Operational Experience with High Power Beams at the SNS Linac

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XXIV Linac Conference

Victoria, Canada

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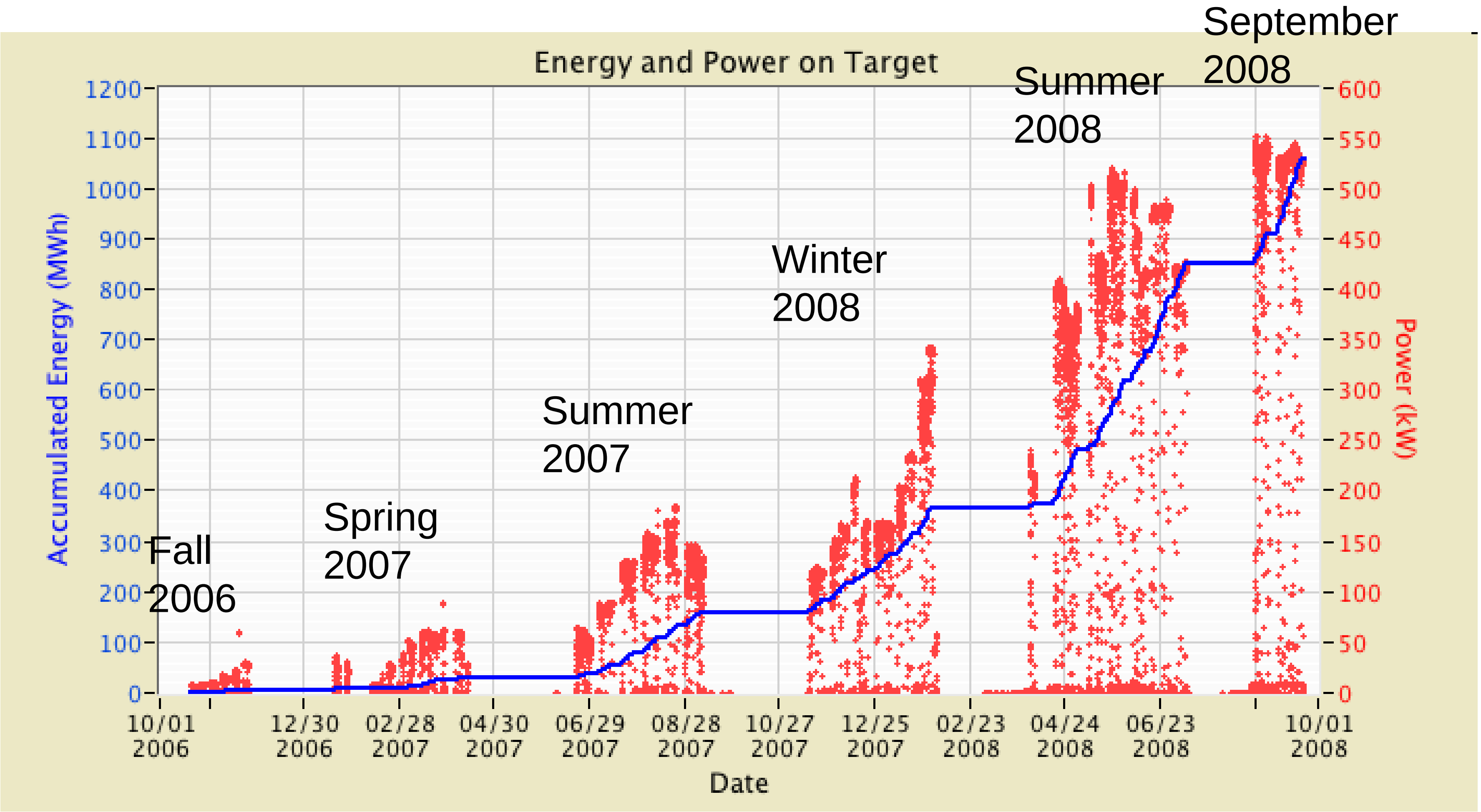
Outline
Beam Related Issues

- **Superconducting Linac RF setup**
  - **Model based RF phase scaling**
- **Beam Loss in the SCL**
  - **Magnitude and sensitivities**

The SNS Power Ramp-up Experience



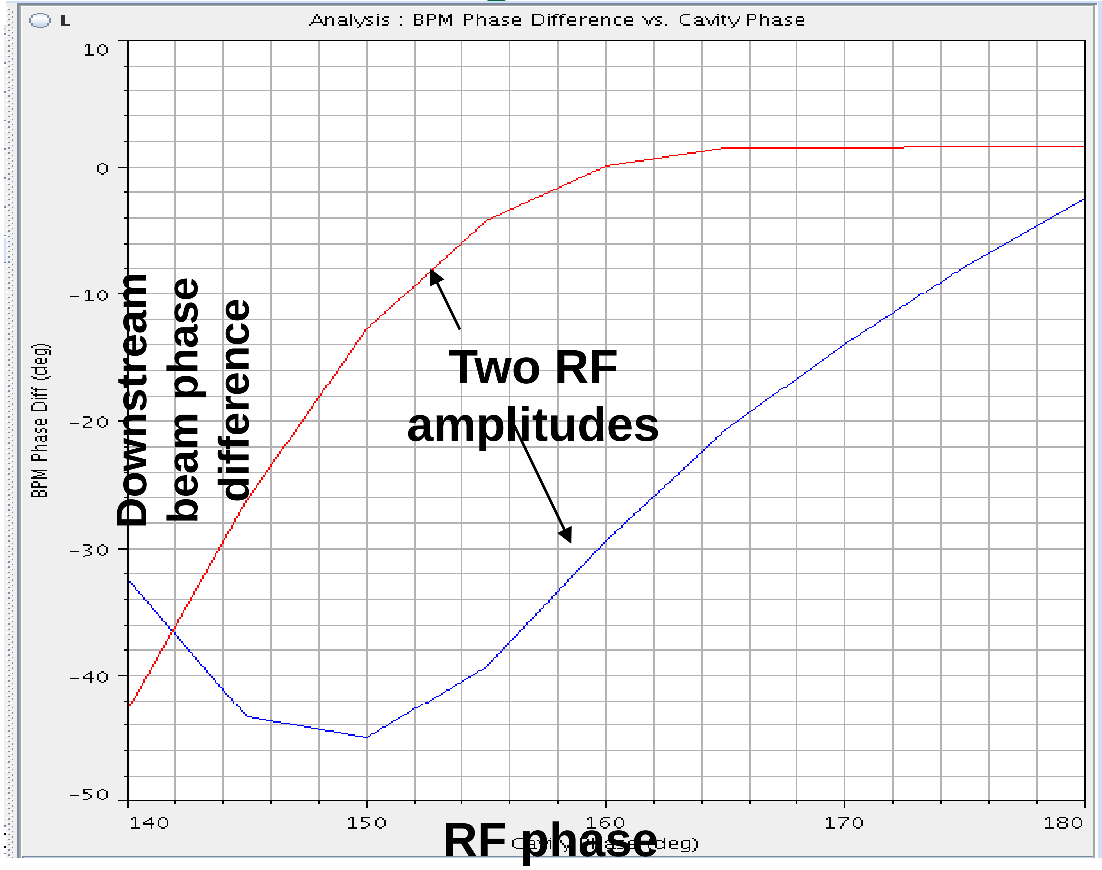
- **Power increased x 100 in ~ two years**

