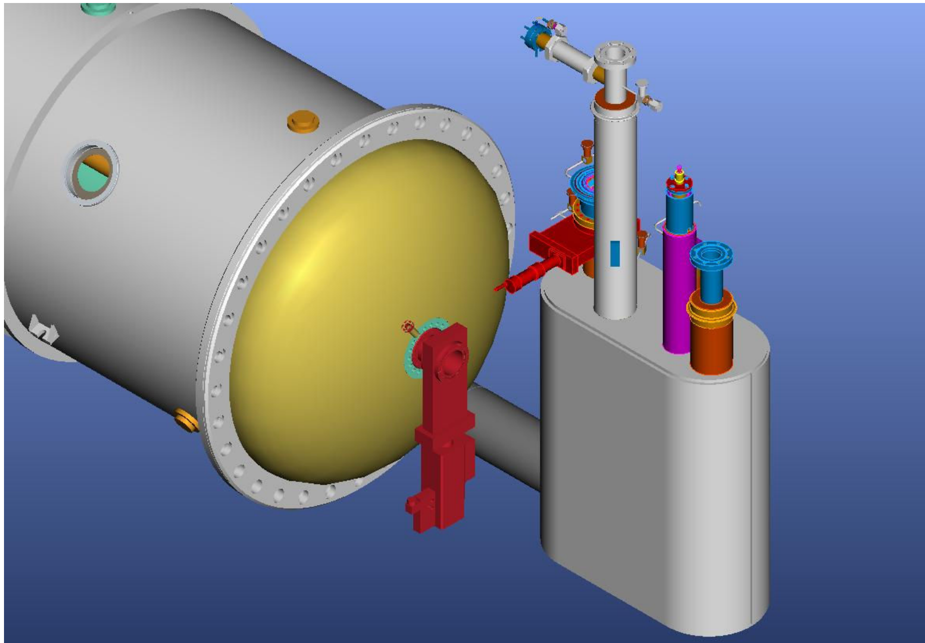
Ongoing and Future Activities

- As an urgent matter, we are constructing two spare high-beta cryomodules
  - These will be 10CRF851-compliant; vacuum vessel envelope was redesigned for pressure vessel compatibility
  - Cavities are currently being qualified at Jefferson Lab (1st string qualified)
  - Plan is to construct/integrate these spare CMs in-house
- The SNS Power Upgrade Project (PUP) has CD-1 approval, and includes the following scope:
  - 9 additional high-beta CMs to increase energy to 1.3 GeV
  - Associated RF systems
  - Ring modifications to support higher energy
- We expect to involve industry in PUP CM construction (expect CD-2 approval in the next FY)
- We are continuing to build SRF support facilities to provide basic repair and testing capabilities in support of long-term maintenance and the Upgrade

