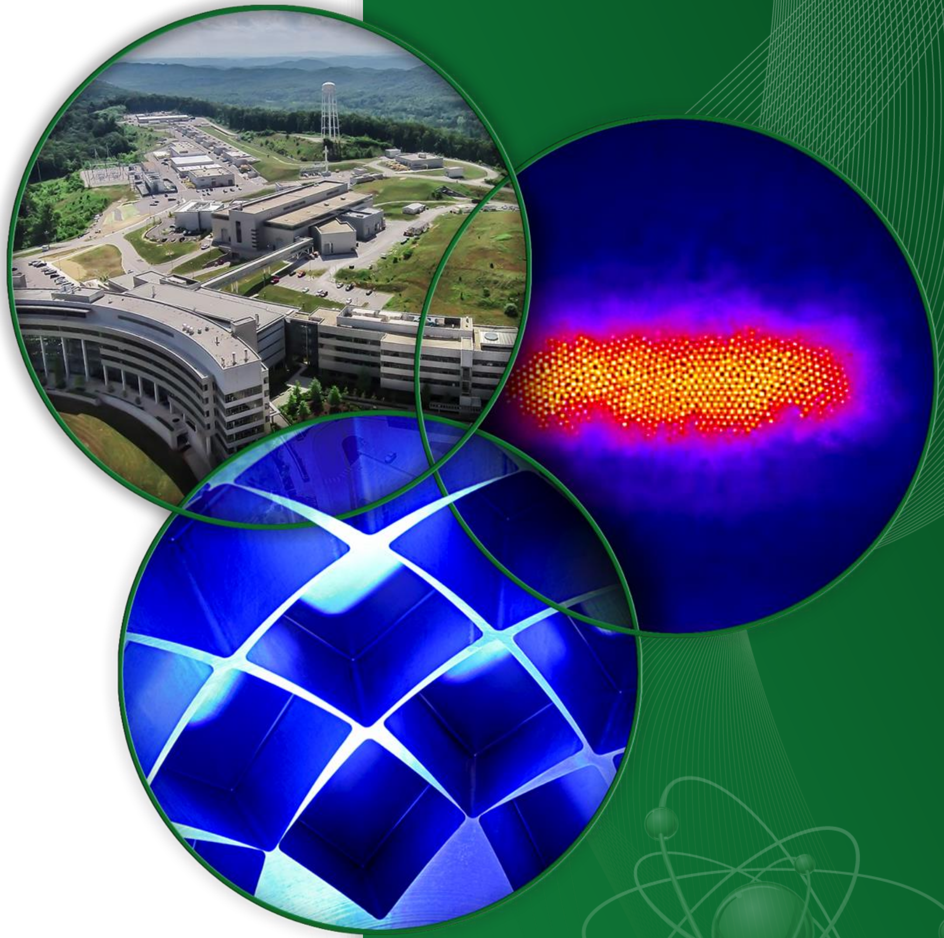
New Linac Tuning Algorithms and Setup Automation



AAC, March 16, 2015

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Warm Linac Manager

ORNL is managed by UT-Battelle
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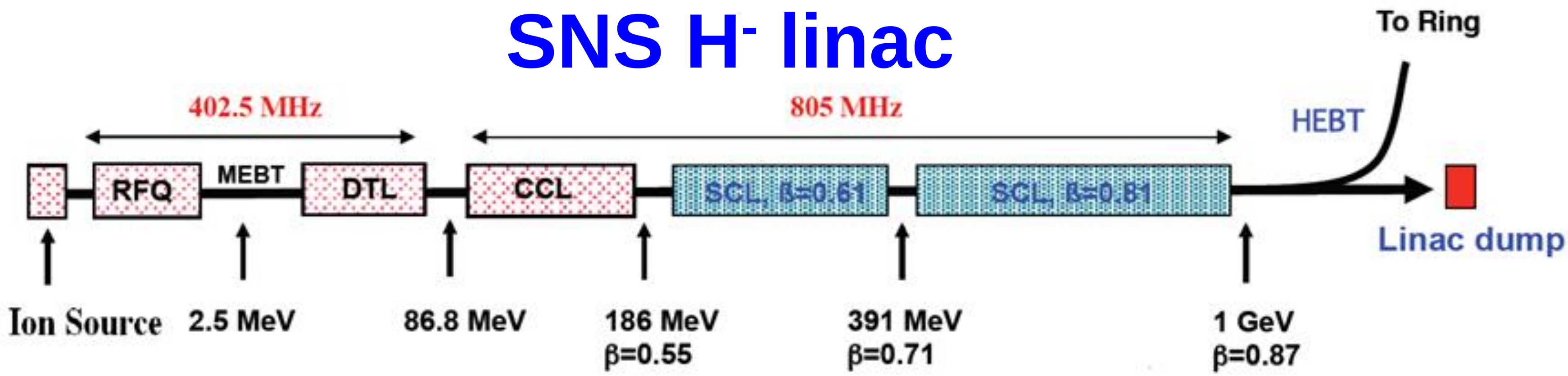
Oak Ridge National Laboratory | Spallation Neutron Source

Outline

- Rationale for the automation
- Warm linac setup
  - MEBT
  - DTL1
  - DTL2-CCL4
- Superconducting Linac Setup
- Conclusions

SNS Linac Structure



Length: 330 m (Superconducting part 230 m)

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

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

Rationale

- I will talk only about RF parameters (amplitudes and phases) setup procedures. The magnets parameters usually are the same from the previous setup.
- In the recent past, the SNS linac RF setup usually took:
  – Warm linac (14 cavities) - from 4 to 6 hours
  – SCL linac (81 cavities) – from 6 – 8 hours
- Problems:
  – Setup procedure need a constant attention. Stress level is high
  – Human errors are very likely
  – Accuracy and repeatability were unknown
  – Different setups studies are prohibitively time consuming
  – In a case of some equipment replacement the fast retune is needed
- Solution: automation

