OAK RIDGE National Laboratory

Optimizing Performance of the SNS High Power SCL

ICFA HB2021

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U.S. DEPARTMENT OF ENERGY

(WEDC4)

Outline

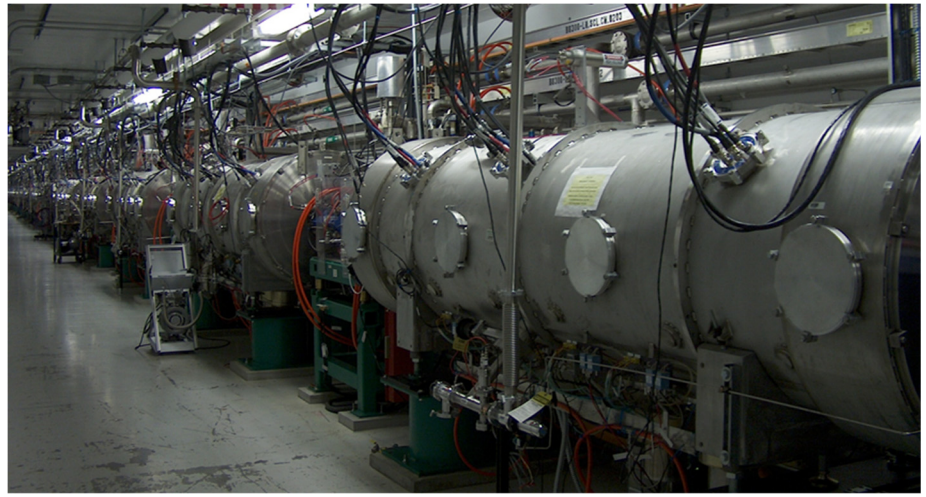
- SNS Accelerator Complex
- SCL Performance
- SCL Model Based Tuning and Retuning
- Conclusions

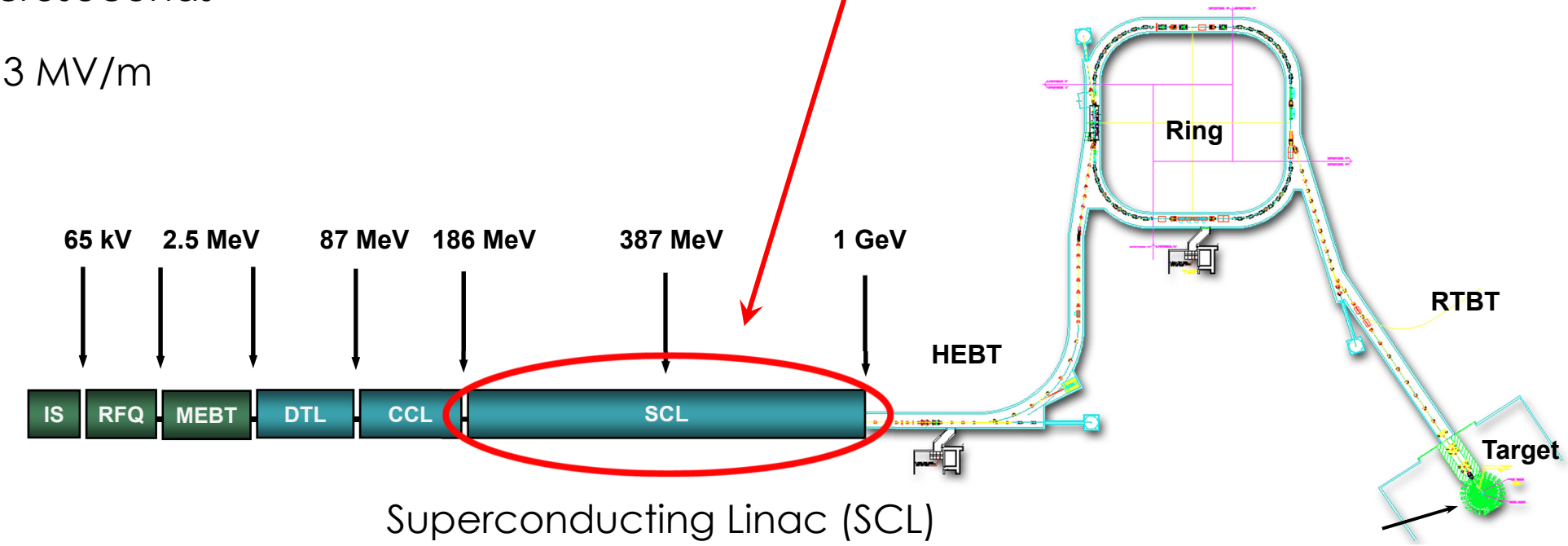
SNS Accelerator Complex and SCL

- SNS : 1 GeV H- Linac + Accumulation Ring + Target
- Linac includes Superconducting Cavity Linac (SCL)