OAK RIDGE National Laboratory

SNS Linac Overview

- **A warm (copper structure) linac for low energy beam**
  - **6 DTL tanks from 2.5 to 87 MeV / 6 klystrons**
  - **4 CCL modules from 87 to 186 MeV / 4 klystrons**
- **A Superconducting Linac for high energy beam (186 to 1000 MeV)**
  - **33 medium beta (β = 0.61) cavities/ 33 klystrons**
  - **48 high beta (β = 0.81) cavities / 48 klystrons**

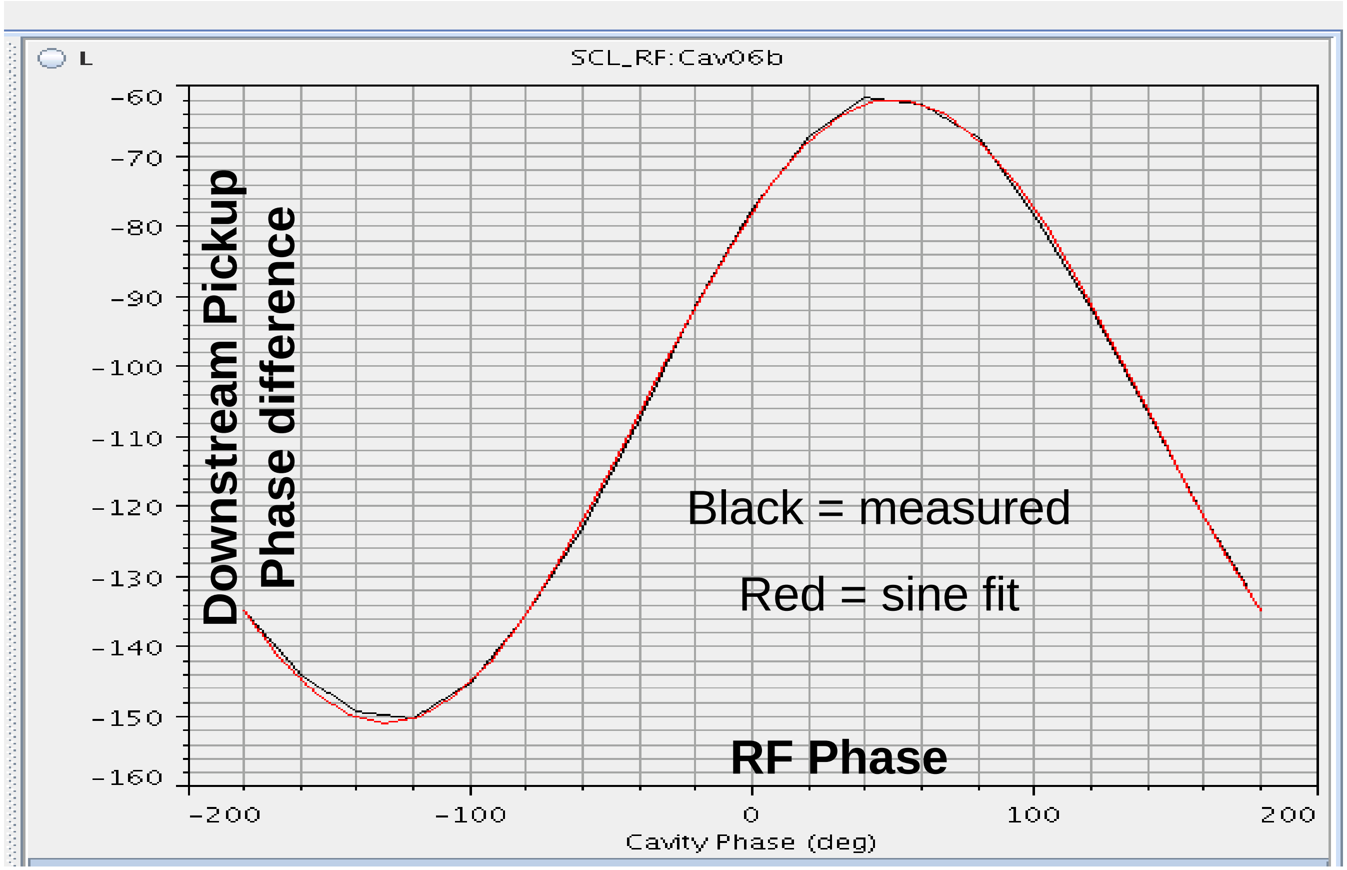
Warm Linac Longitudinal Beam Setup



Downstream beam behavior has complicated dependence on RF phase and amplitude – each cavity has a unique signature

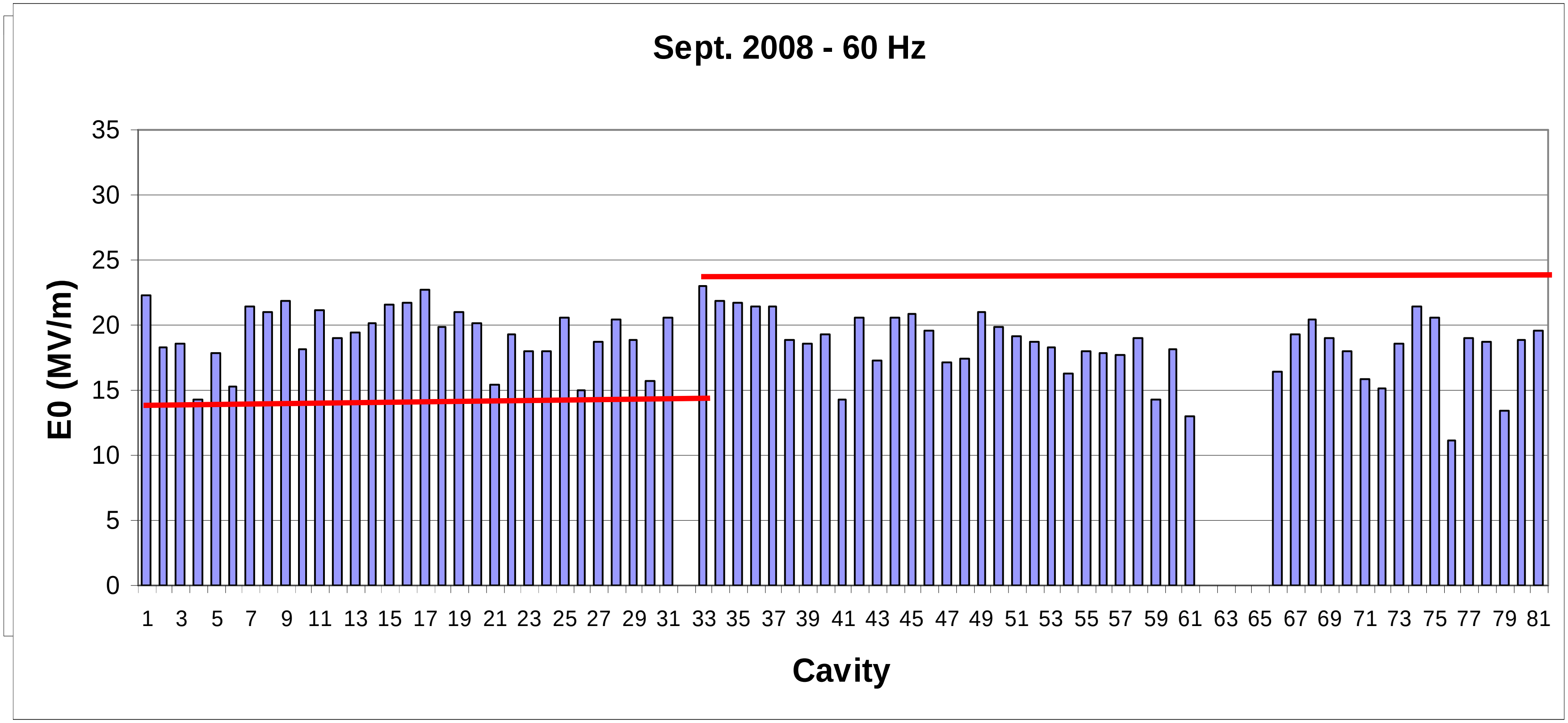
- **Large phase advance (longitudinal) and energy gain per accelerating structure**
- **Single correct RF phase and amplitude setting**