Power Upgrade Cryomodule Design

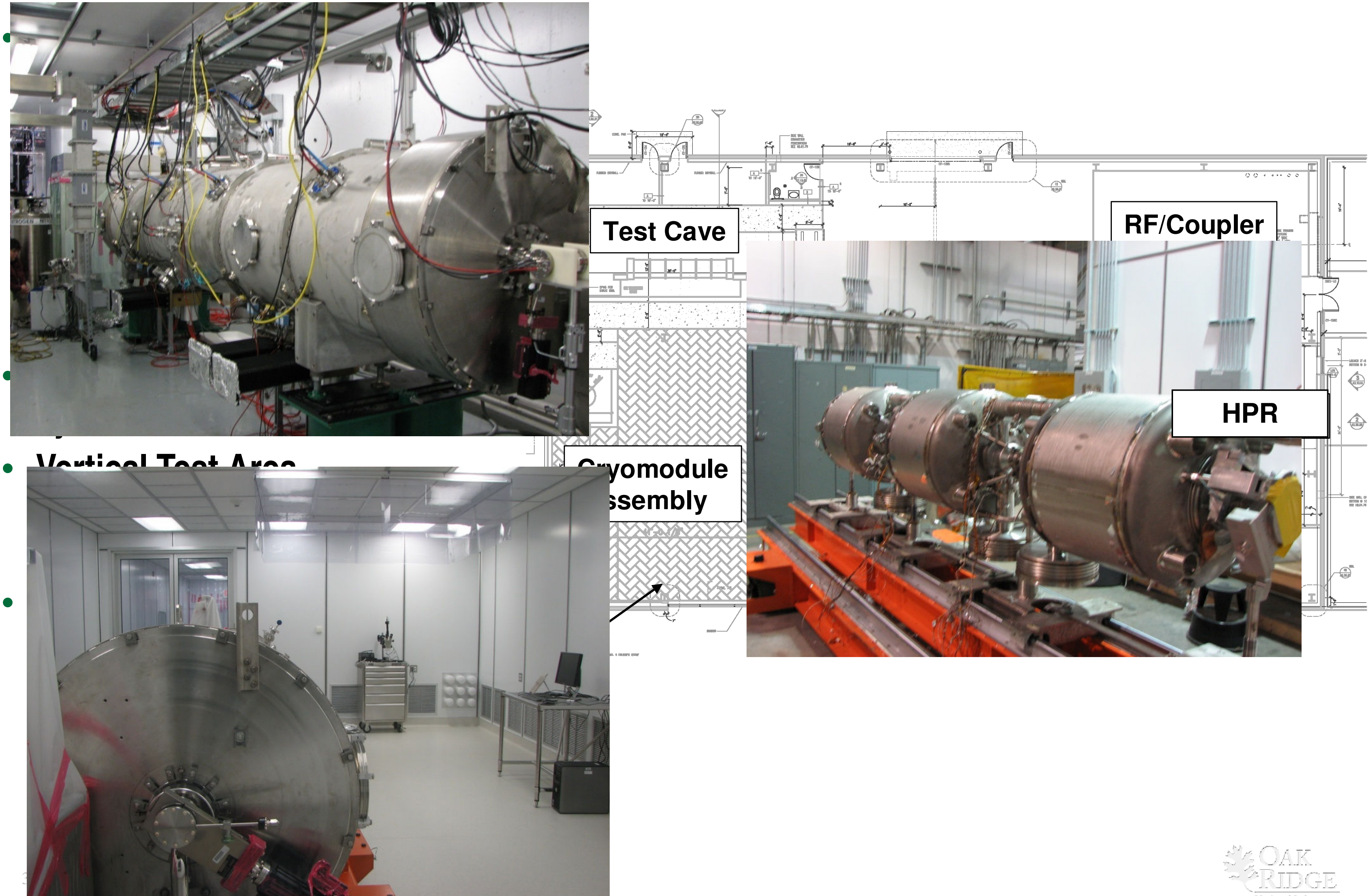






SRF Maintenance and Test Facility

- Vertical Test Area



OAK RIDGE National Laboratory

Power Upgrade Project (PUP)+ Accelerator Improvement Project (AIP)