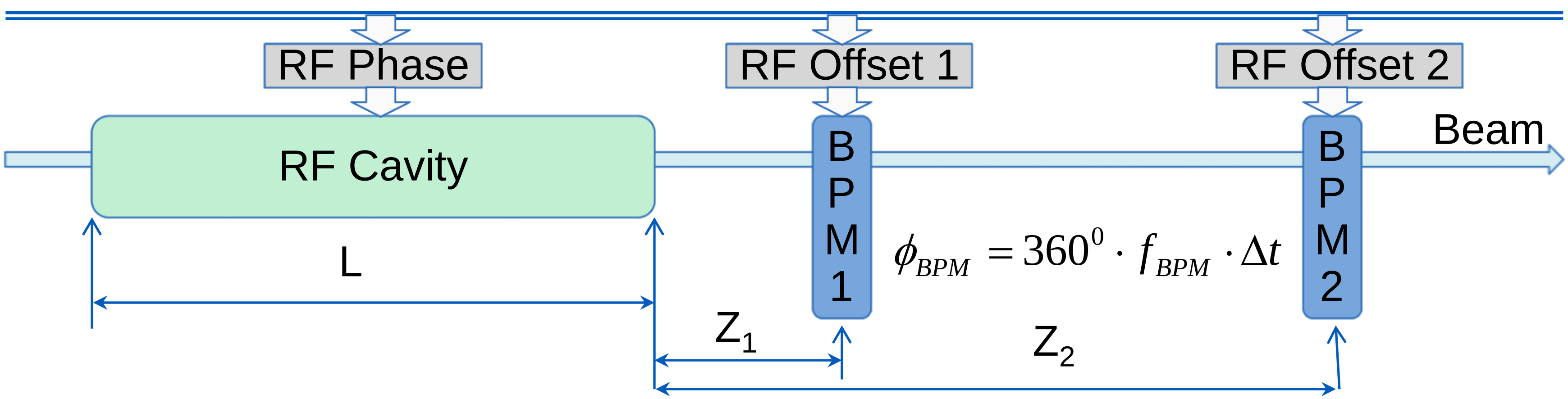
SNS Linac RF Setup Algorithms

- **Different Algorithms:**
  - MEBT – RF rebunchers are single RF gap cavities
  - DTL1 – does not have BPMs inside the tube
  - DTL2 – CCL4 – have inner BPMs
  - SCL – 81 cavities have 6 RF gaps each

- **XAL Applications:**
  - Warm Linac Setup Wizard
  - SCL Setup Wizard

All algorithms are based on BPMs' signals

The Measurement Technics

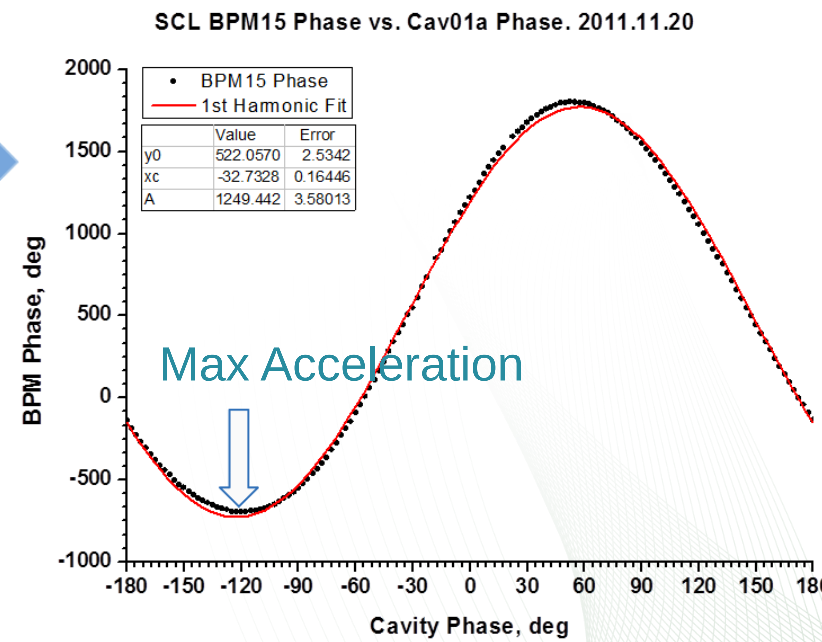


By using the BPMs phase signals we have to set the cavity's phase and amplitude according to the design.

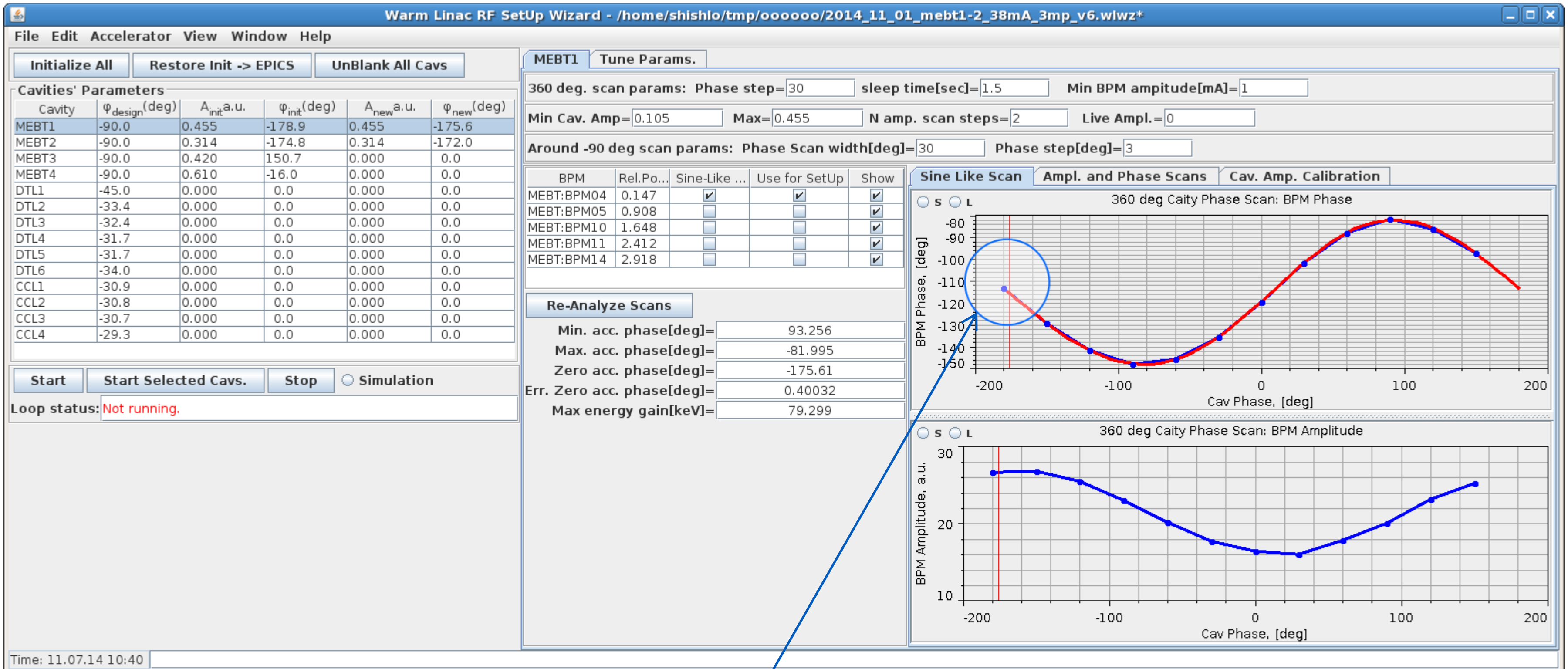
A short cavity example:

"Sine"-like shape of BPM's phase vs cavity phase

For a cavity with many RF gaps this dependency is more complex.