SCL Longitudinal Beam Setup



- **Small $\delta\beta$ and small longitudinal phase advance per cavity**
  - **Close to ideal RF gap kick**
- **No correct setting for each cavity!**
  - **Set each cavity amplitude for the maximum safe gradient**
  - **Flexibility in the RF phase setup**

SCL Cavity Amplitudes



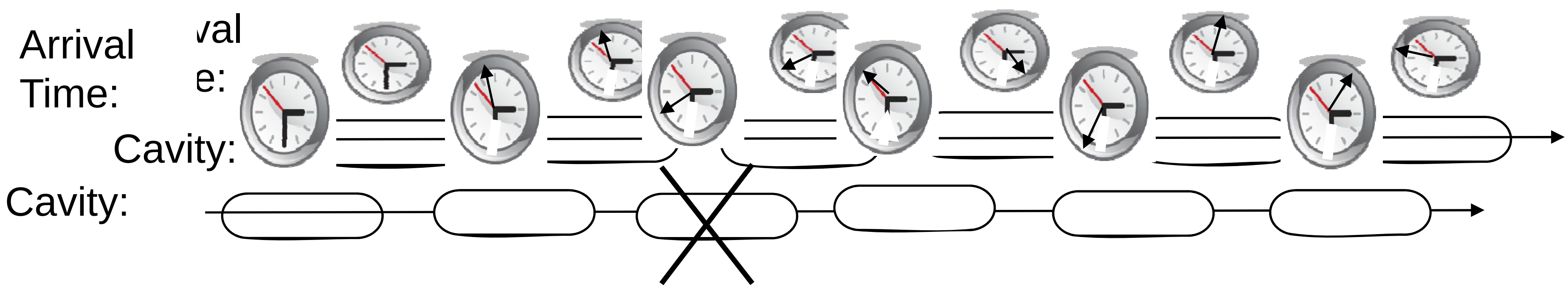
- **Strategy is to run cavities at their maximum safe amplitude limit**
- **Need to be *flexible* – SRF capabilities change, not near the design**
- **Linac output energy is not fixed**

Model Scaling to Adjust Cavity Phase for Upstream RF Changes

Step 2: Change an RF phase and / or amplitude

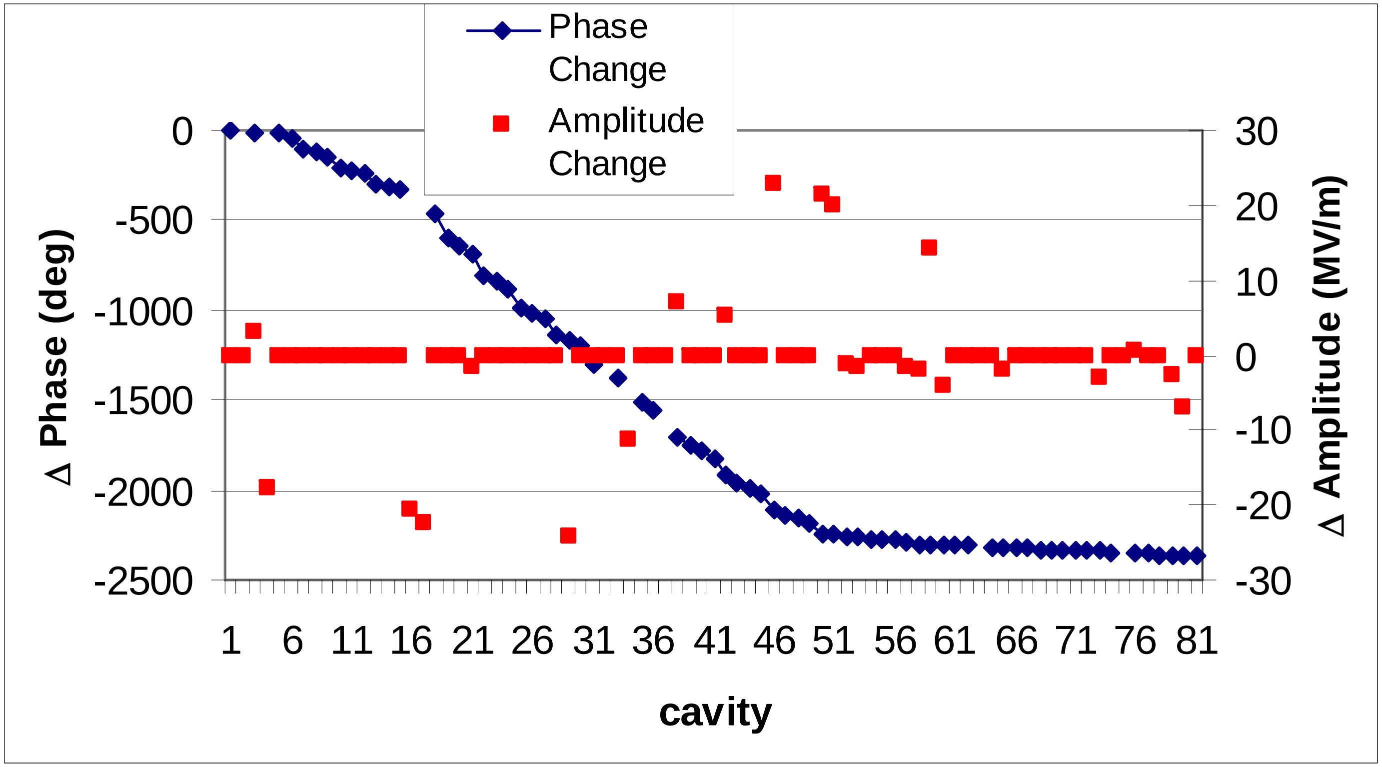
ıinal setup

Step 3: Use a simple model to calculate the change in downstream arrival time (RF phase setpoint) for modifications in the RF setup



