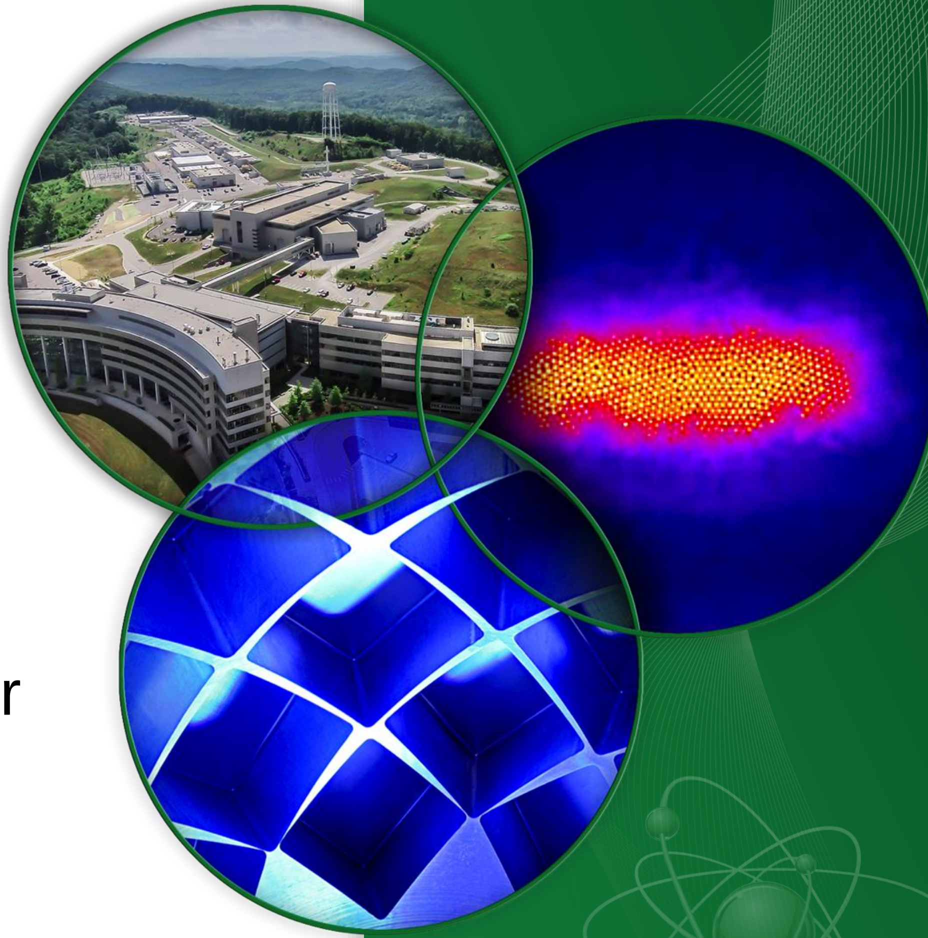
SNS Operations – Status and Experience



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On behalf of SNS Accelerator Physics Group

