CONTROL ROOM ACCELERATOR PHYSICS

Day 4

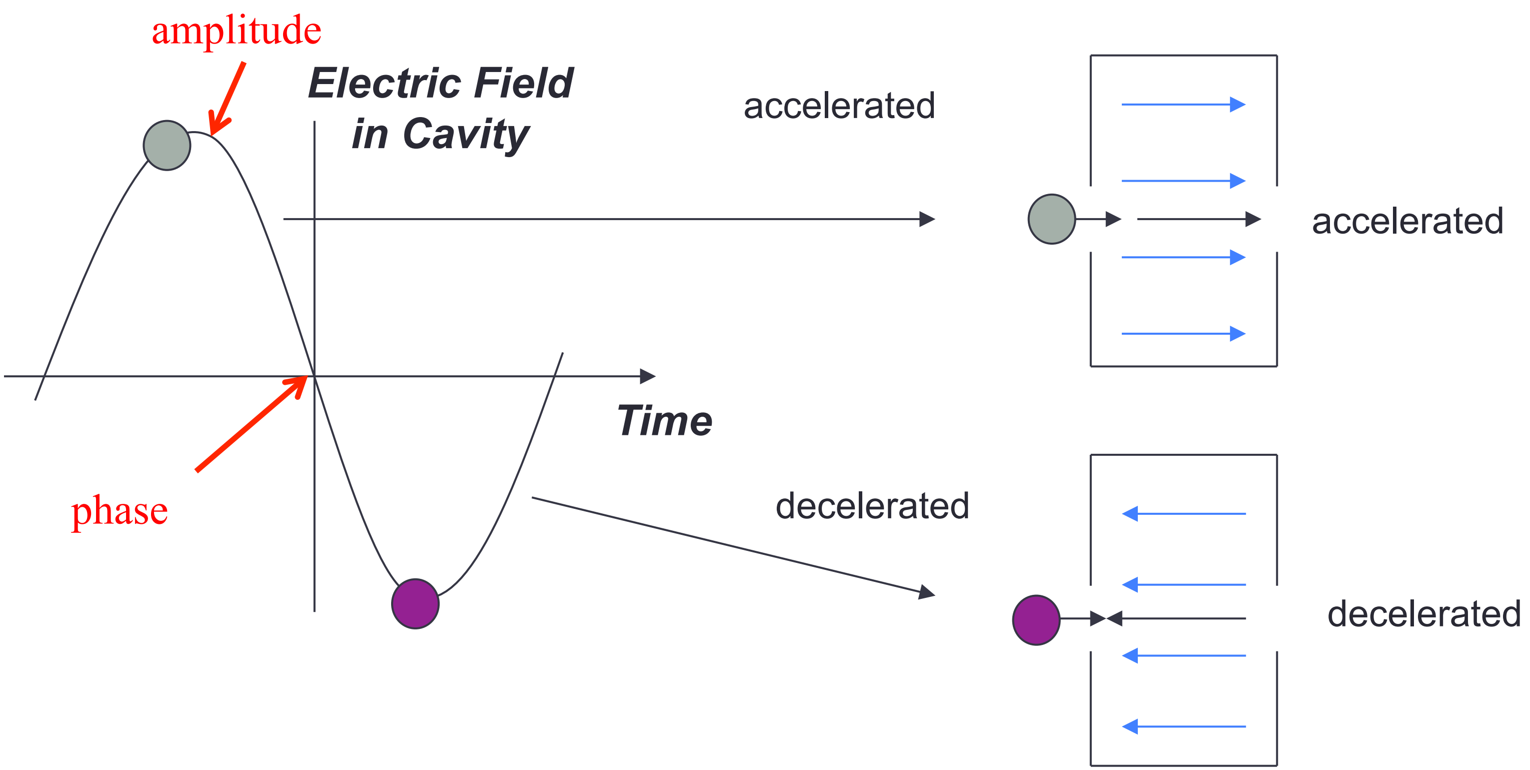
RF Applications - Setting RF With Respect to the Beam

Introduction

Radio Frequency (RF) Acceleration

RF electromagnetic (EM) fields are the primary means of acceleration for particle accelerators

- Time oscillating electric fields in a resonant structure
- Must set the RF phase to within 1-2 degrees (few x 10^{-12} sec)
- Need to set the EM field amplitude to correct value also, complicated by cavity cooling



Motivation

- Objective: Set the phase and amplitude of an accelerating cavity so that it performs according to design

- We decide to build an application to satisfy this objective
  - (and automate it?)