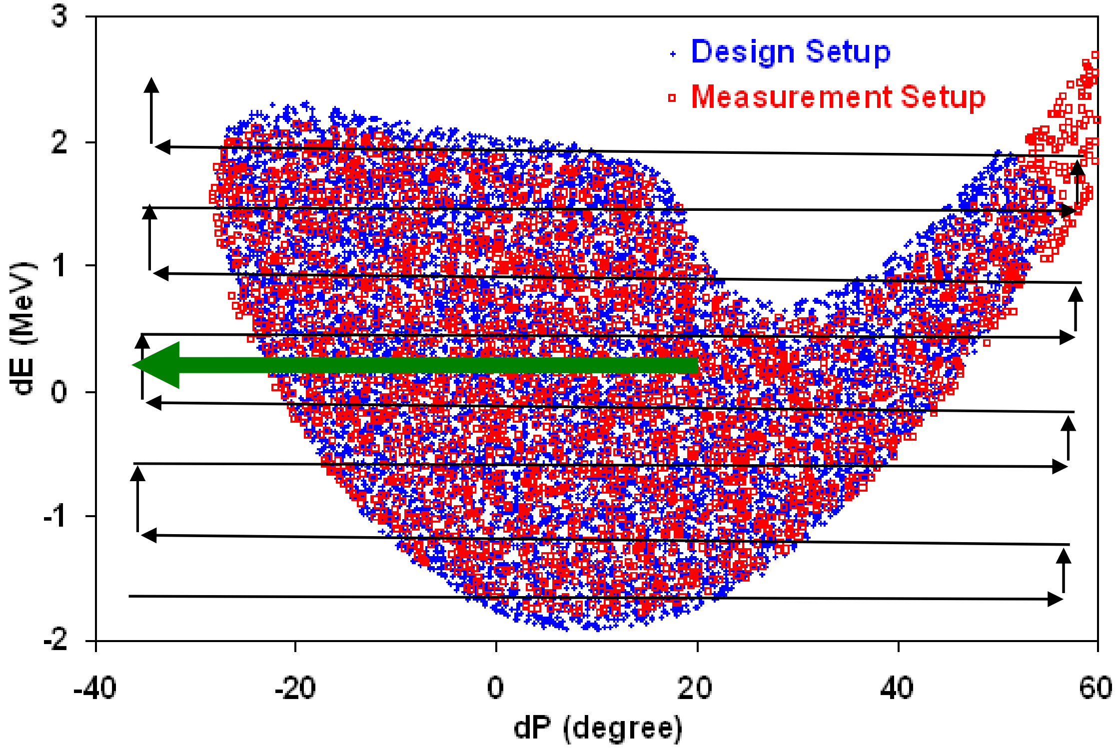
- **Proton beams for high power applications (< 10 GeV) are not fully relativistic and the velocity is energy dependent**
- **For SNS if an upstream cavity fails, the arrival time at downstream cavities can be delayed up to 5 nsec**
  - **This is over 1000 degrees phase setting of an 805 MHz RF cavity**
  - **Our goal is to set the cavity to within ~ 1 degree**

Application of the Cavity Fault Recovery Scheme (II)



- **In April 2007 the SCL was lowered from 4.2K to 2 K to facilitate 30 Hz operation.**
- **About 20 cavity amplitudes changed.**
- **The fault recovery scheme restored beam to the previous loss state.**

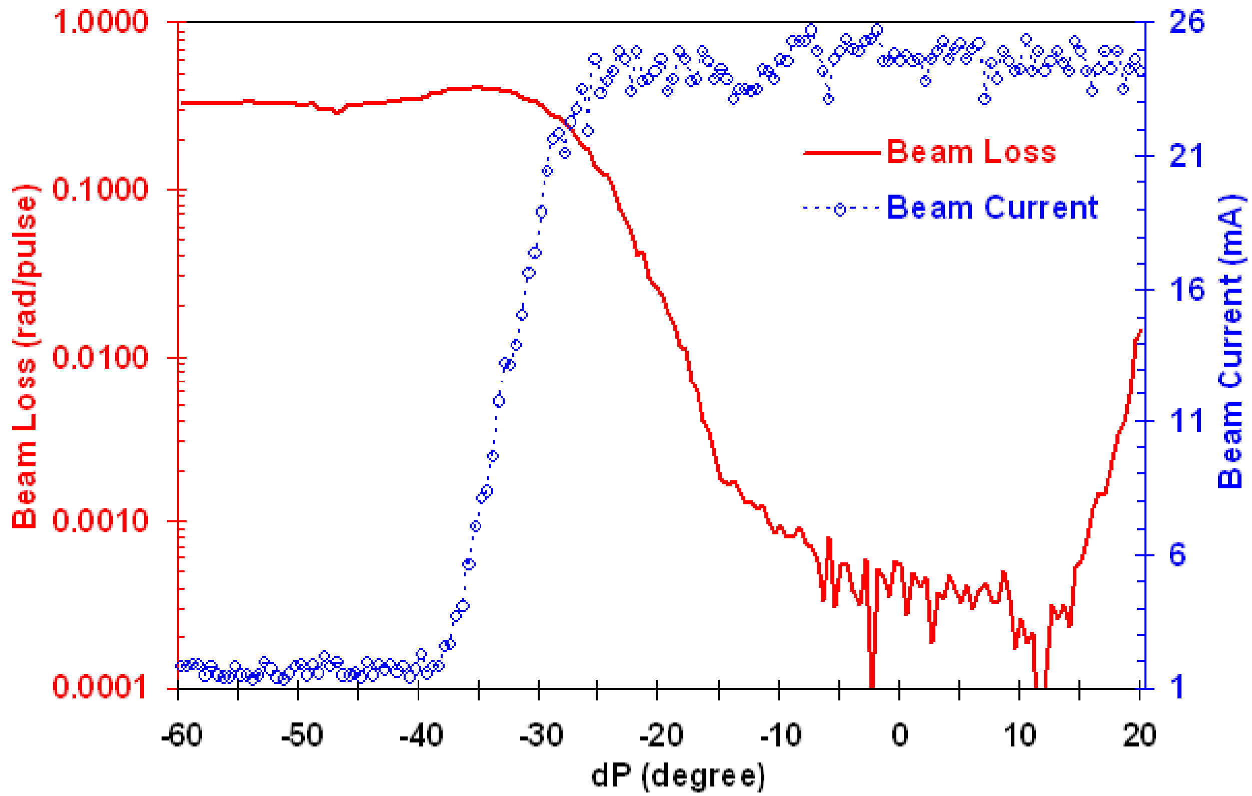
SCL Acceptance Measurement (Y. Zhang)



Consider this part of the scan

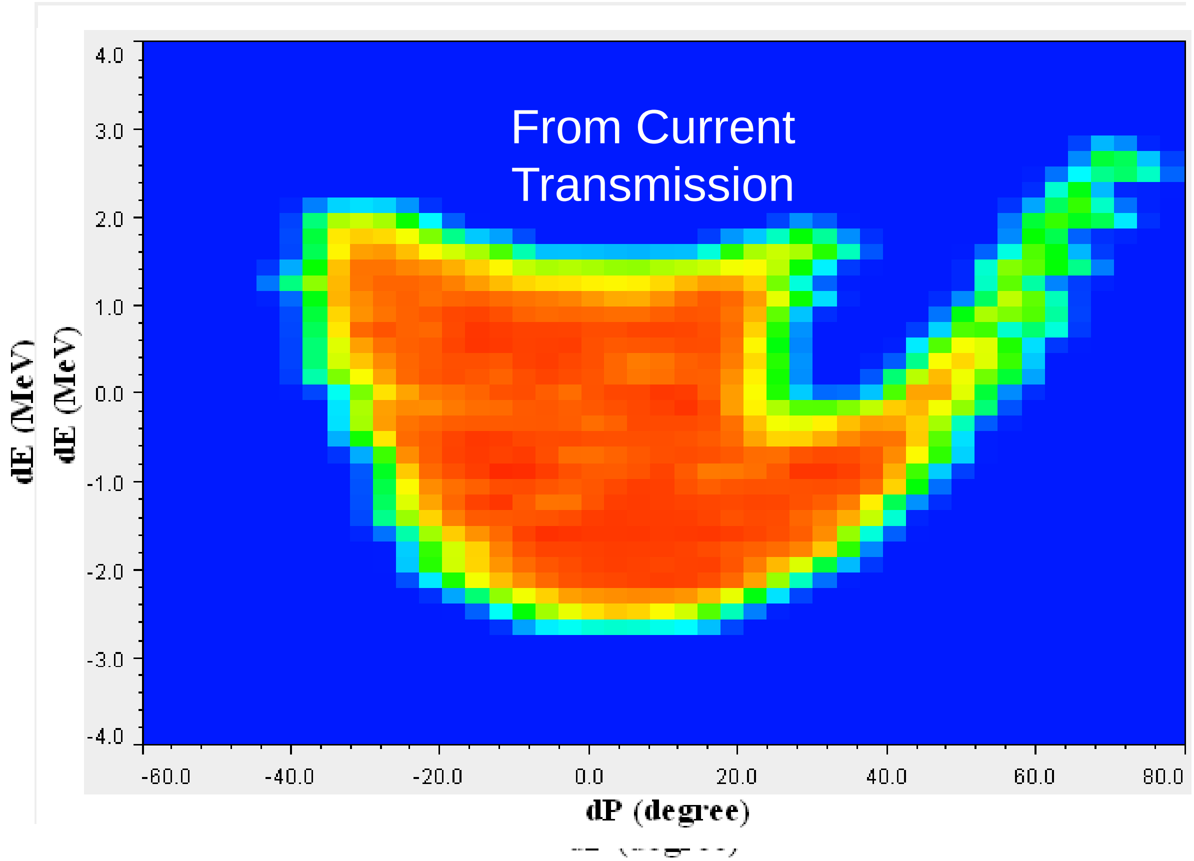
- **Can calculate the longitudinal acceptance space for the SCL linac**
- **Using scaling techniques one can perform scans across the phase space and measure transmission**