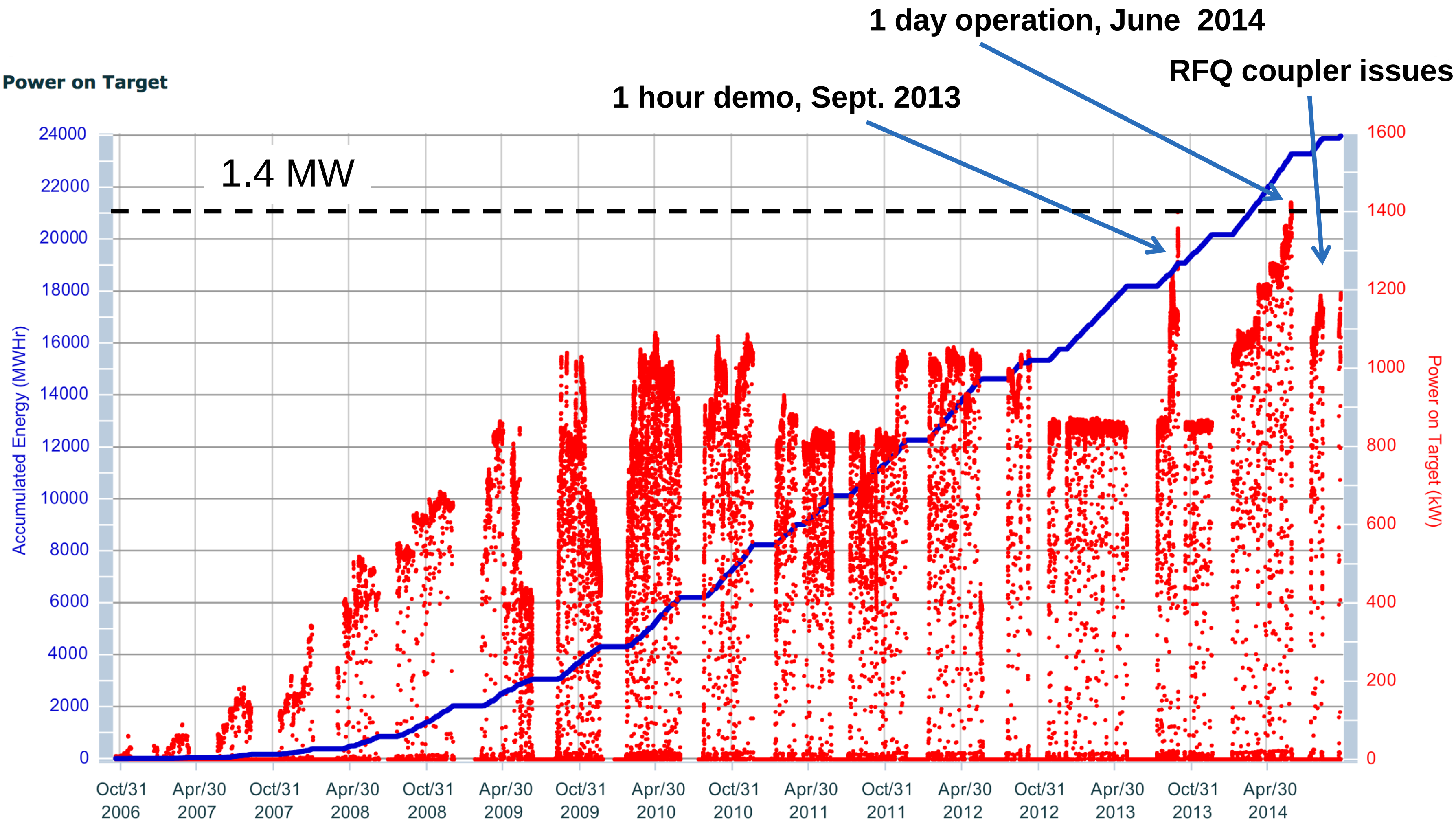
HB2014 Workshop
Nov. 10-14, 2014

Oak Ridge National Laboratory | Spallation Neutron Source

Outline

- SNS Linac Overview
- Old vs. new SNS SCL setup procedure
- 3-D Twiss parameter measurement
- Matching Considerations
- Future Works and Conclusions

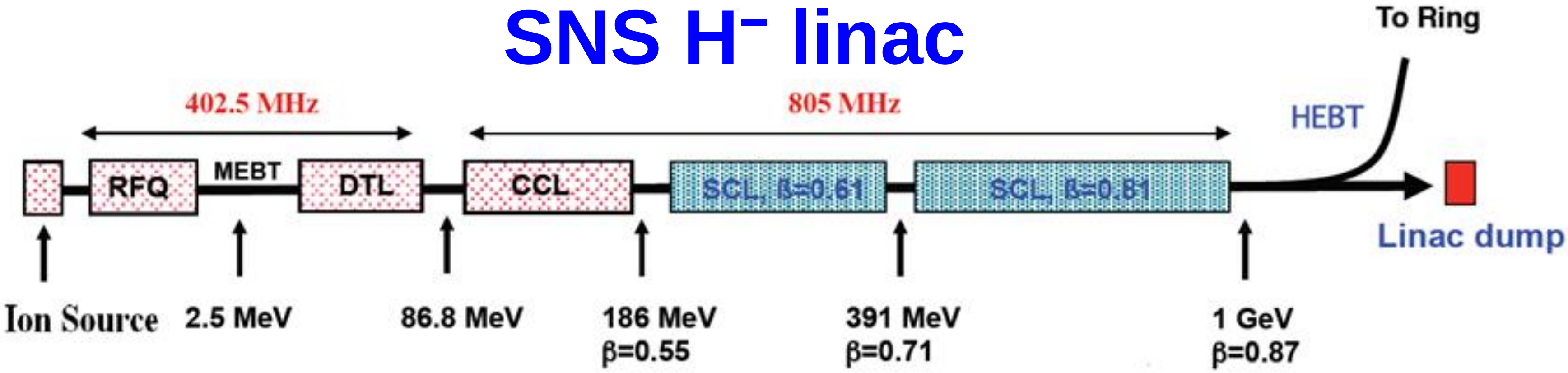
1.4 MW Beam Power at SNS



➢ First neutron production at 1.4 MW: June 29, 2014

SNS Linac Structure

SNS H^- linac



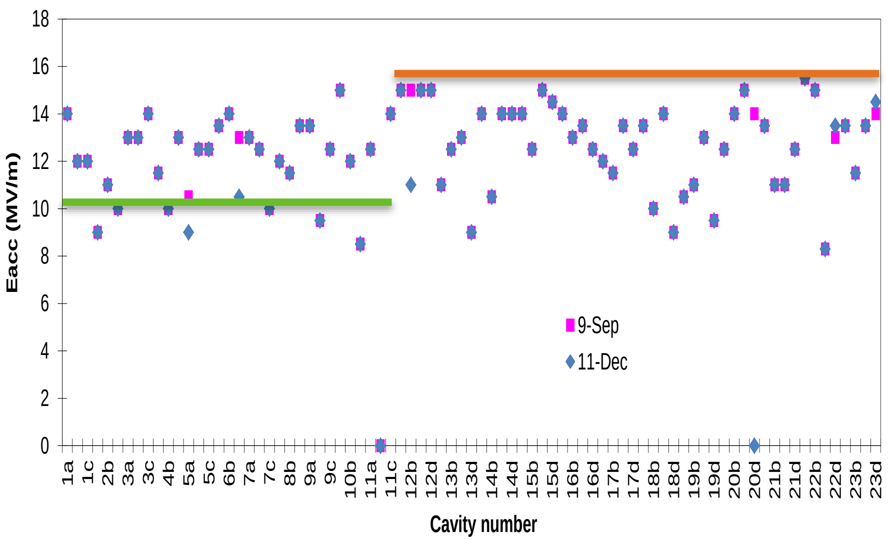
Length: 330 m (Superconducting part 230 m)