SCL

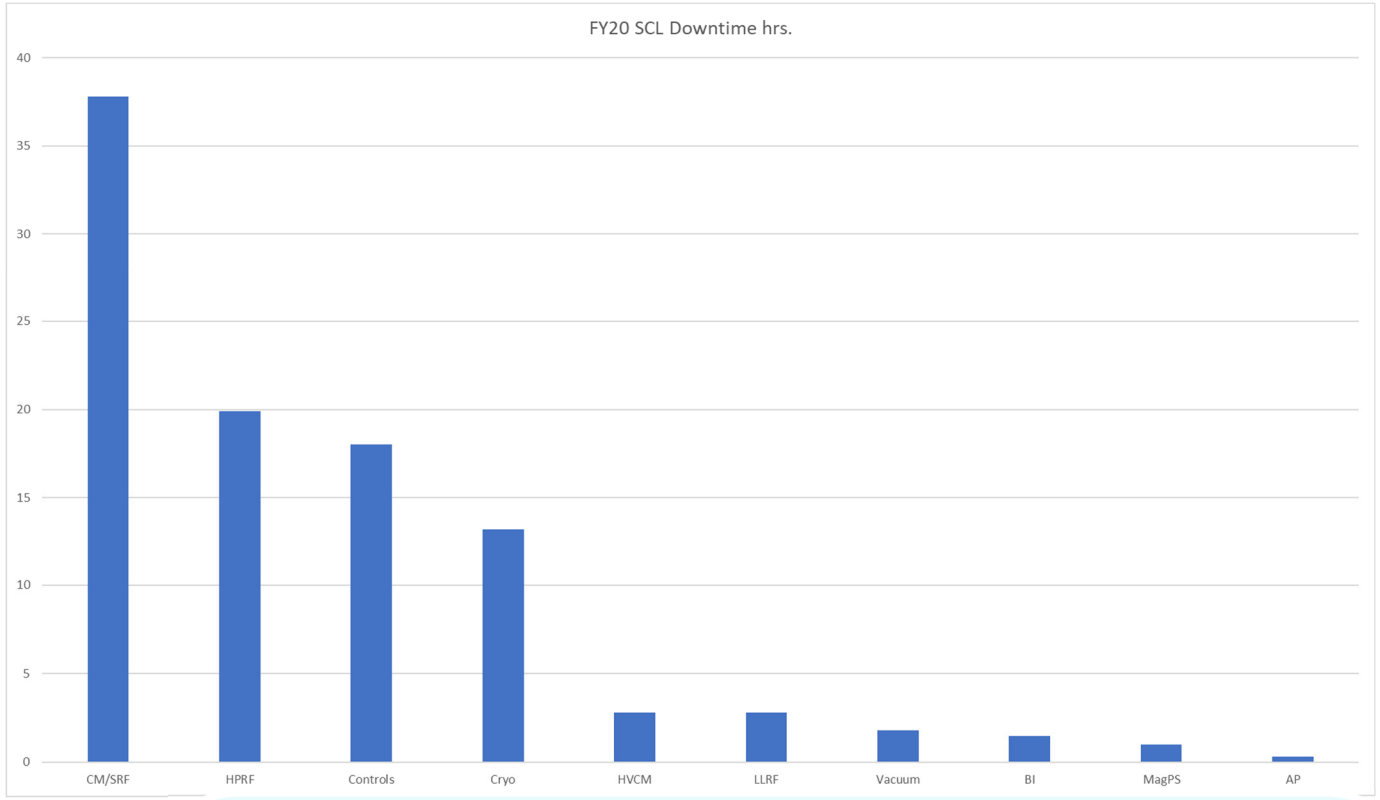
- 81 cavities @ 2 K
- 33 medium beta cavities in 11 cryomodules
- 48 high beta cavities in 12 cryomodules
- 805 MHz
- Pulse width 1265 microseconds
- Rep rate 60 Hz
- Average gradient 13 MV/m