MEBT Rebunchers Tuning (1st Step)



Region of interest

- Two step tuning
- First step: full 360^0 scan and a “sine”-wave analysis. It gives us an approximate position of a “zero-acceleration” phase
- Second step: amplitude and phase scans around the guess phase

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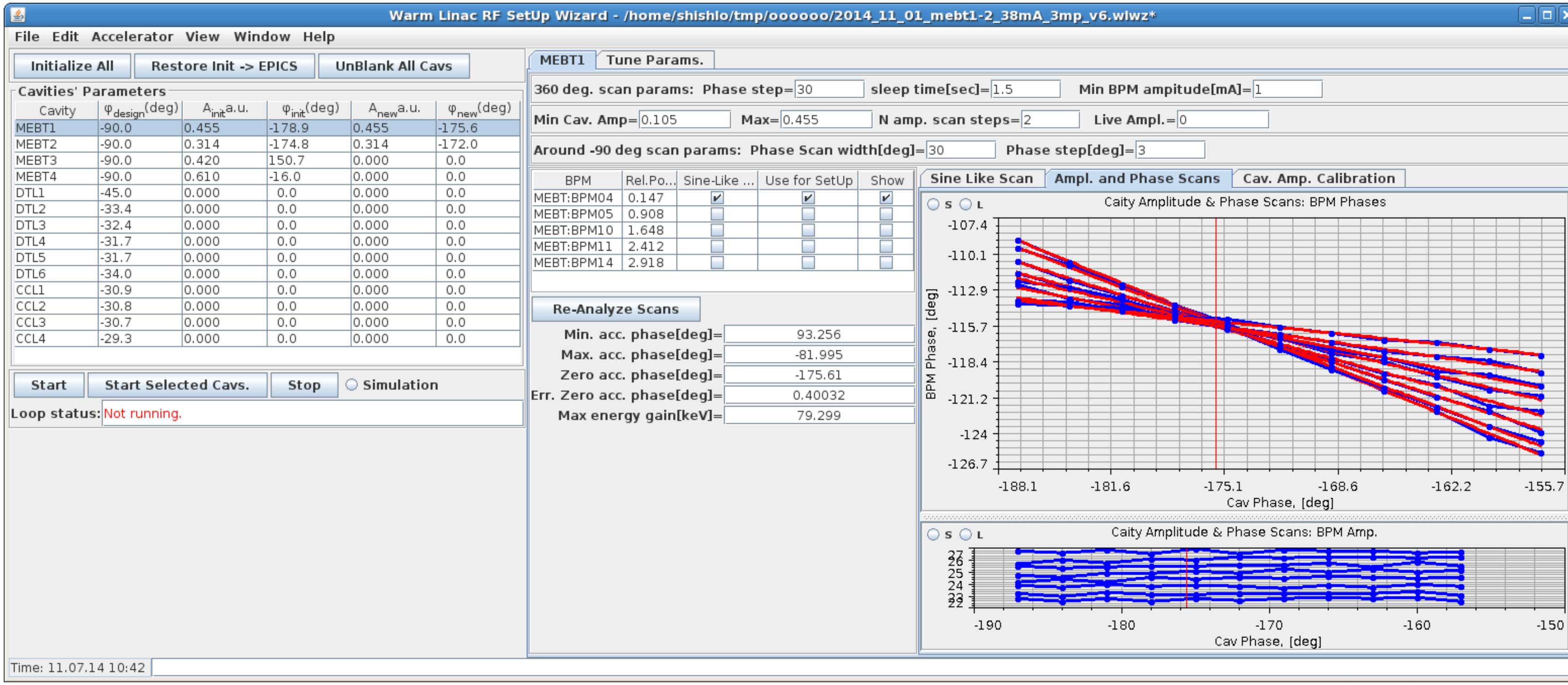
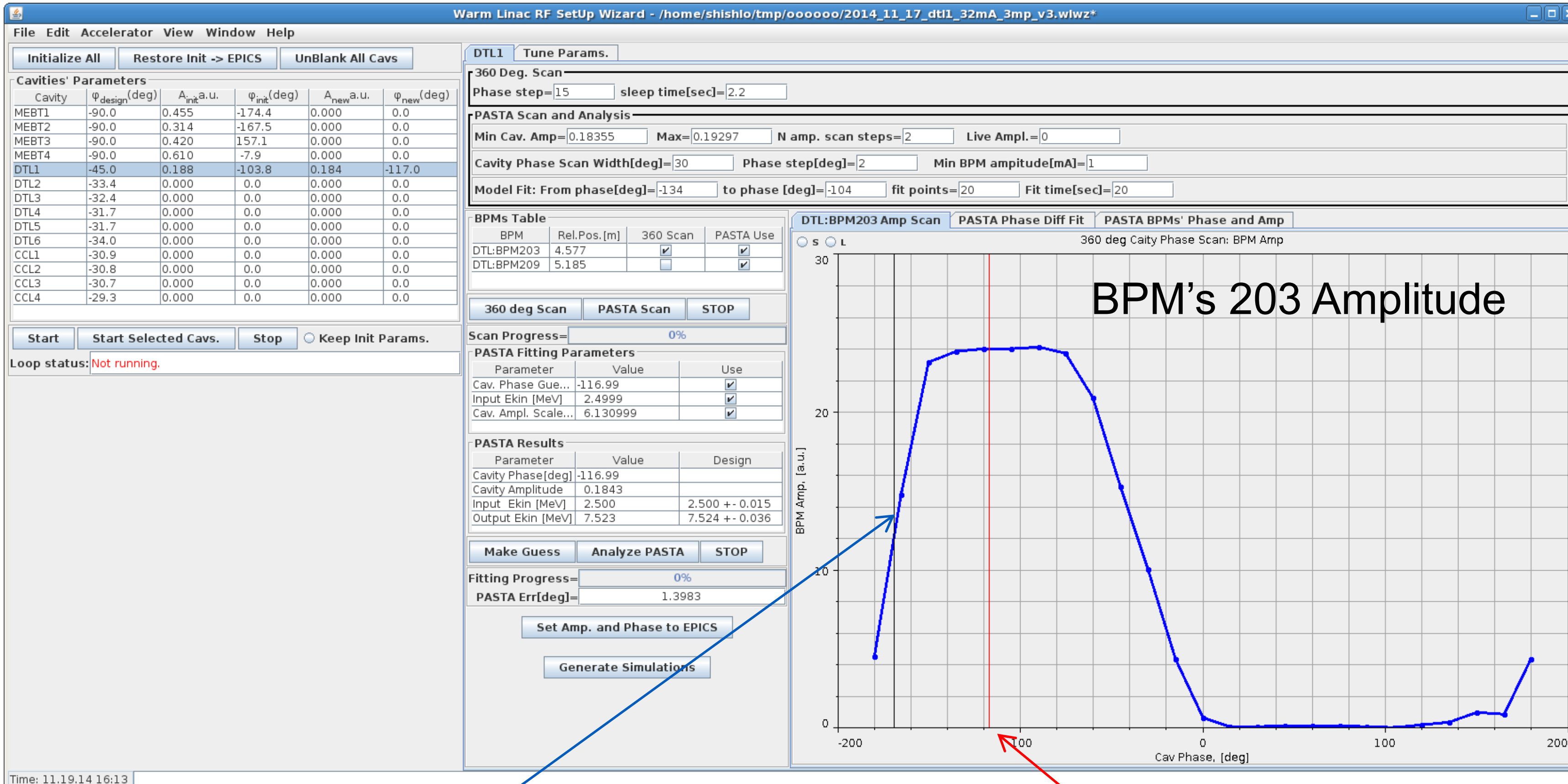
MEBT Rebunchers Tuning (2st Step)