Production parameters:
Peak current: 38 mA H^- ion beam
Repetition rate: 60 Hz
Macro-pulse length: 1 ms
Final Energy: 940 MeV (1000 MeV design)
Average power: 1.4 MW

SCL Diagnostics: only non-intercepting allowed
BPM - Beam Position and Phase Monitors through the whole linac
LW - Laser Wire stations, 9 stations in SCL – Transverse Profiles

Old SNS SCL Setup Procedure

- RF Cavities:
  - Amplitudes are fixed. They are defined by the SRF group to be as high as possible for stable operation. They are all different.
  - No model consideration for cavity phases. Usually we use -18^0 shift from the maximal acceleration phase.
  - Phases are setup by phase scans using just two nearby BPMs
  - After phase scan setpoints are complete, empirically adjust cavity phases (mostly in the warm linac) to minimize beam loss
- Quad magnets:
  - Start with historical field gradients empirically determined to give lowest beam loss, and adjust for further beam loss improvements



New SNS SCL Setup Procedure

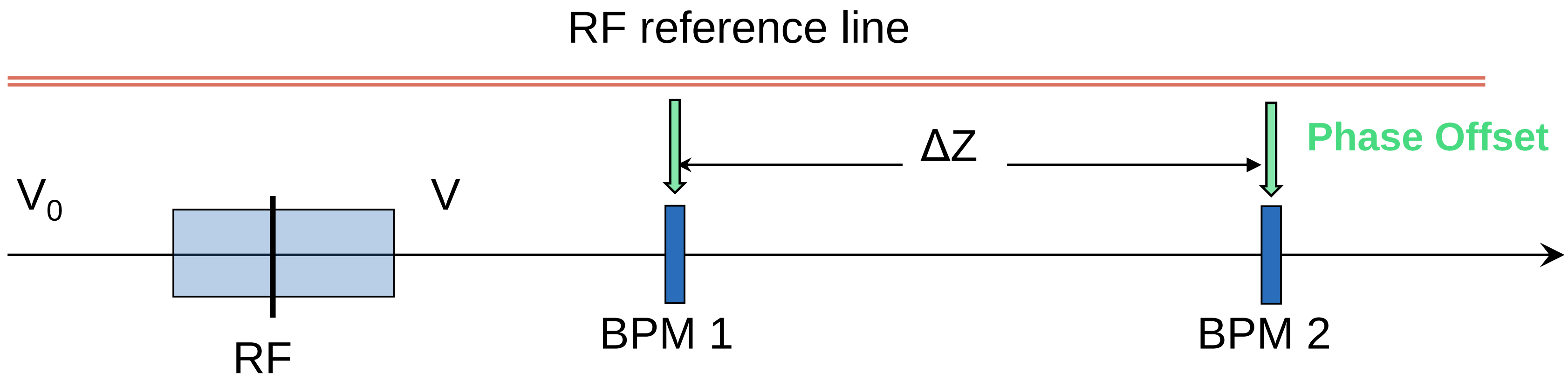
- Record all BPMs for each SCL cavity scan (instead of just 2 BPMs)
- Use ring to measure absolute beam energy
- Use ring energy measurement to calibrate all SCL BPM phase measurements (i.e. correct for variation or drift in electronics)
- Recalculate the actual synchronous phases obtained during the cavity phase scans, this time using multiple calibrated BPMs (estimated error reduced from 2-3 deg. to <1 deg.)
- Calculate beam energy after each cavity, and the actual cavity gradients
- Update the on-line model with the measured cavity gradients and synchronous phases
- Empirical adjustments to cavity phases (mostly in the warm linac) and quad magnets (some in warm linac, some in SCL) to minimize beam loss

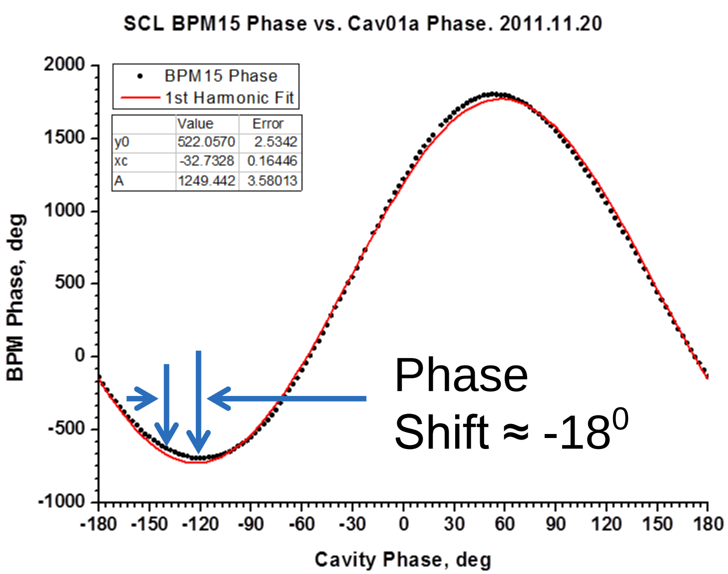
New SNS SCL Setup Procedure (cont.)