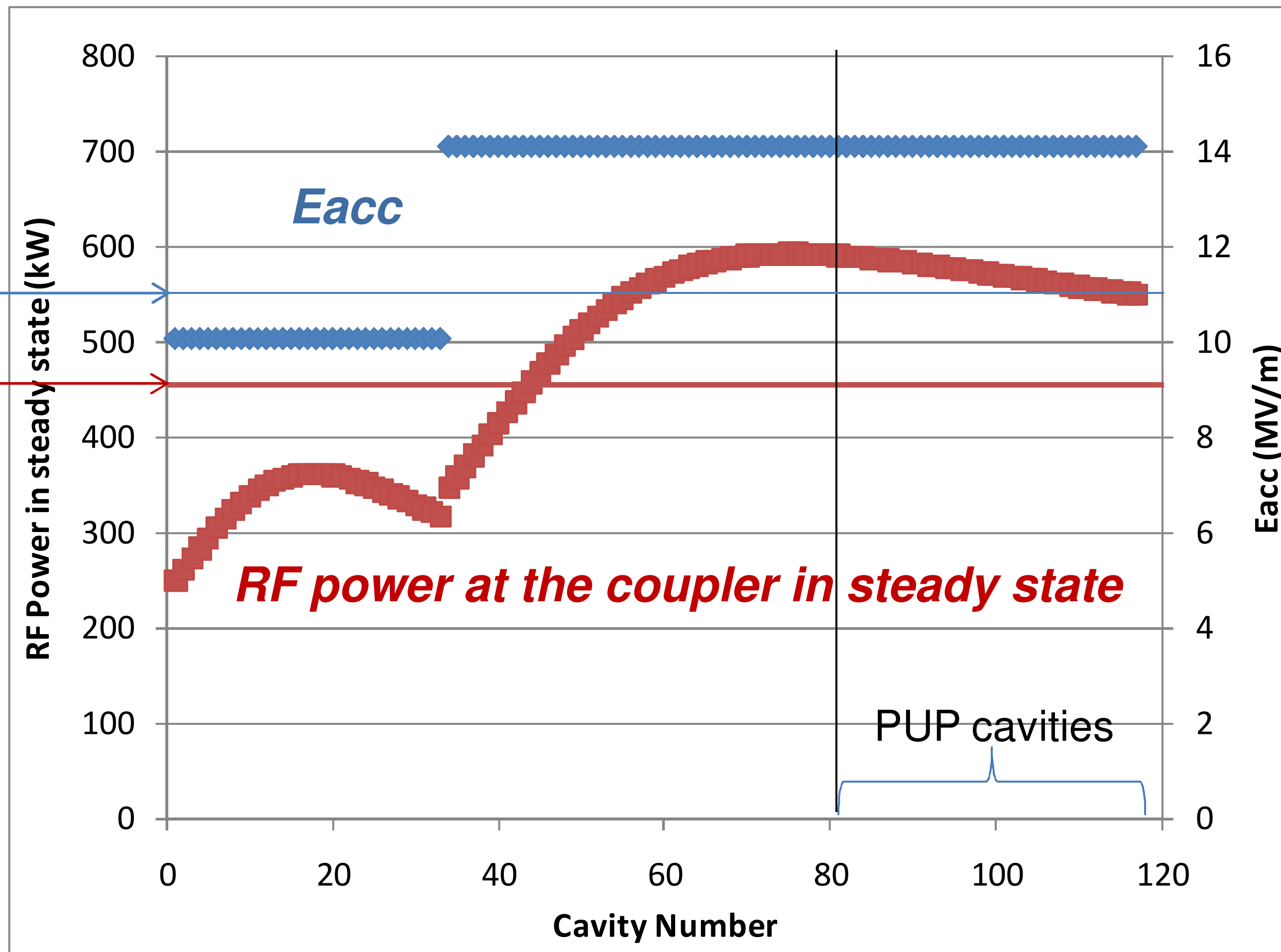
Parameter	SNS Baseline	Power upgrade
Kinetic energy [MeV]	1000	1300
Beam power [MW]	1.4	3.0
Chopper beam-on duty factor [%]	68	70
Linac beam macropulse duty factor [%]	6.0	6.0
Average macropulse H- current, [mA]	26	42
Peak macropulse H- current, [mA]	38	59
Linac average beam current [mA]	1.6	2.5
SRF cryo-module number (medium-beta)	11	11
SRF cryo-module number (high-beta)	12	12+8 (+1 reserve)
SRF cavity number	33+48	33+80 (+4 reserve)
Peak surface gradient (b=0.61 cavity) [MV/m]	27.5 (+/- 2.5)	27.5 (+/- 2.5)
Peak surface gradient (b=0.81 cavity) [MV/m]	35 (+2.5/-7.5)	31
Ring injection time [ms] / turns	1.0 / 1060	1.0 / 1100
Ring rf frequency [MHz]	1.058	1.098
Ring bunch intensity [10^{14}]	1.6	2.5
Ring space-charge tune spread, DQ_{sc}	0.15	0.15
Pulse length on target [ns]	695	691

Concerns

- Balancing (rf power, gradient, coupler average power)
  - 42 mA average current (59 mA peak)
  - Existing RF system; 550 kW (at saturation) per cavity
  - Existing HVCM; 75 kV, 10 pack configuration
  - Existing FPC; ~50 kW average power
    - No active cooling for inner conductor at vacuum side
    - Thermal radiation load to end group ~3W
- Optimization works are in progress
  - Based on what we learned from operational experiences
  - Minimize reworks of existing cryomodules
  - Multiple approaches for margin (remove the weakest links)
- Changes
  - Vacuum vessel, FPC (Qex, Higher average power), HOMless, Coupler cooling configuration, etc.