- The “crossing point” search algorithms improved (linear fits first)
- The slope gives us the absolute value of the maximal energy gain in the cavity
- The user can choose the BPM for this step
- The known problem: different BPM gives different results (10-15 deg)

DTL1 Tuning. Warm Linac Wizard 360^0 Scan (1^{st} Step)



Half-height front position

A guess for cavity phase

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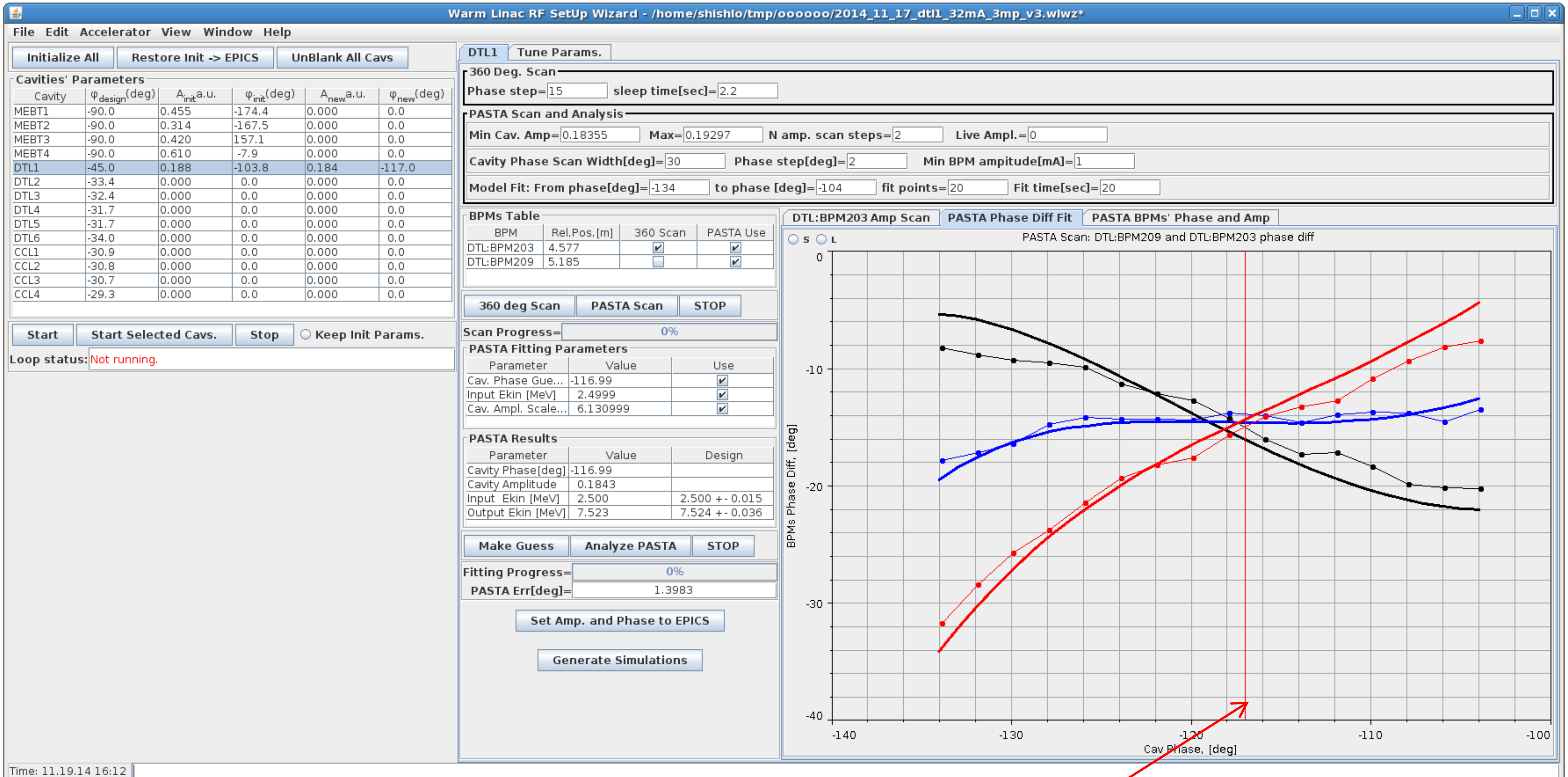
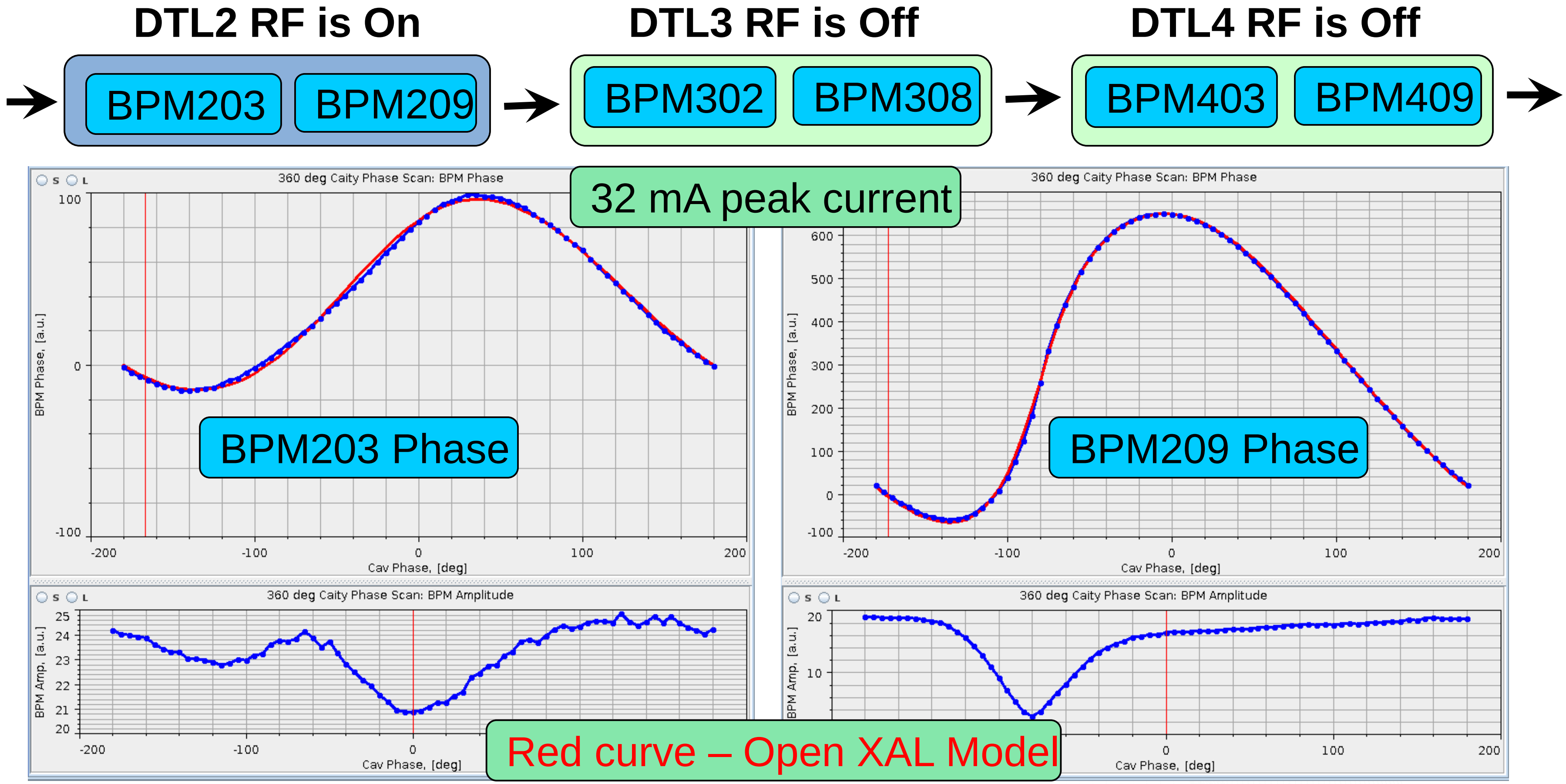
DTL1 Tuning. Warm Linac Wizard PASTA Scan (2nd Step)