Superconducting Linac (SCL)

SCL Performance – FY2020 Example



Cavities' Trips Retune
Klystrons
Controls
Cryo-plant
HVCM
LLRF Electronics
Vacuum Pumps
BLMs
Magnets PS
Acc. Phys. Beam loss

Statistics FY20

Total hours: **5000 h**
Availability: 95%
Downtime : **250 h**

SCL Downtime

Total: **100 h**

Cryo-modules, cavities' trips, tune, retune: **37.8 h**

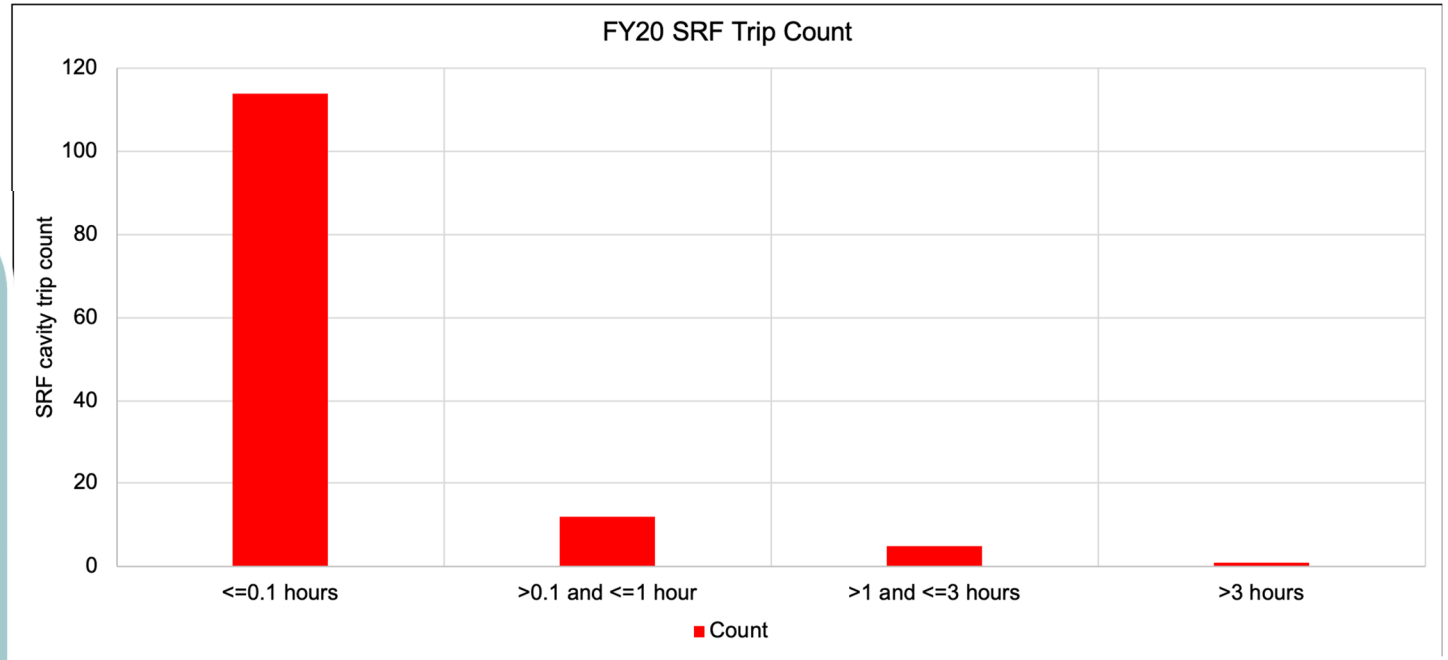
We are talking about 0.8 % of total production time

Data courtesy of Shane Passmore

Recovery SRF Cavities Timing Distribution

- **Recovery times in FY20**
  - 85% of the time restoring beam took <6 minutes (no expert required)
  - 10% of the time restoring beam took 30 minutes (**no expert required**)
  - 4% of the time restoring beam took 1.5 hours (**expert required**)
  - 1% of the time restoring beam took 3 hours (**expert required**)