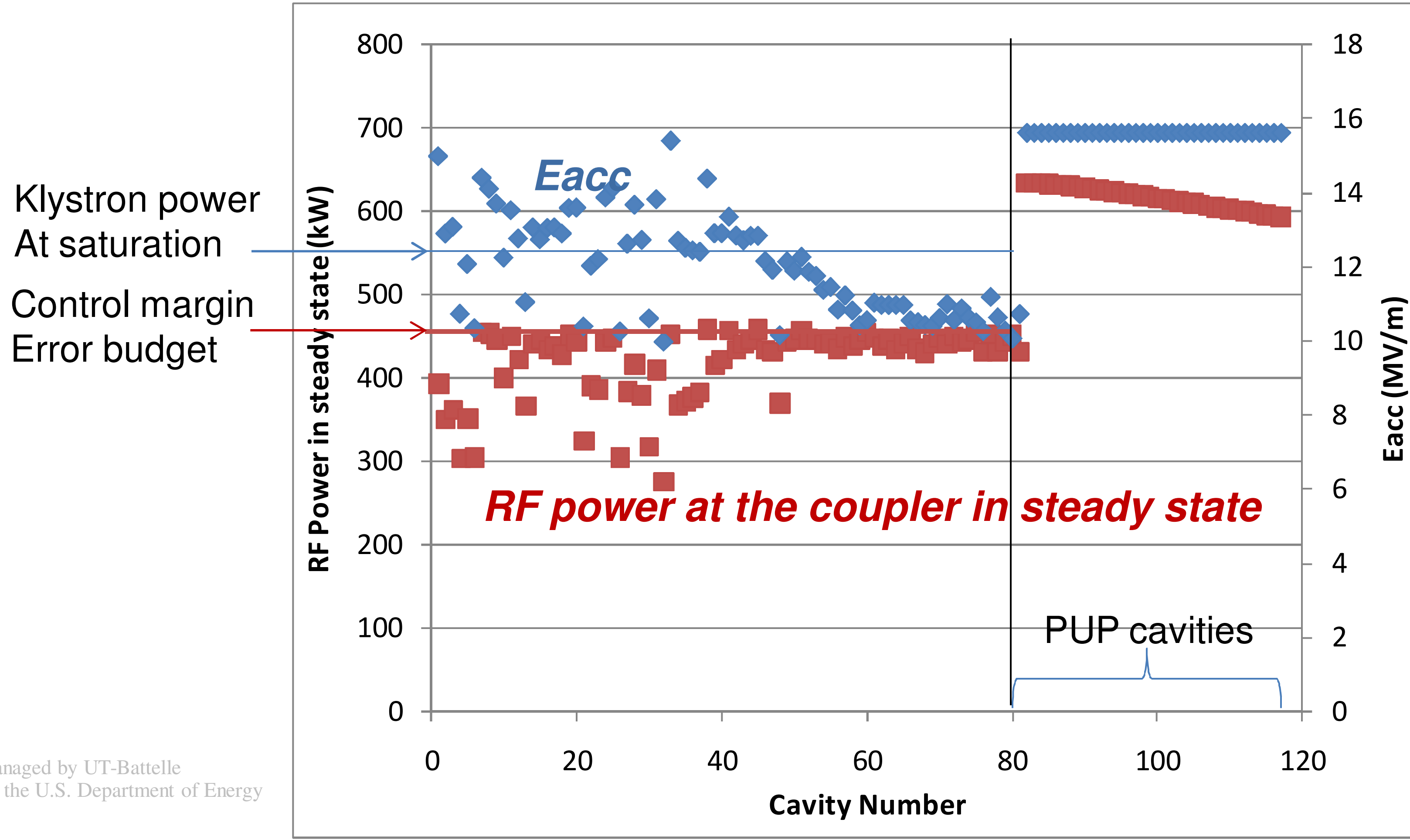
PUP impact on SCL

- **Baseline number; 10.1 MV/m (MB), 14.1 MV/m (HB)**
- **Need reworks for the most of existing HB cryomodules; power coupler (average power) + HP RF + Modulator**