Found cavity phase

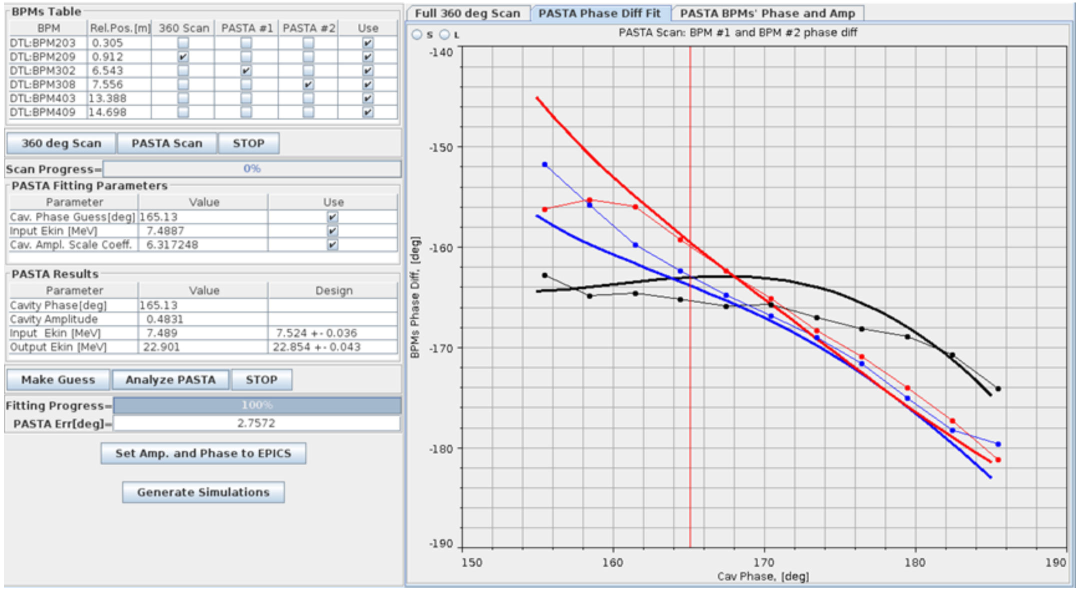
PASTA – Phase and Amplitude Scan and Tuning Algorithm (Fermilab -> Galambos, XAL)

DTL2-CCL4 Tune Up Method (1^{st} Step)



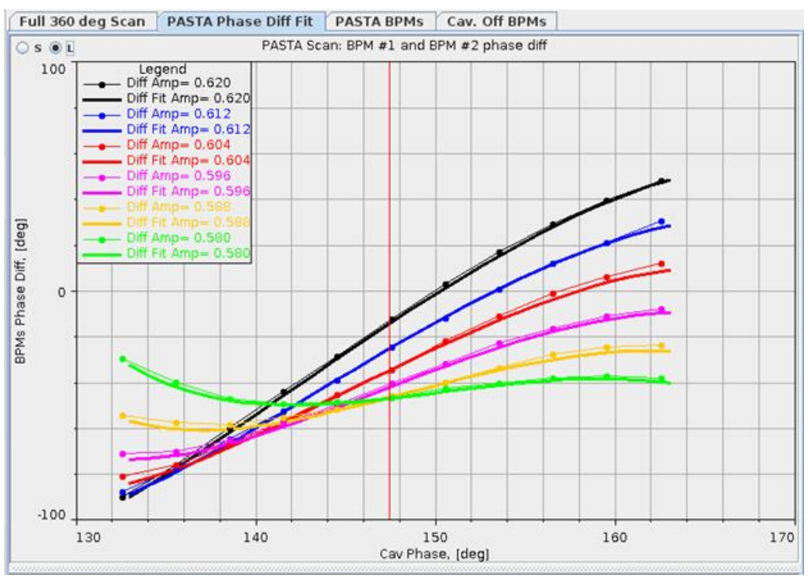
- **Two step tuning**
- **First step: full 360^0 scan and a model-based analysis for BPMs inside the cavity. It gives us a guess for the cavity phase**
- **Second step: traditional PASTA scan and analysis**