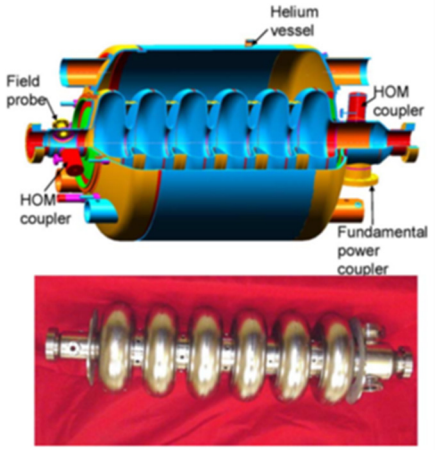
Model Based Retuning

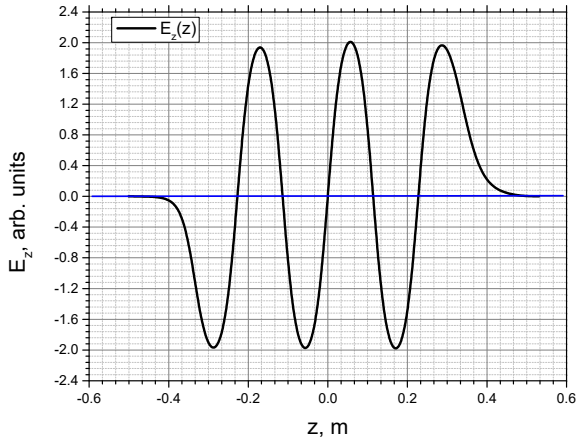


Expert := Machine Specialist from Operations or Accelerator Physicist

Courtesy of Charles Peters

6 RF Gaps Cavity Model





For each RF gap

$$\Delta W = q \cdot \int_{-\infty}^{+\infty} E_z(z, t = \frac{z}{c \cdot \beta}) \cdot dz = qV_0 \cdot (T(k) \cdot \cos(\varphi_0) - S(k) \cdot \sin(\varphi_0))$$