- Now that have accurate parameters in the on-line model, use stored BPM phases to calculate the longitudinal Twiss parameters at entrance to SCL
- Optional: Use transverse profile measurements from laser-based diagnostics to calculate the transverse Twiss parameters
  - This calculation needs the cavity phases and gradients to calculate the transverse focusing (up to 40% of the total focusing strength)

(See A. Shishlo, LINAC14 proceedings, for more details)

SCL RF Cavities Phase Scans



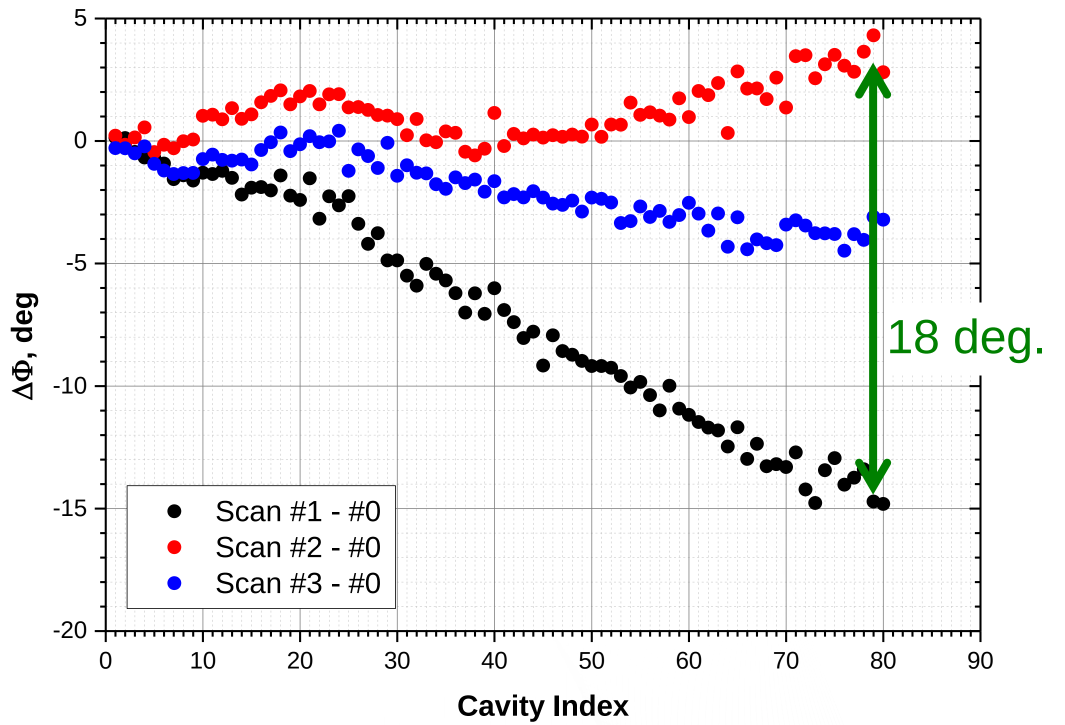


- RF Phase Setup by Time Of Flight measurements
- No model involved, only a “sine”-like curve analysis
- No need for BPM timing calibration before the scan
- Estimated error in synchronous phase set point is 2 – 3 deg, due to shape is not actually “sine”-like, random errors in measurement, and short distance between BPM pairs