  - (Model the acceleration process)
  - Devise a strategy for determining the proper RF phase and amplitude
  - Design a control room application based upon the strategy
  - Implement the application according to the design
  - Test the application
  - Support and maintain the application

Radio Frequency Acceleration

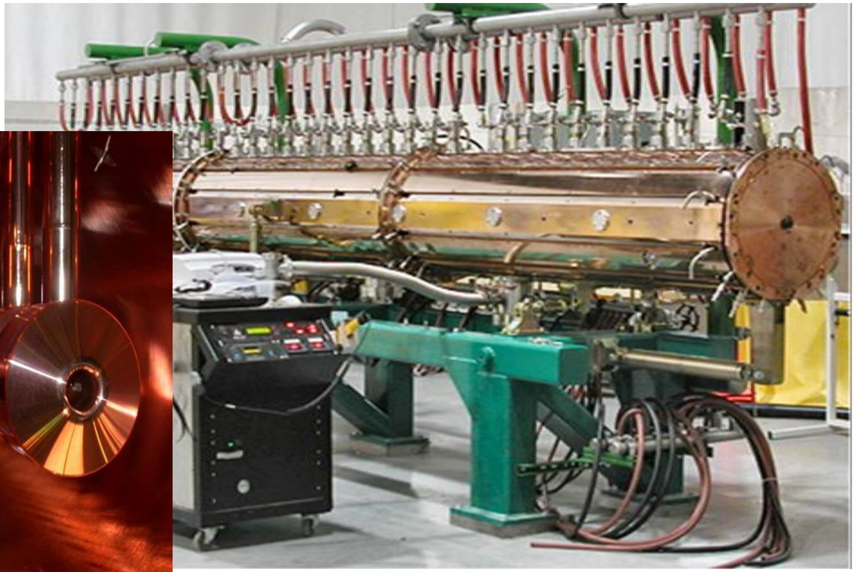
Cavity Types

- Often RF structures have multiple accelerating cells, providing multiple instances for particle acceleration (if things are timed properly)
- In Open XAL there is a cavity device type which may contain multiple cells
- The Open XAL convention is that the cavity phase is the phase of the RF field relative to the synchronous beam particle in the first gap of the cavity
- The average phase of the beam throughout all the cavities can be quite different for low energy particles

Radio Frequency Acceleration

Cavity Types

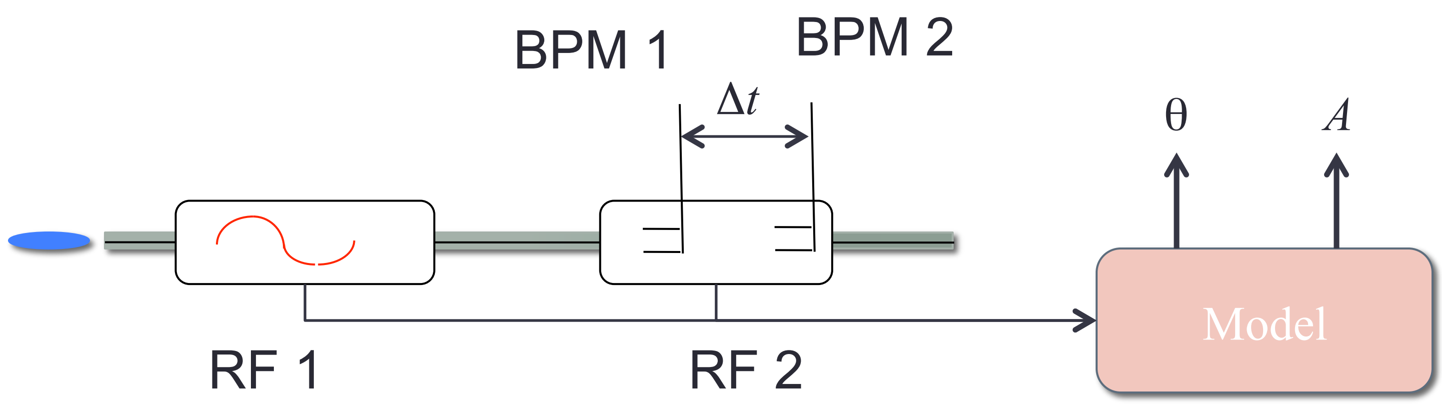
- Drift Tube Linac (DTL) – many cells per cavity (typically 50-100)
  - Used at low energy, β changes rapidly throughout the structure
  - Need to have phase/amplitude nearly correct to transmit beam
- Superconducting Cavity – fewer cells per cavity (say ~ 6)
  - Used at higher energy, β changes only slightly throughout the structure
  - Less sensitive to RF variations