$$E_z(z,t) = E_z(z) \cdot \cos(\omega \cdot t + \varphi_0)$$

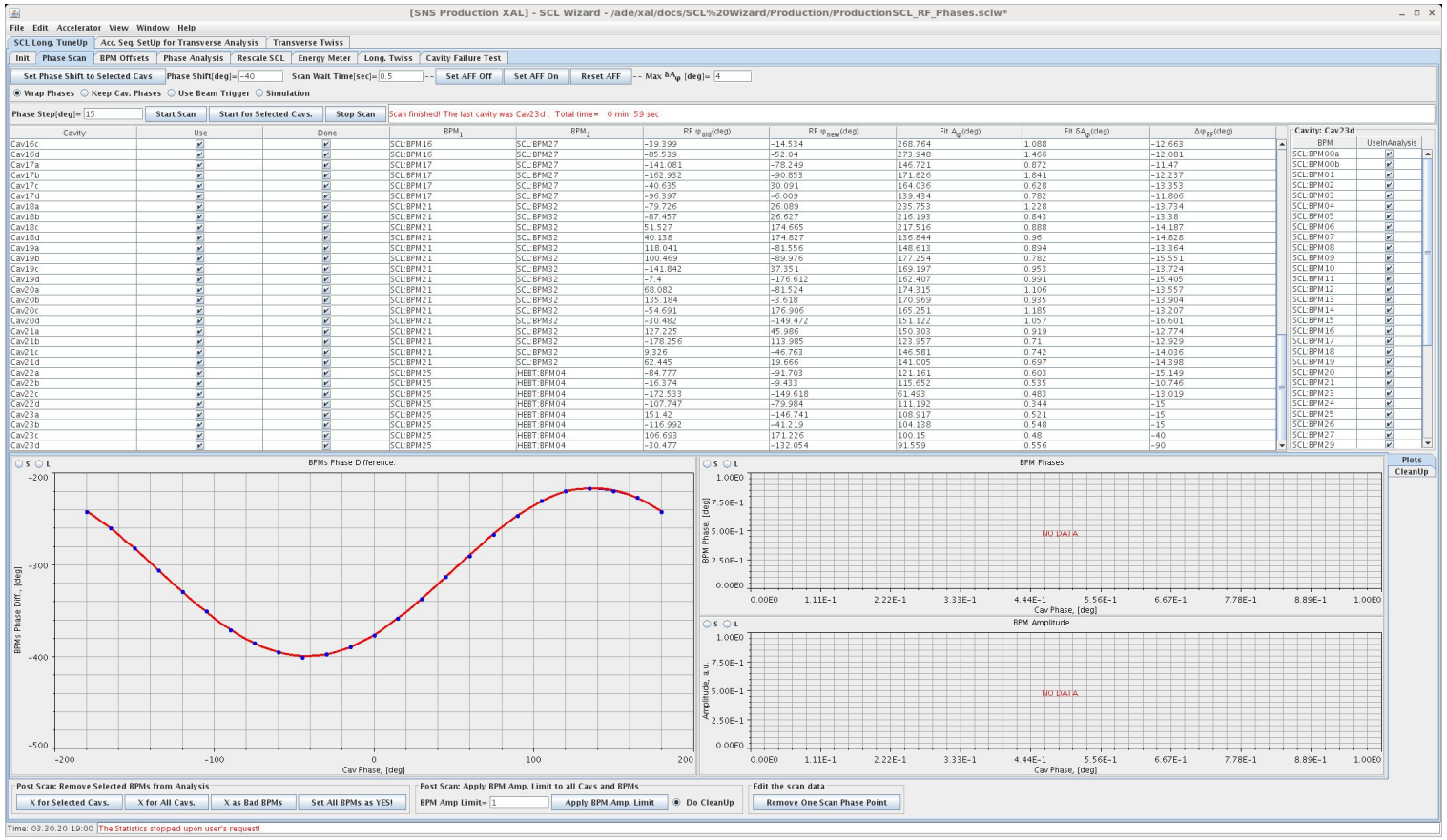
$$T(k) = \frac{1}{V_0} \int_{-\infty}^{+\infty} E_z(z) \cdot \cos(k \cdot z) dz$$

$$S(k) = \frac{1}{V_0} \int_{-\infty}^{+\infty} E_z(z) \cdot \sin(k \cdot z) dz$$

- SCL Model is a combination of 81 of 6-gap cavities (two types: medium and high beta)
- Cavity is a combination of 6 RF gaps
- Each gap is a zero-length accelerating RF gap with its own full voltage and transit time factors.
- There is a cavity amplitude parameter. It is used as a one scaling factor for each RF gap. For the design value for this amplitude is 1.0
- This amplitude could be 0 (cavity is off) or 10 to 30% different from design value of 1.0. We do not touch cavities' amplitudes during tuning/retuning

SCL Beam Setup: SCL Tuner Wizard (OpenXAL App)

- SRF phases are set by beam time of flight measurements using Beam Position Monitors (BPMs)
- SCL Tuner Wizard Application
  - RF Phase Scans for Setup and Documentation ≈ 1 hour
  - BPM Phase Offset Calculations
  - Energy Meter
  - Model Based Analysis
  - **Model Based Phase Rescale**



SCL Tuning / Retuning Procedures and Results

- SCL tuning is fully automated, takes about 1 hour (initially was 8 hours). Model is not involved into the initial tuning
- It is possible to perform "non-destructive" tuning (SCL state will stay as is)
- During the initial tuning one or two last cavities are kept as a reserve (no acceleration) for future retuning with the same final energy
- SCL model is calibrated based on data collected during the tuning
- If we significantly change amplitude of one or more cavities, we perform retuning of the SCL based on the calibrated model to get the same final energy. The procedure is performed by Operations.
- Usual retuning approach: keep the same synchronous phases for all cavities except last one or two
- After applying changes, the model predicted energy usually has less than 1.5 MeV deviation from the measured energy around 1 GeV

Conclusions

- Automated model-based tuning / retuning of SCL reduced
  - Initial tune up from 8 to 1 hour
  - SRF cavity failure and retuning downtime
- Procedures can be performed by Operations without physicists involved (mostly)
- There are some discrepancies between model-predicted and measured final energies after retuning. The source of these discrepancies are not identified yet. Further studies are desirable even though it does not affect SNS availability