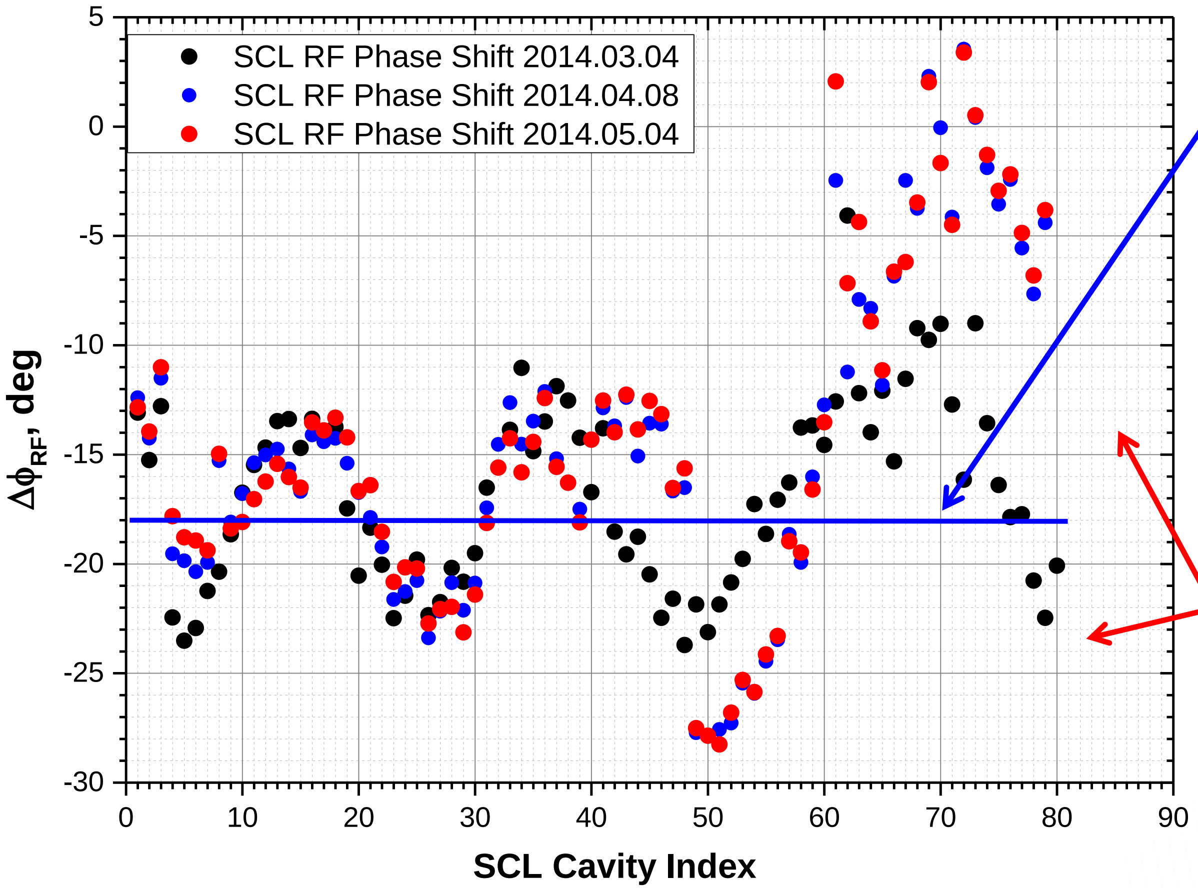
Scan to Scan Stability

- Four successive scans give gradually changing set points
- Each result gives practically same beam loss and beam output energy
- Best guess at this time: linac tunnel temperature variation

Cavity phase set point change for repeated scans



SCL Cav. Synchronous Phases – Production Values for Low Beam Loss

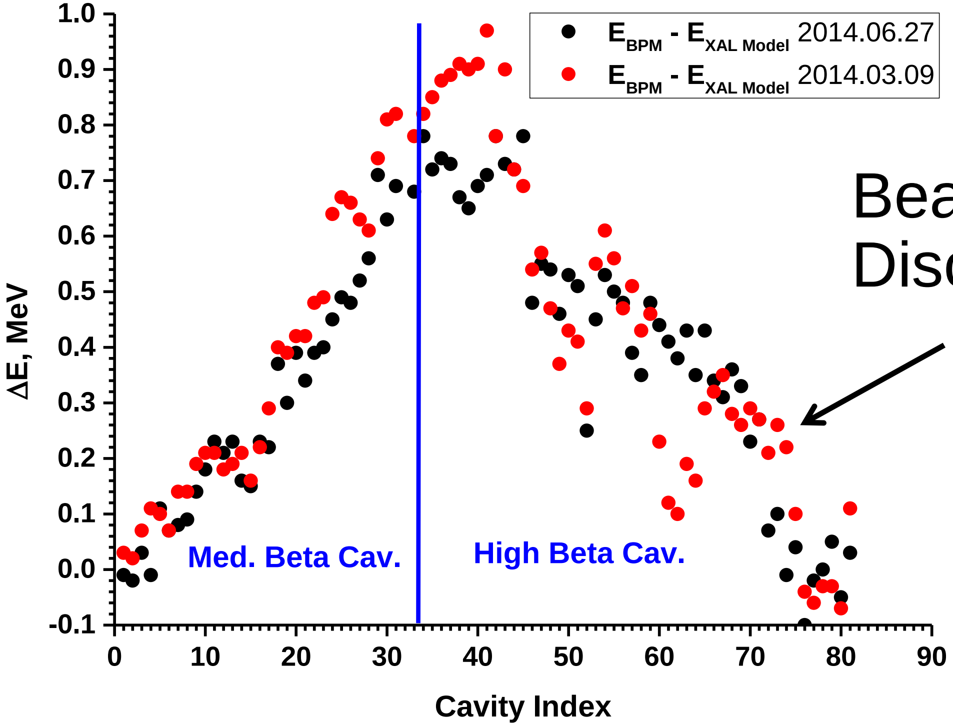


Result of Feb. 2014 phase scan procedure

After tweaking the warm linac (quads and RF) and SCL(quads only) to minimize beam loss, 1, 2, and 3 months later

Clearly, there is a structure.

Energy Tracking: XAL Model vs. measurement



Beam energy: measured – model
Discrepancy is up to 1 MeV

XAL model for cavities is not perfect.
Good opportunity for improvement!
Also good opportunity for code benchmarks!

Longitudinal Twiss Analysis

→ SCL RF → BPM1 → BPM2 … → BPM{n}

Amplitudes of BPMs as byproduct of phase scans

For case of Gaussian distribution of the longitudinal density:

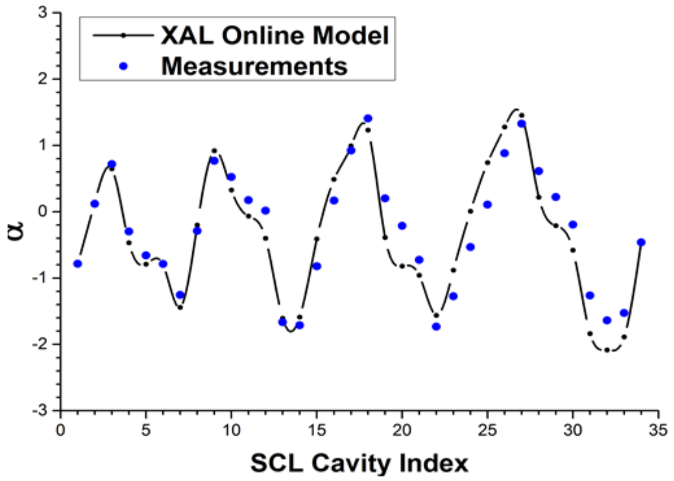
$$U_{BPM}(\sigma_\varphi) = A_0 \cdot \exp\left(-2 \cdot \pi^2 \cdot \left(\frac{\sigma_\varphi}{360^0} \right)^2 \right)$$