A Closer Look at a Phase Scan (courtesy Y. Zhang)



- **Scan the beam phase for a constant input beam energy**
  - **Measure the transmitted beam current (core beam)**
  - **Measure the Beam Loss (halo indicator)**

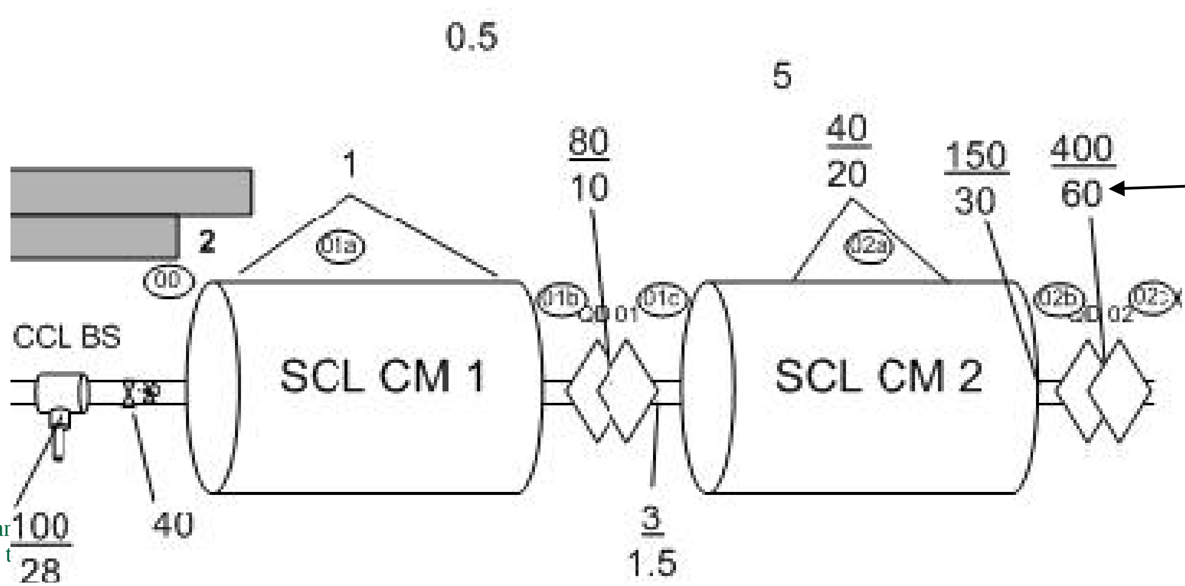
Measured SCL Acceptance



- **Create an acceptance measurement from the scans across the**

Beam Loss in the SNS Superconducting Linac

- **We measure beam loss and residual activation in the warm sections between SCL cryomodules**
  - **Location of focusing elements and aperture restriction**
- **Residual activations range from 10 to 60 mrem/hr at 30 cm, after one day shutdown**
- **Not an issue for worker dose during maintenance or equipment lifetime**



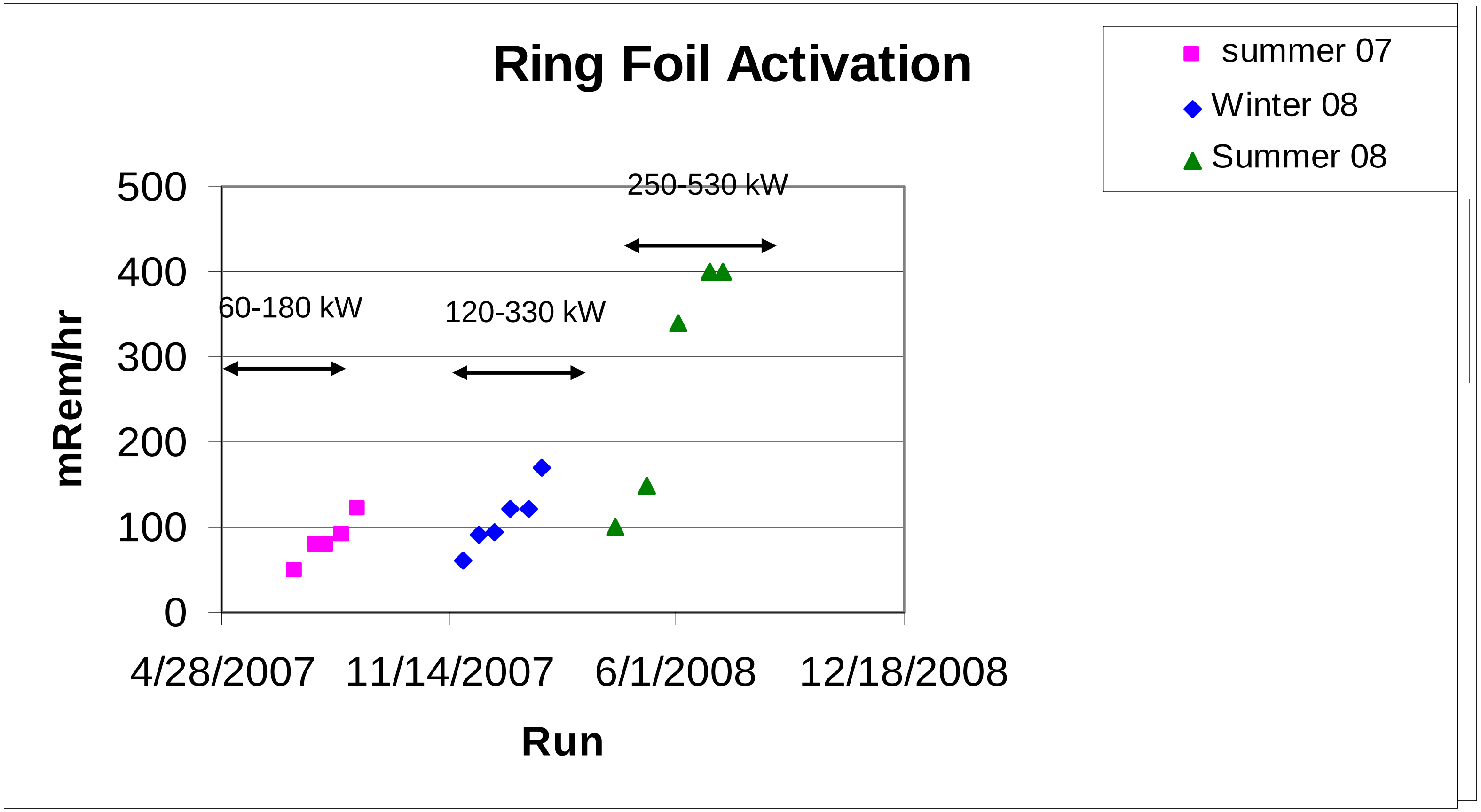
Residual dose rate at 30 cm, 24hrs. after production run