DTL2-CCL4 Method (2^{st} Step - PASTA)



DTL2

The agreement is different for different cavities



DTL4

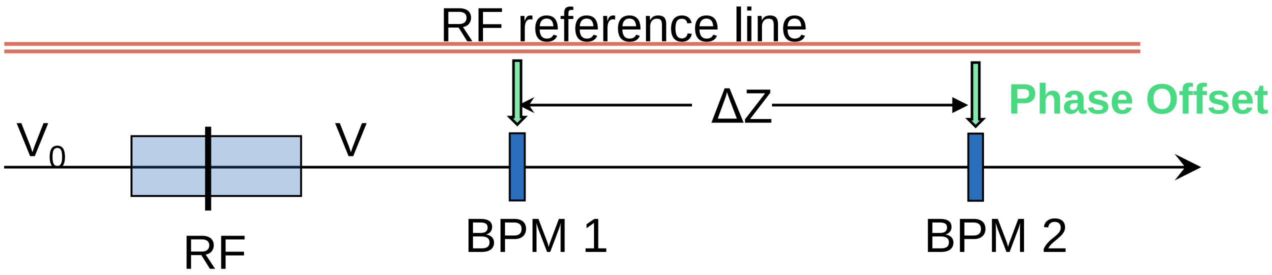
Warm Linac Tuning Experience

- 1st test in December 2014
- MEBT scans give different results for different BPMs. They are not very stable. Cavities' phases can move about +-10 degrees at the MEBT4.
- DTL1-CCL4 scans are repeatable within a few degrees for phases and less than 1% in amplitudes.
- For some cavities the model (XAL) - measurements agreement is not perfect. The fields in these cavities could be different from the model.
- The setup time was 56 minutes (vs. 8 hours) without human intervention.

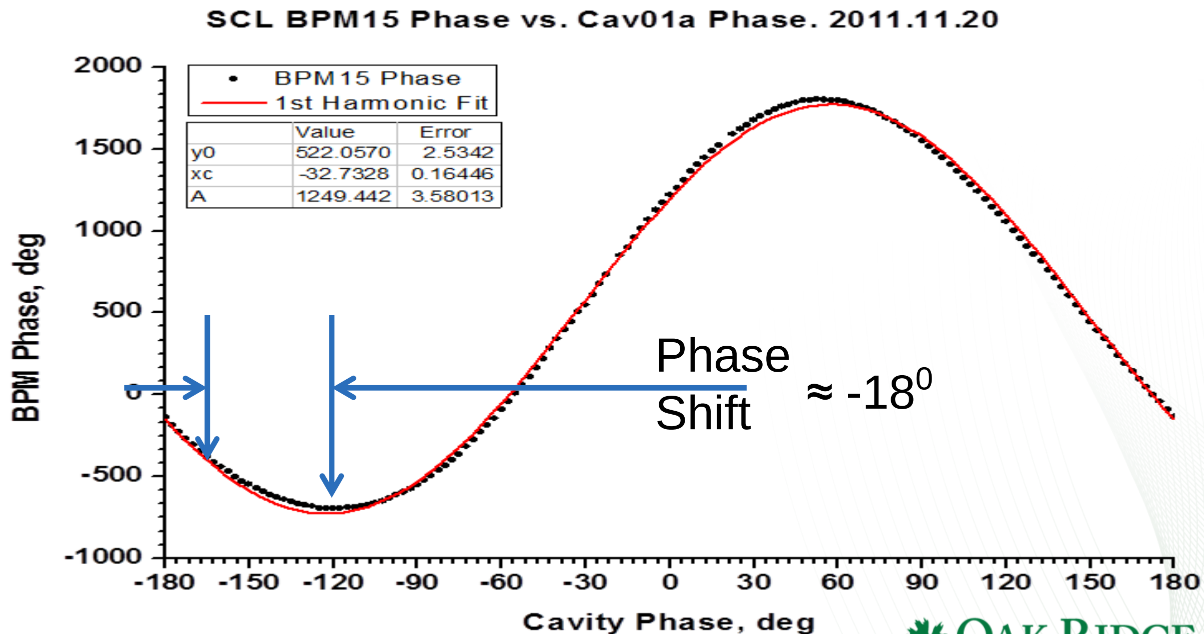
SNS SCL Setup Procedures

- Setup Procedures for SCL Linac:
  - RF Cavities Scans (1st Step):
    - Amplitudes are fixed.
    - Synchronous phase for all SCL cavities are -18^0 .
    - Phases are setup by phase scans
  - RF Cavities Analysis of Scans (2nd Step):
    - Perform the timing calibration of all BPMs (using ring). After that we know the energies everywhere.
    - Find the parameters of the model for all SCL cavities for a possible future scaling.
  - Quads - setup field gradients (historic data + empirical loss reduction)
  - The final step includes tweaking the warm linac parameters

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



BPM Timing Calibration: Phase Offsets

index	BPM	Position , [m]	Phase Offset, Deg	Err., Deg
1	SCL_Diag:BPM23	93.691	34.69	0.28
2	SCL_Diag:BPM24	101.579	33.26	0.26
3	SCL_Diag:BPM25	109.47	26.45	0.29
4	SCL_Diag:BPM26	117.366	30	0.2
5	SCL_Diag:BPM27	125.253	-150.98	0.21
6	SCL_Diag:BPM29	141.038	-170.8	0.17
7	SCL_Diag:BPM30	148.928	-170.28	0.15
8	SCL_Diag:BPM31	156.817	9.62	0.11
9	SCL_Diag:BPM32	164.71	8.57	0.1
10	HEBT_Diag:BPM01	172.545	-45.15	0.18
11	HEBT_Diag:BPM02	176.545	-43.77	0.15
12	HEBT_Diag:BPM03	180.545	-5.88	0.13
13	HEBT_Diag:BPM04	184.545	-8.01	0.19
14	HEBT_Diag:BPM05	188.545	0	0
15	HEBT_Diag:BPM06	192.545	-0.5	0.17
16	HEBT_Diag:BPM07	196.545	31.78	0.15
17	HEBT_Diag:BPM08	200.545	34.88	0.18
18	HEBT_Diag:BPM10	208.545	-150.83	0.19
19	HEBT_Diag:BPM11	212.543	24.09	0.22