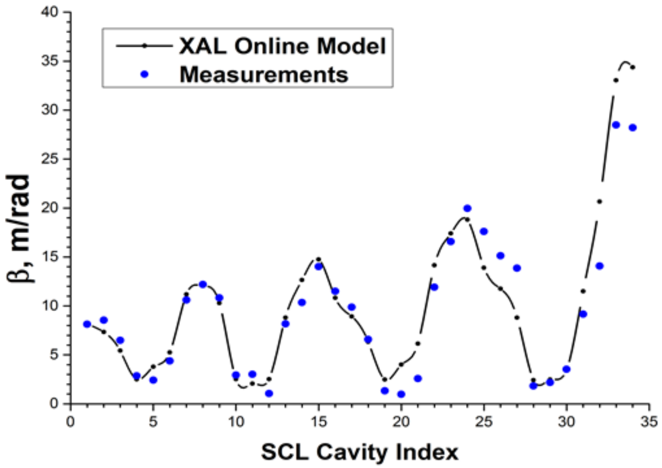
σ_φ = Longitudinal RMS bunch size in deg.

- U_{BPM} = sum signal of BPMs' electrodes as a function of the cavity phase measured during the phase scans
- Each cavity and downstream BPMs are "Bunch longitudinal RMS size" monitors
- Use model to get the longitudinal Twiss at the entrance of the cavity
- The approach only works for "Gaussian"-like distributions