Fractional SCL Beam Loss Characterization: (Y. Zhang)

- **Spill an entire (small) single mini-pulse locally in the SCL by purposefully destroying the RF setup: gives nC/Rad calibration**
  - **Medium β: 36 nC/Rad $\pm$ factor of 3 variation**
  - **High β: 13 nC/Rad $\pm$ factor of 2**
- **For production conditions we are losing < 2×10^{-6} beam / warm section**
  - **< 10^{-4} total loss in SCL**
- **Consistent with the excepted activation for < 1W/m beam loss**
- **Very small fractional beam loss!!!!**

	nC/Rad
SCL_Diag:BLM14b	19.6
SCL_Diag:BLM18b	10.4
SCL_Diag:BLM18c	18.8
SCL_Diag:BLM19b	6.4
SCL_Diag:BLM19c	18.7
SCL_Diag:BLM21c	6.8
SCL_Diag:BLM22c	18.3
SCL_Diag:BLM23c	6.2
SCL_Diag:BLM24b	14.6
SCL_Diag:BLM24c	5.8
SCL_Diag:BLM25c	17.3
SCL_Diag:BLM32b	8.3
average	**12.6**

SCL Activation Buildup

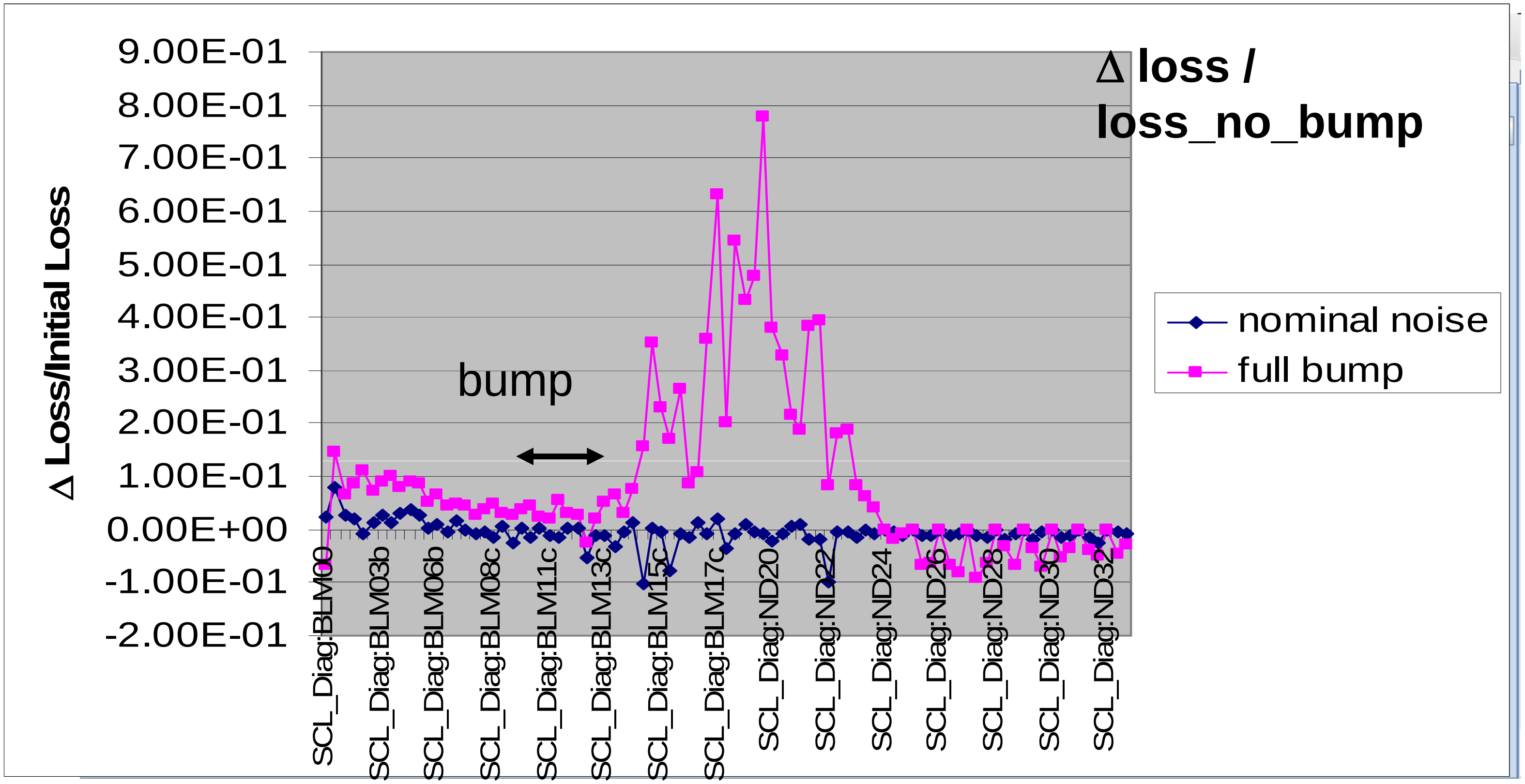


- **Average residual activation of the warm sections saturates after < ~ one month of running**
- **Ring residual activation shows slower rate of saturation - also higher value**

SCL Beam Loss Sensitivities

- **Sensitive to upstream warm linac RF set-up**
- **Insensitive to input SCL matching quads**
- **Insensitive to longitudinal RF tune (constant phase, constant focusing phase law)**
- **Insensitive to flattened trajectory (± 3 mm)**
- **Can reduce SCL loss by ~ 1/3 by reducing the quadrupole focusing strength (10-20 %)**
- **Can increase the loss by creating local trajectory bumps**