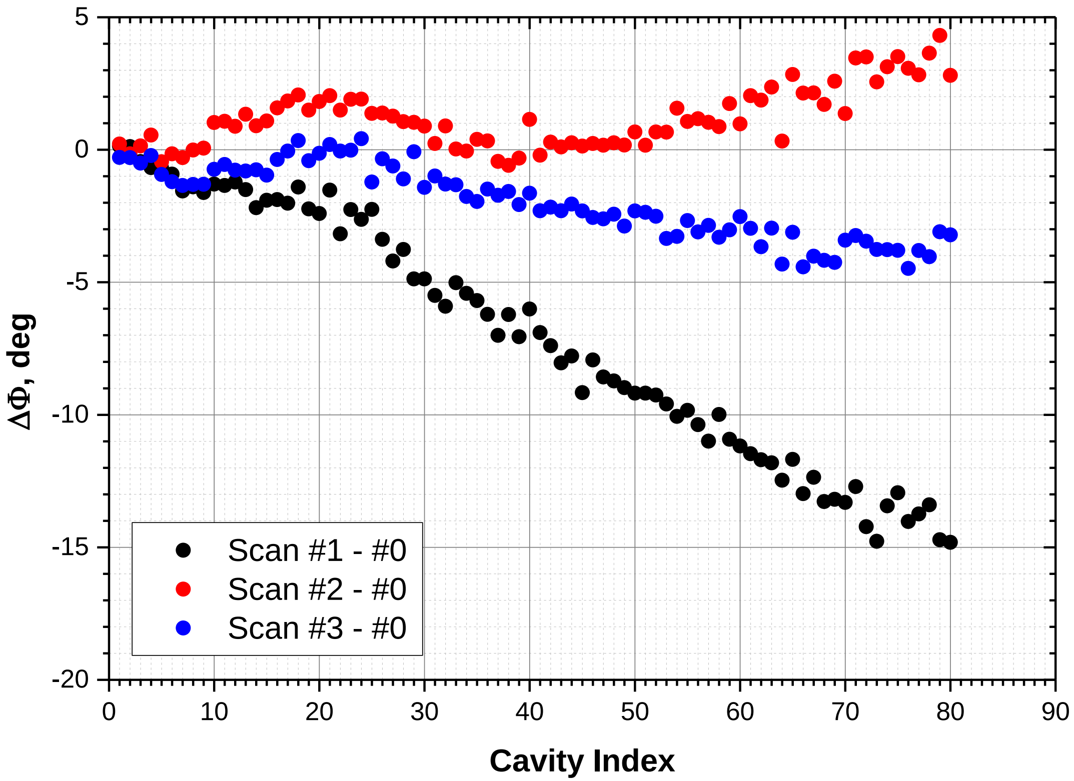
We can clearly see several groups of BPMs. After calibration the energy measurement accuracy is about 50 keV.

The SCL Automated Tuning Experience

- **Now it takes 32 minutes instead of 6-8 hours.**
- **Can analyze the existing settings.**
- **The data can be used to extract longitudinal Twiss parameters at the entrance of the each cavity.**
- **The stability of the scan results can be checked.**

On the next slides we will discuss some results.

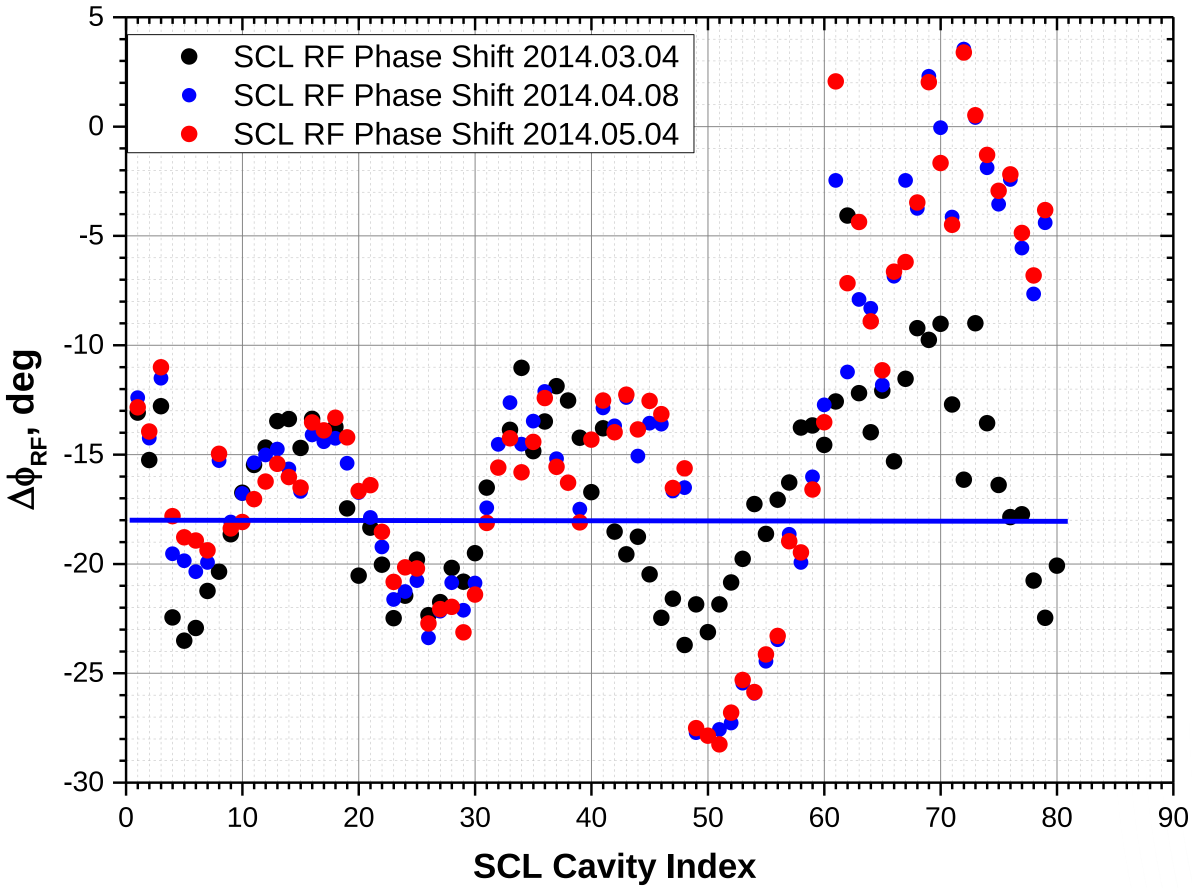
"Scan to Scan" Stability



- **4 back-to-back scans 0-1-2-3**
- **All results are different**
- **No differences in beam loss**
- **All are a good start for tuning**

- ❑ **We do not know the cause yet.**
- ❑ **Based on the time scale, we believe that it is related to the tunnel temperature oscillation.**
- ❑ **The effect has zero effect on our tuning strategy.**

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



The SNS Linac was tuned up in Feb. 2014.