A. Shishlo, A. Aleksandrov, Phys. Rev. ST Accel. and Beams 16, 062801 (2013).

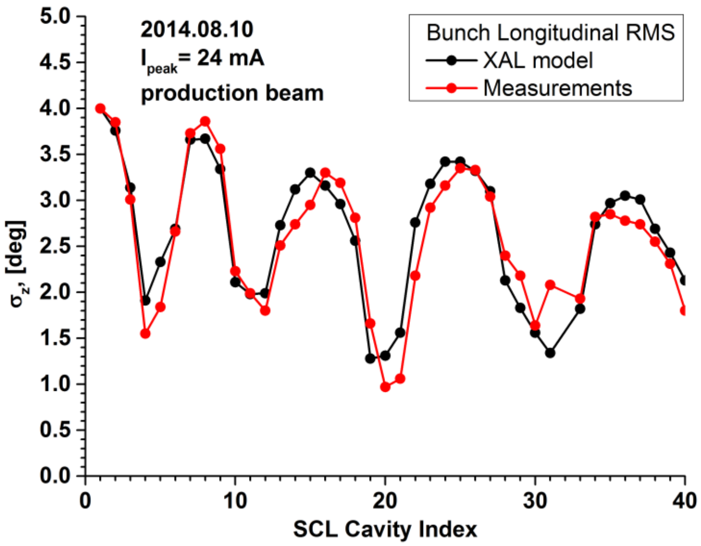
Results of “Z” Twiss Analysis





Year: 2013

Longitudinal Twiss
Peak current 7 mA

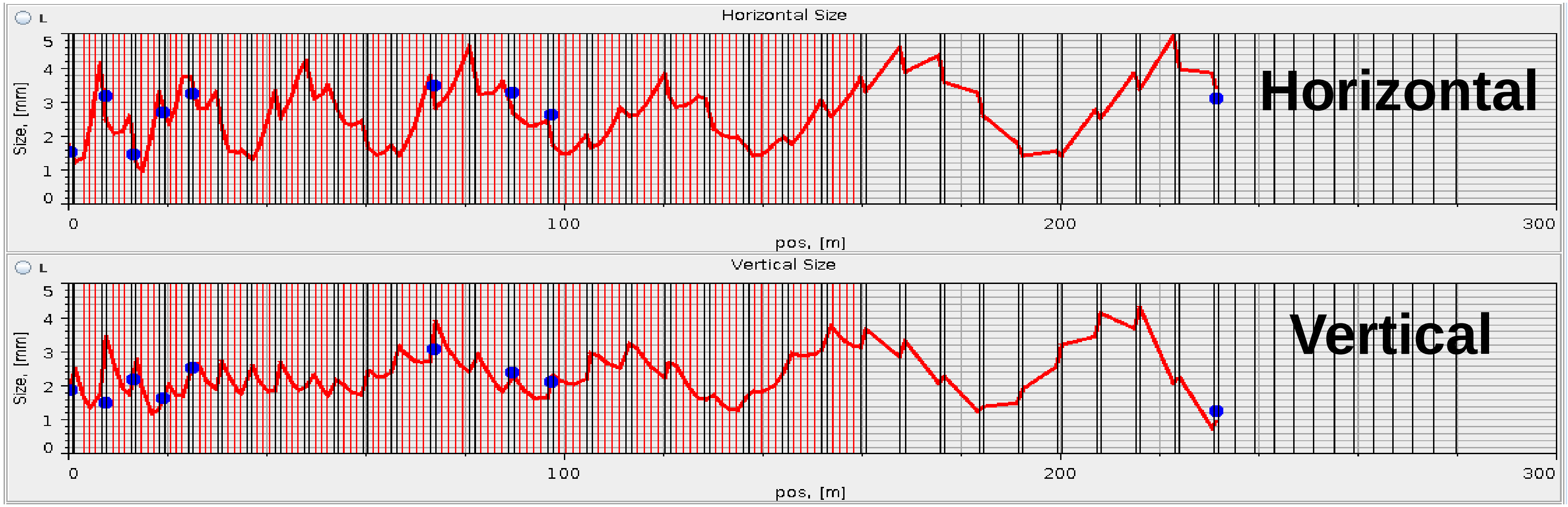


2014.08.10

Longitudinal beam size
Peak current 24 mA
Production beam

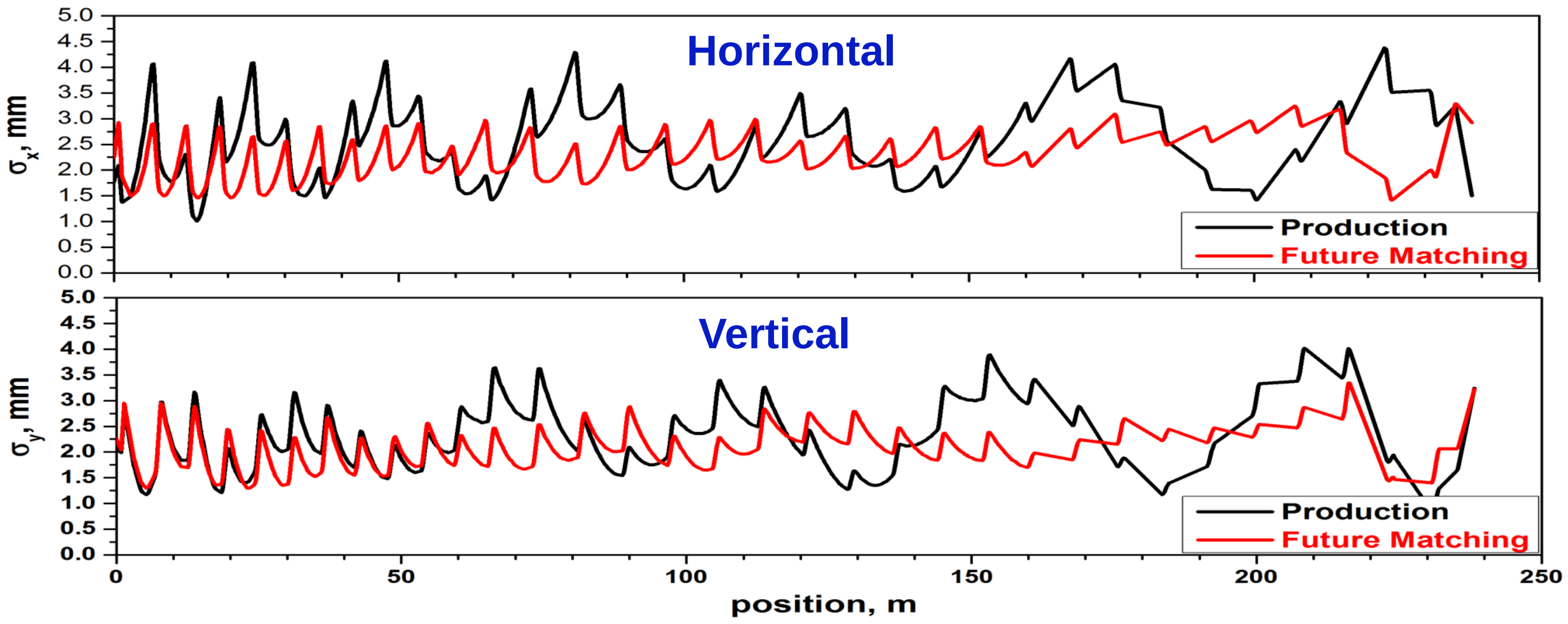
- Beam un-matched longitudinally
- Agreement is good even with space charge presence.

Transverse Twiss Analysis Results



- Peak current is 38 mA. The space charge is strong.
- Analysis was performed based on 8 LW stations measurements
- Procedure takes about 20 min
- RMS sizes calculated from the LW profiles
- XAL online model was used (beam envelop tracking)
- The amplitudes and phases of the SCL RF cavities determined by the SCL RF phase scans

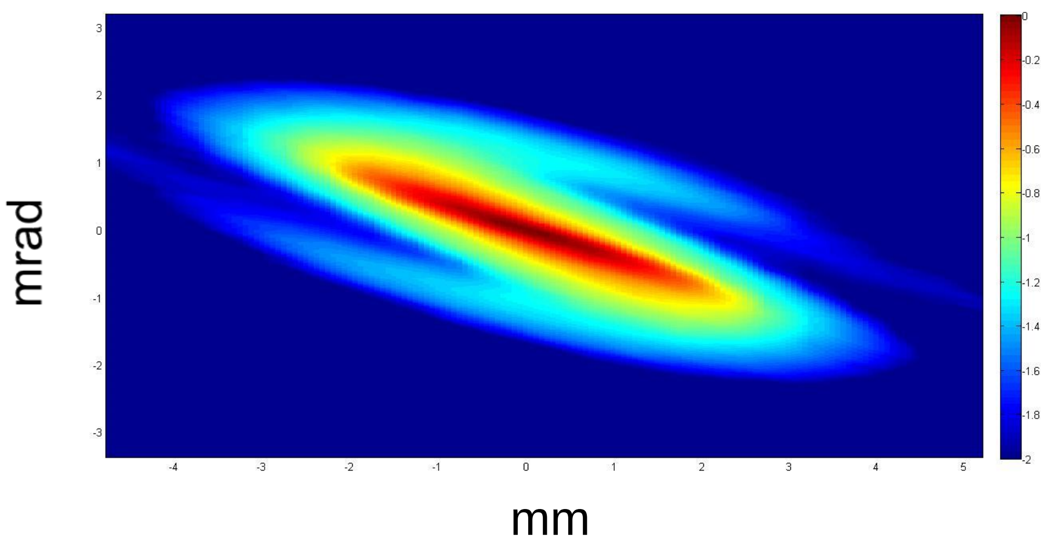
What We Want to Get



- Measurements show highly mismatched beam
- Is this necessary to achieve lowest beam loss?
- Model-based tuning is now possible, may be able to further reduce beam loss