SCL Beam Loss Sensitivity Example



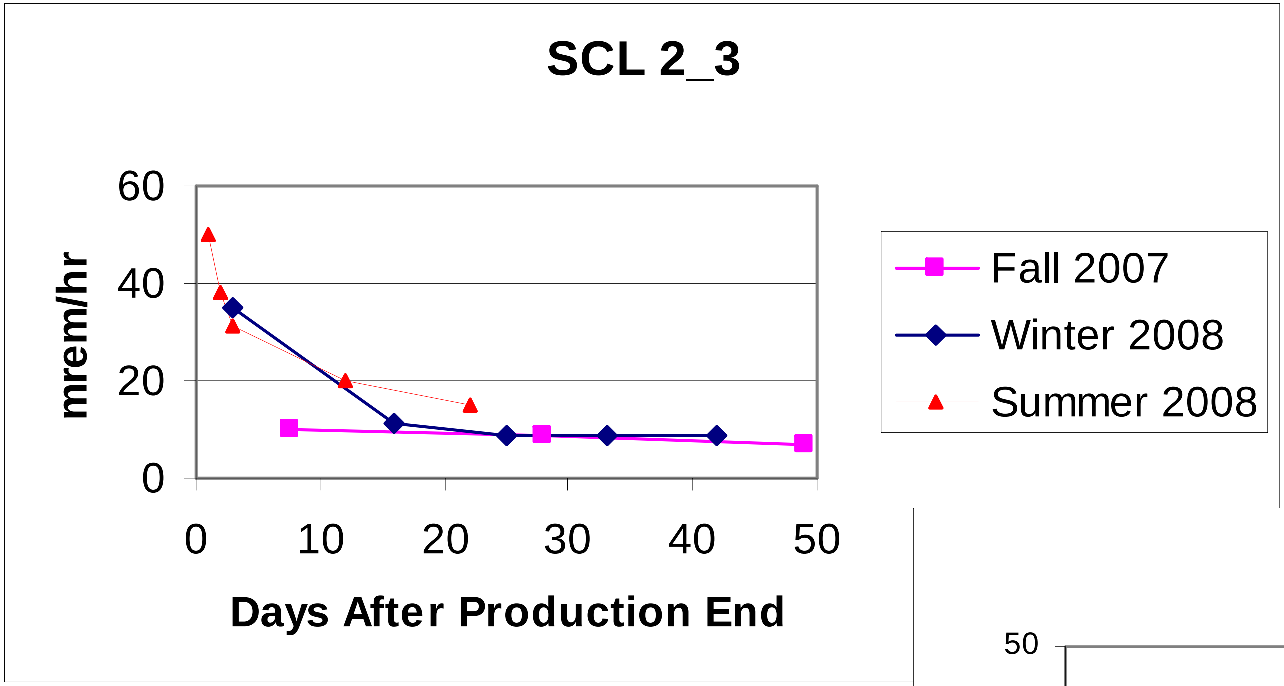
- **Create a local bump (~ 5 mm) and observe loss downstream**
  - **H- magnetic stripping – not likely, fields are lower than transport line**
  - **Off axis RF fields –happens in dummy sections with no cryomodules**
  - **"Shaking' off-energy beam ???**
  - **Strong sextupole component in dipole windings ???**

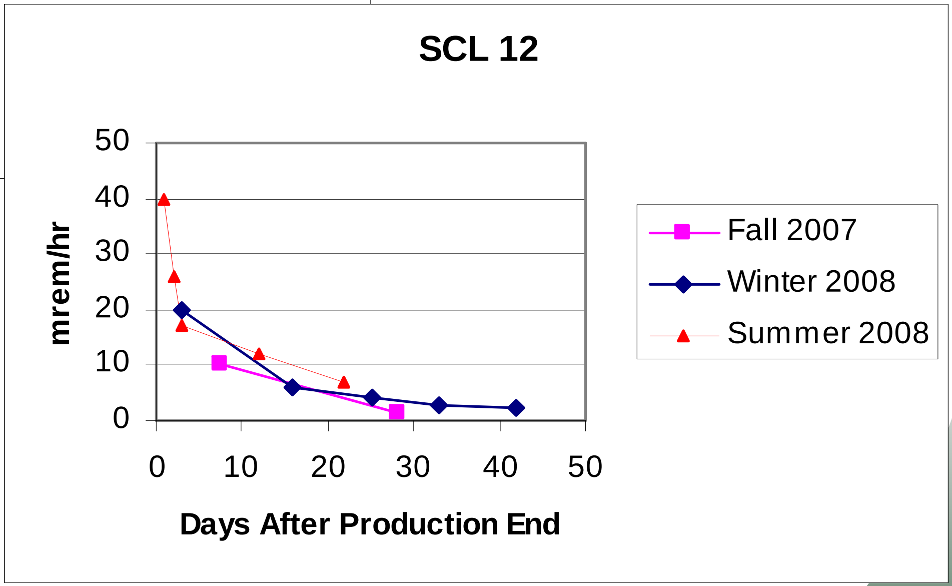
Summary

- **The SNS Superconducting Linac is operating at over 500 kW**
- **We are not running cavities at expected design voltages**
  - **The SCL is flexible to many different operating set-ups**
- **Model based phase scaling works to reset downstream cavities**
  - **Can be used to work around failed cavities an facilitate beam studies**
- **We see a low level of beam loss, albeit higher than expected**
  - **Source is not understood**