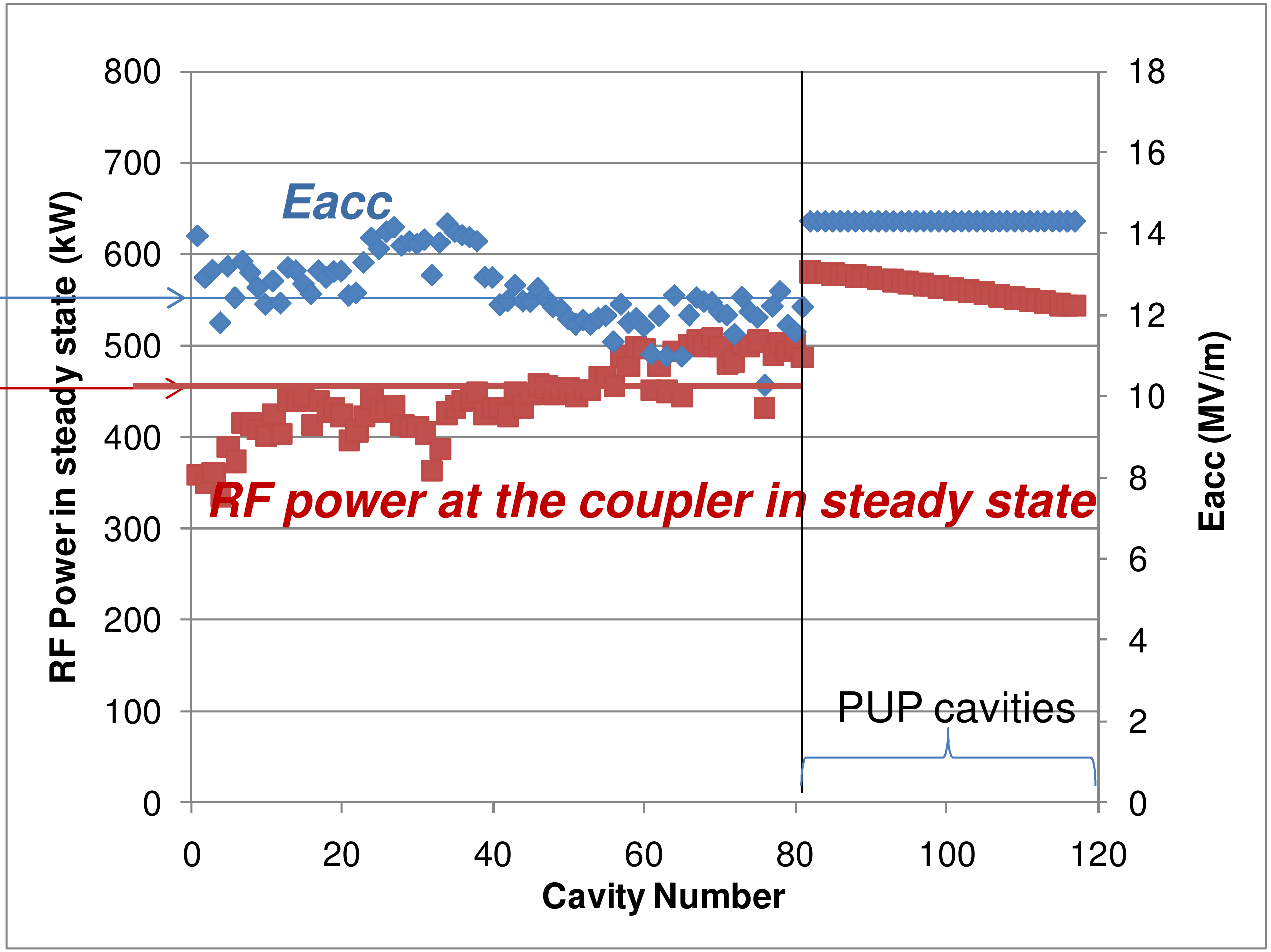
Option I (based on existing cavity performances)

- No reworks for the existing cryomodules + HPRF system +HVCM
- New PUP cryomodules
  - Cavity radiation threshold >15 MV/m, Coupler>70kW average power (end group heating issues due to thermal radiation)
  - 750 kW klystrons + 82 kV HVCM



Option II

- Some reworks for existing system (no rework for the couplers)
  - A few kV higher for HVCM For last several CMs
  - Some performance improvement; plasma processing
- About same loading on PUP cavities (14.3 MV/m, 700kW RF at saturation)



Summary

- 3-yrs operation
  - Reached 1 MW operation
  - Availability is improving
  - Beam loss seems not a show stopper in SNS
- Technical issues and status
  - RFQ; Better understanding, very stable operation
  - HVCM; better in this op. period.
    Operational stability needs to be improved
  - Foil; New batch of foils/brackets, so far no failure
    Need more understanding of failure mechanism
  - SCL; Tight control, very stable operation
    Plasma processing R&D to get 1 GeV
- PUP; technical design in this FY.