Model Based Tuning

- All previous attempts at SCL beam matching failed. Possible causes include:
  - Unknown or wrong RF settings for the model
  - Unknown longitudinal Twiss
- We are finishing the integrated application to measure and to analyze the RF setting and initial Twiss
- The matching part is under development.
- We are going to do matching based on RMS sizes, but beam loss is defined not only by core through IBSt. The halo matching is different from the core matching.
- We have to pay attention to the warm linac tuning to reduce or to eliminate non-Gaussian tails.

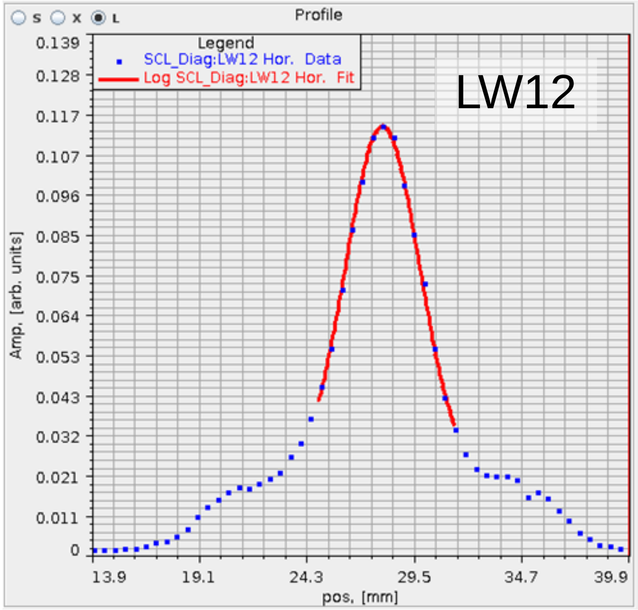


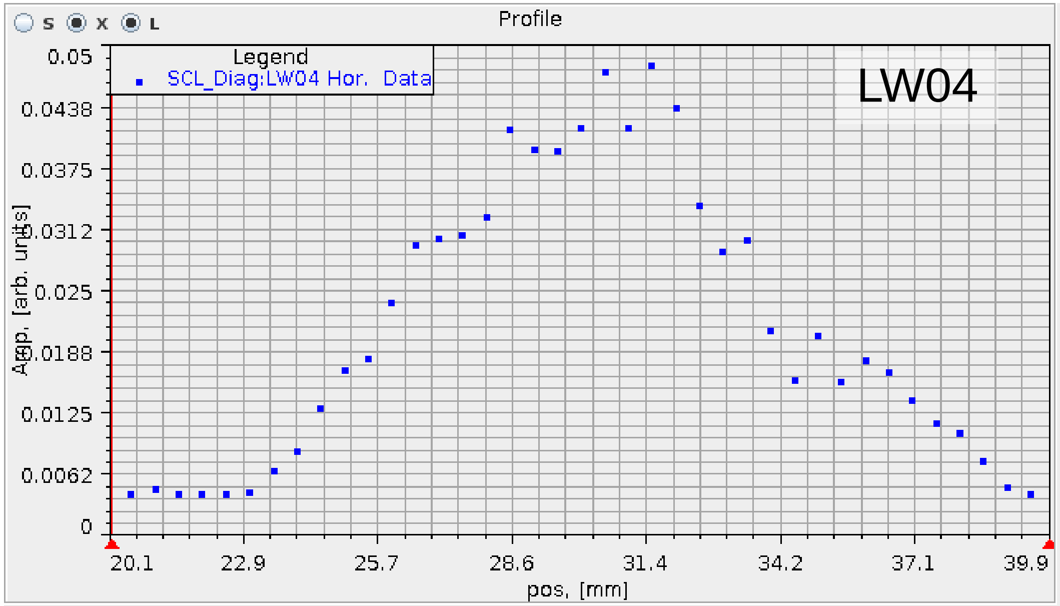
X-X' Phases Space Density After SNS SCL. Spring 2014.

Color scale is logarithmic from .01 to 1

(courtesy of A. Aleksandrov)

Laser Wire Profiles





- Some distributions have big tails. These tails start to show up far upstream in DTL and CCL.
- Similar profile tails seen at JPARC were reduced by MEBT rebuncher tuning.
- Some are asymmetrical, some are noisy
- It is difficult to estimate errors in RMS size calculations

Conclusions and Future Plans

- The SCL RF phase tuning procedures were improved
  - The accuracy of the phase setting were analyzed
  - The tuning time of 81 SCL cavities was reduced to 20 min (was ~8 hours by hand)
- An integrated application for the 3D initial Twiss measurement has been developed
- The tuning of warm linac should be understood and should be improved to reduce tails of transverse profiles
- The matching part of this application is under development

Acknowledgement

- Most of the work presented was done by Andrei Shishlo

Thank you for your attention!