Backup

SCL Activation decay

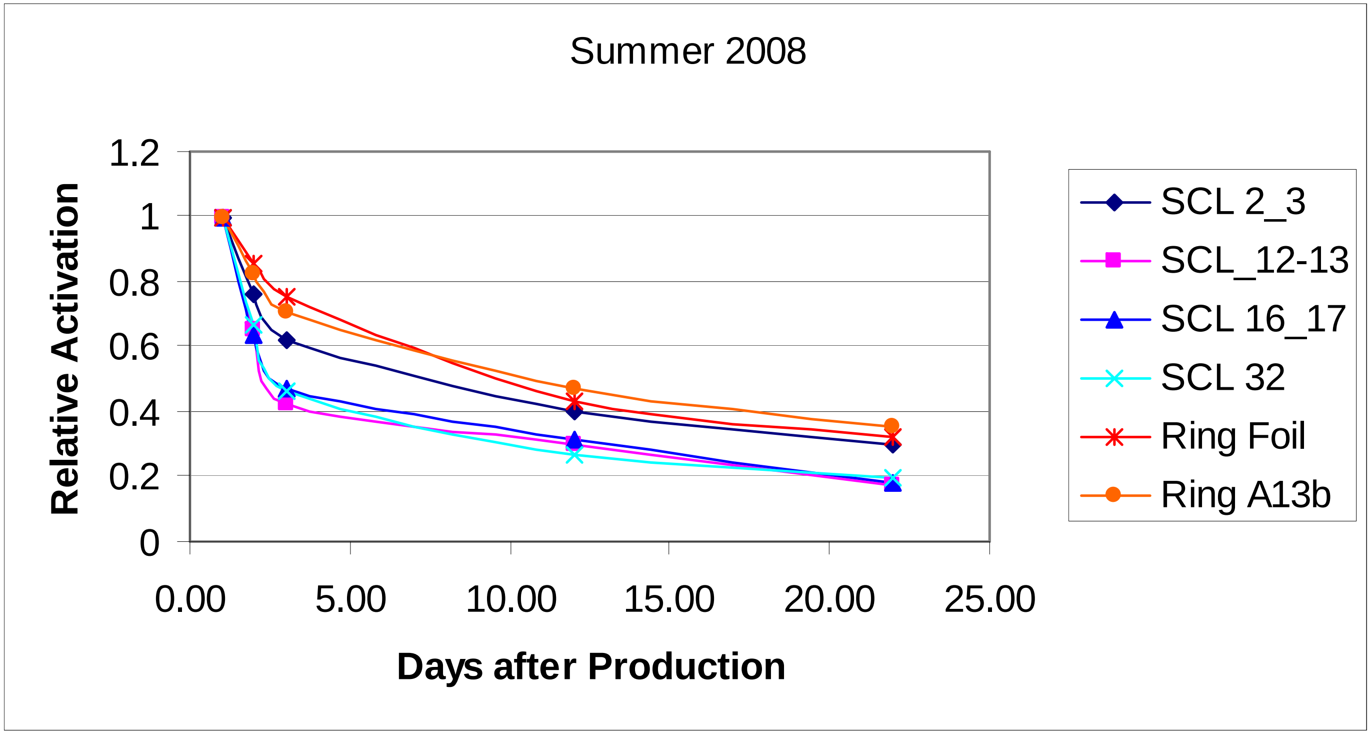




- **Decays close to starting value**

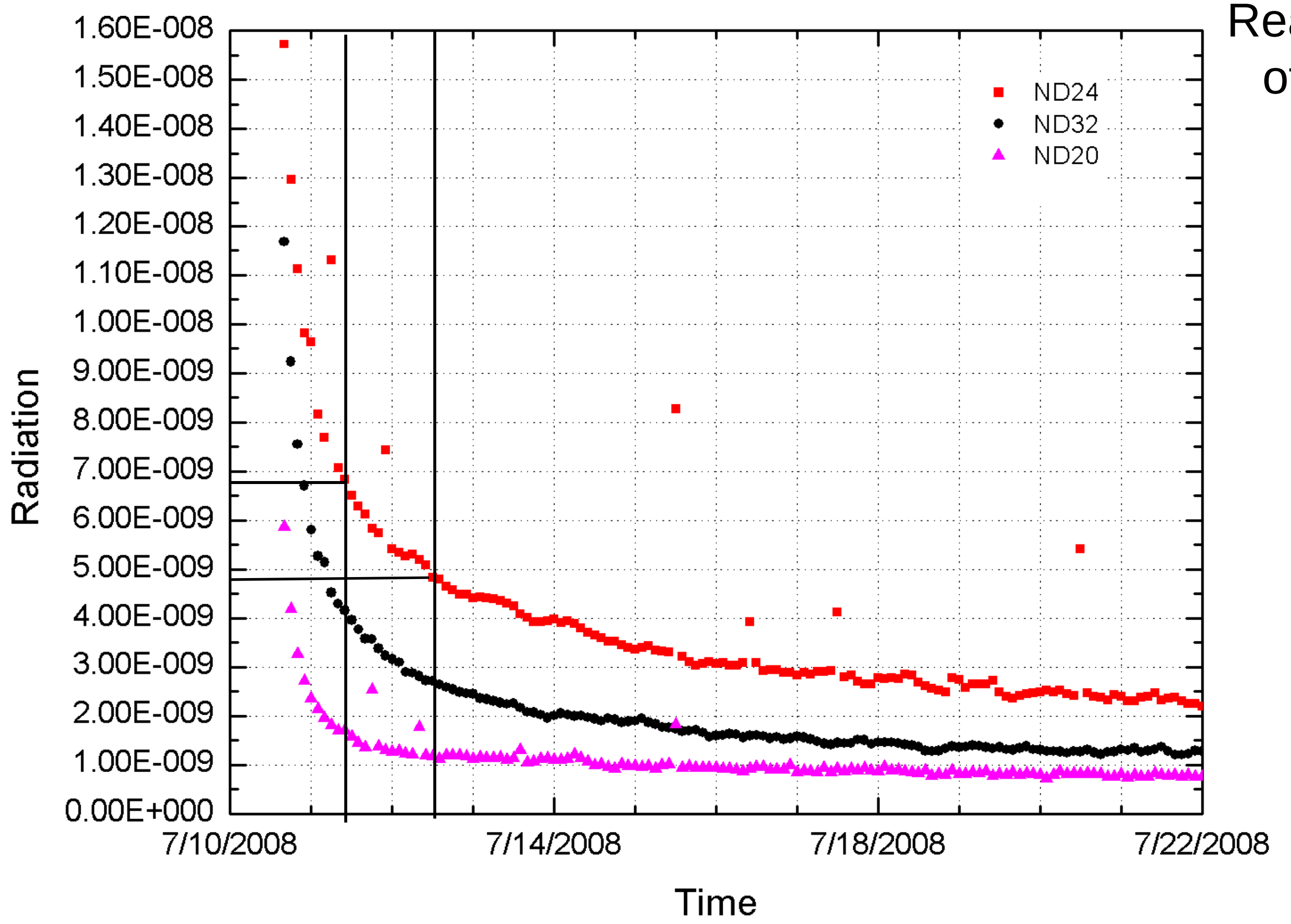
Residual Activation Decay Across the Machine

Beam loss normalized to the initial reading



- **The SCL warm sections decay faster than the rest of the machine**
  - **Except SCL2_3 is intermediate**

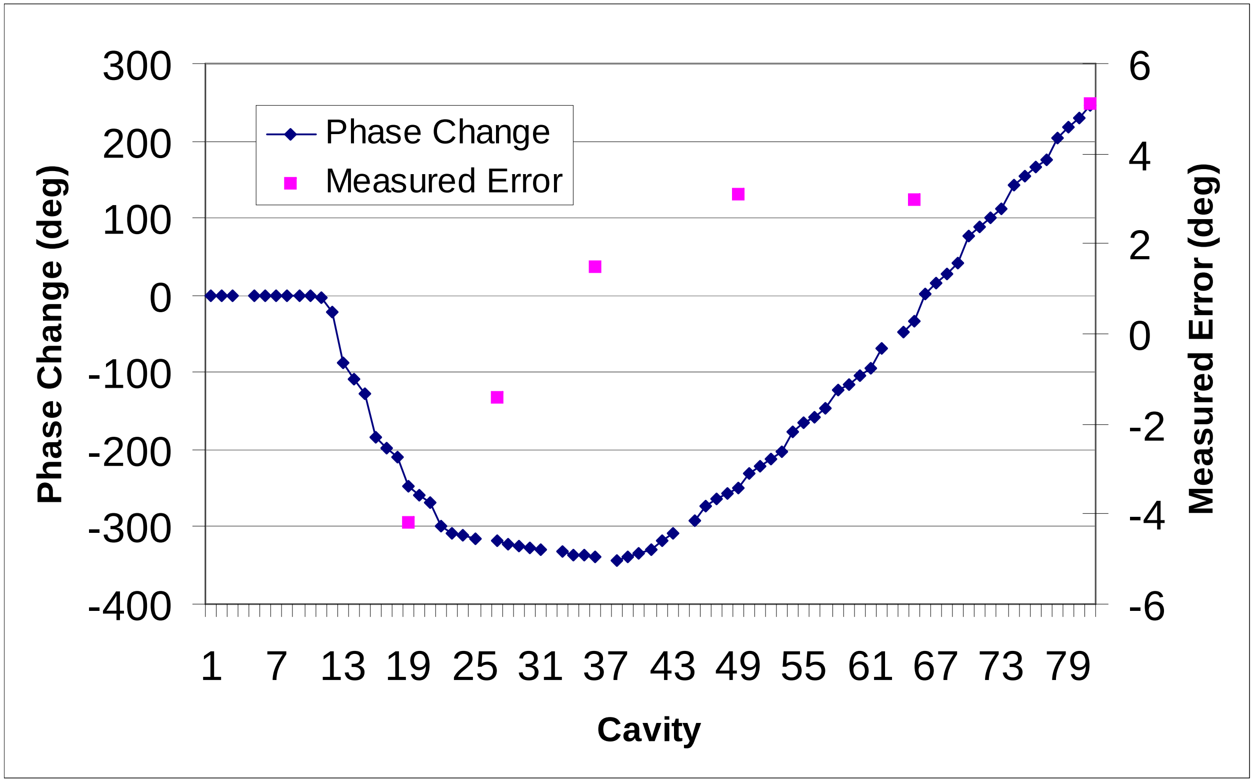
Residual Activation Decay (Zhukov, Assadi, Popova)



Real time measurement of residual activation after shutdown

- **SCL decays quite fast – model comparisons are underway**

Application of the Cavity Fault Recovery Scheme



- **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**

SNS Linac Beam Parameters

	Design	Best Ever (Not Simultaneous)	Highest Power Run (Simultaneous)
Pulse Length (μSec)	1000	1000	570
Beam Energy (MeV)	1000	1010	890
Peak Accelerated Current (mA)	38	40	32
Average Accelerated Current (mA)	26	22	18
Repetition Rate (Hz)	60	60	60
Beam Power (kW)	1440	540	540