Phase shifts -18^{0} for all SCL RF cavities.

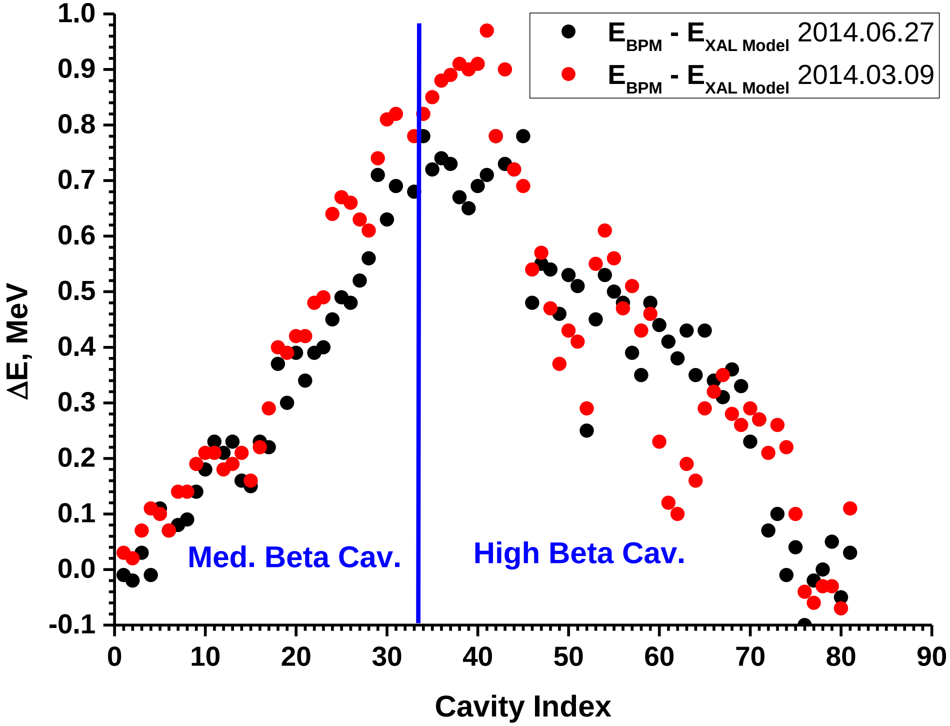
On the left are the measured production synchronous phases.

We are far from design.

Beam loss is good.

Clearly, there is a structure.

Energy Tracking: XAL Model vs. BPM

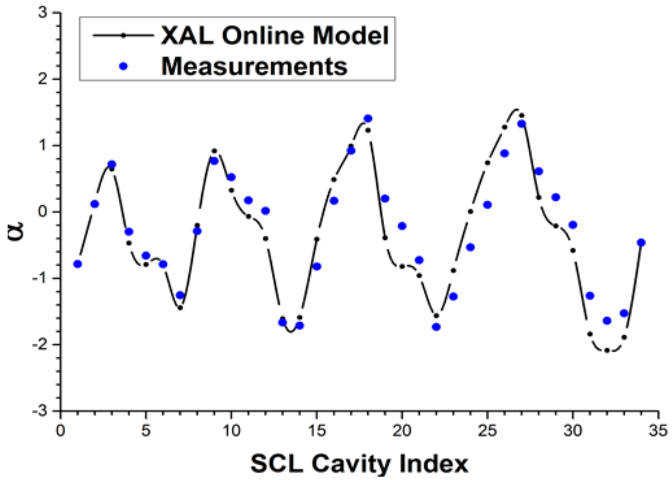


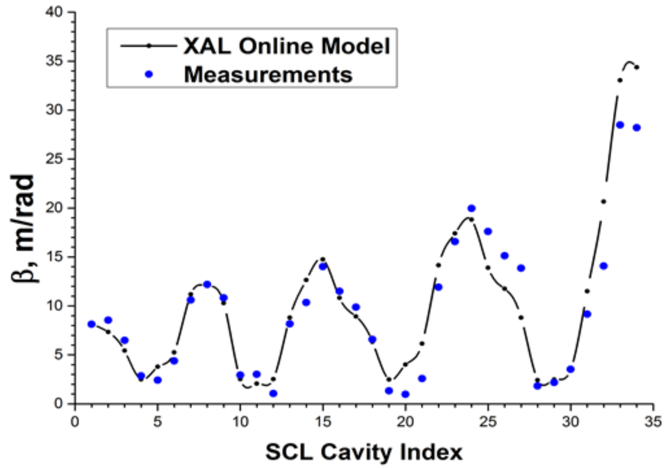
- Model parameters of each RF cavity are from scan data
- After that they all combined into one lattice
- Track energy through this lattice
- Compare to the BPMs data

May be our XAL model for cavities is not perfect, and we have to pay attention.

That is experiment results vs. one particle model tracking!
A good case for the code benchmark!

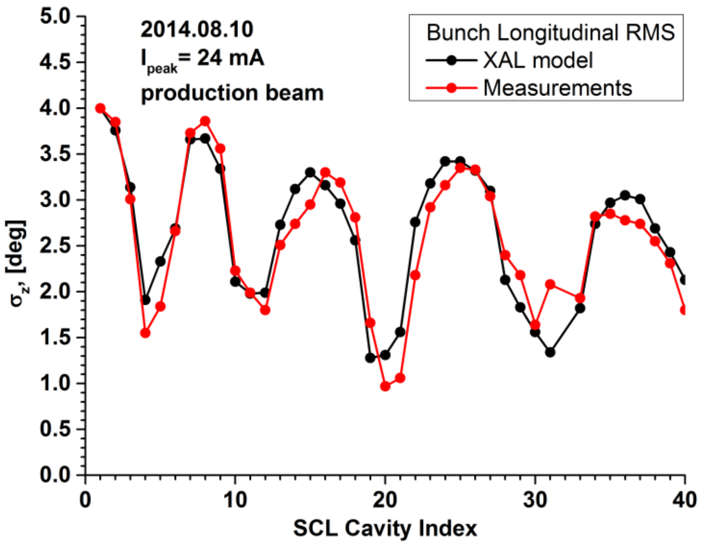
Results of "Z" Twiss Analysis





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.

Conclusions

- The total RF setup time for the SNS linac was reduced to about 1.5 hour (2 buttons setup).
- The exposure of the SCL part to beam loss was significantly reduced.
- The setup procedures still need a human attention during the automated scans and analysis, but the stress level is reduced significantly.
- The procedures now are well defined and formalized.
- All results can be easily saved and reviewed offline.