RF Applications
Phase Matching

Must determine the proper RF phase and amplitude for a cavity

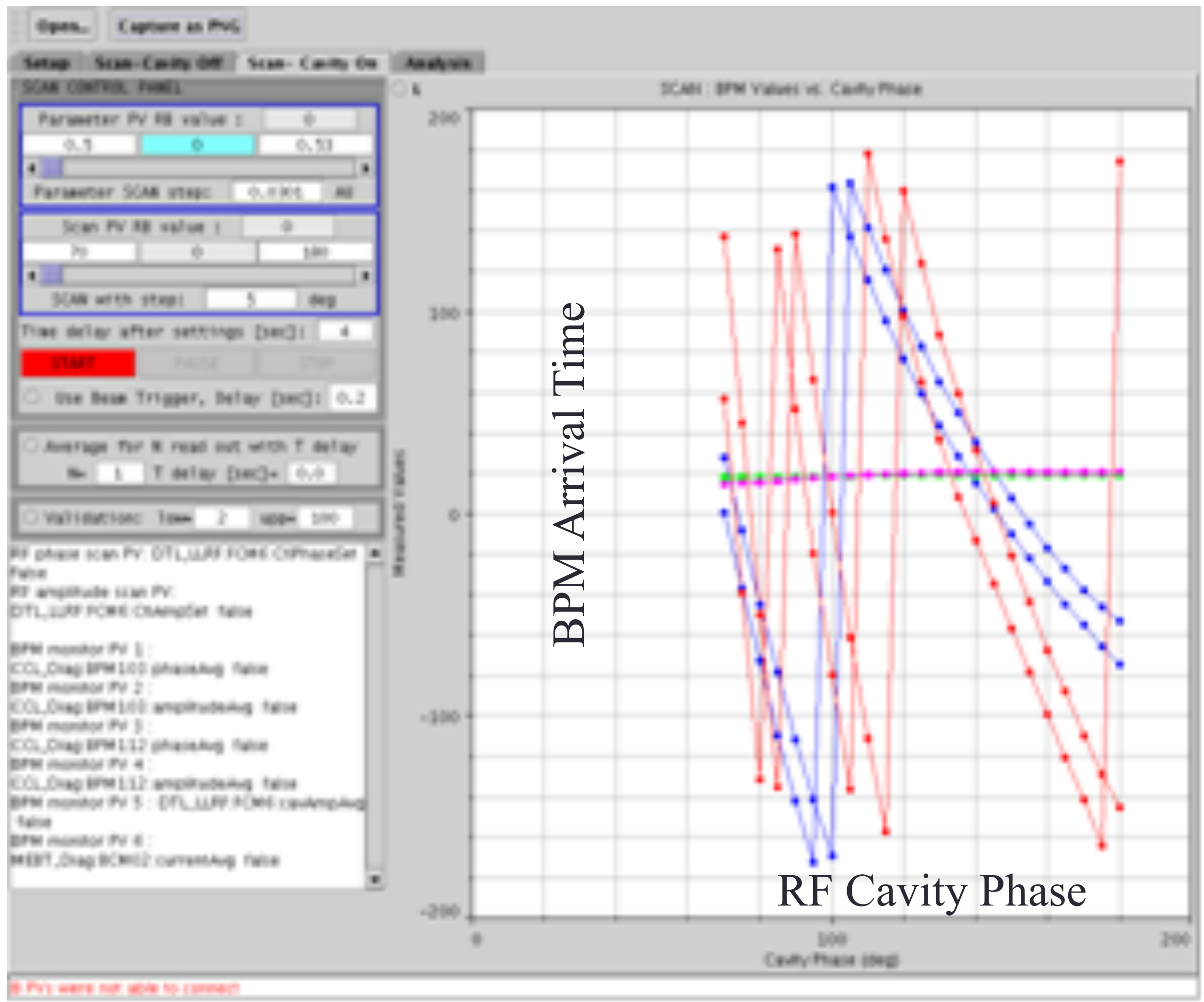
- A technique for proton beams is the RF phase scan (signature matching)
  - Use the beam to measure cavity phase and amplitude offset
  - Vary the phase and amplitude of an upstream RF cavity
  - Measure the response of the arrival time at downstream BPMs
  - Use a model to calculate the amplitude and phase offset of the RF generating device



RF Applications

PASTA: An XAL DTL Phase Scan Application

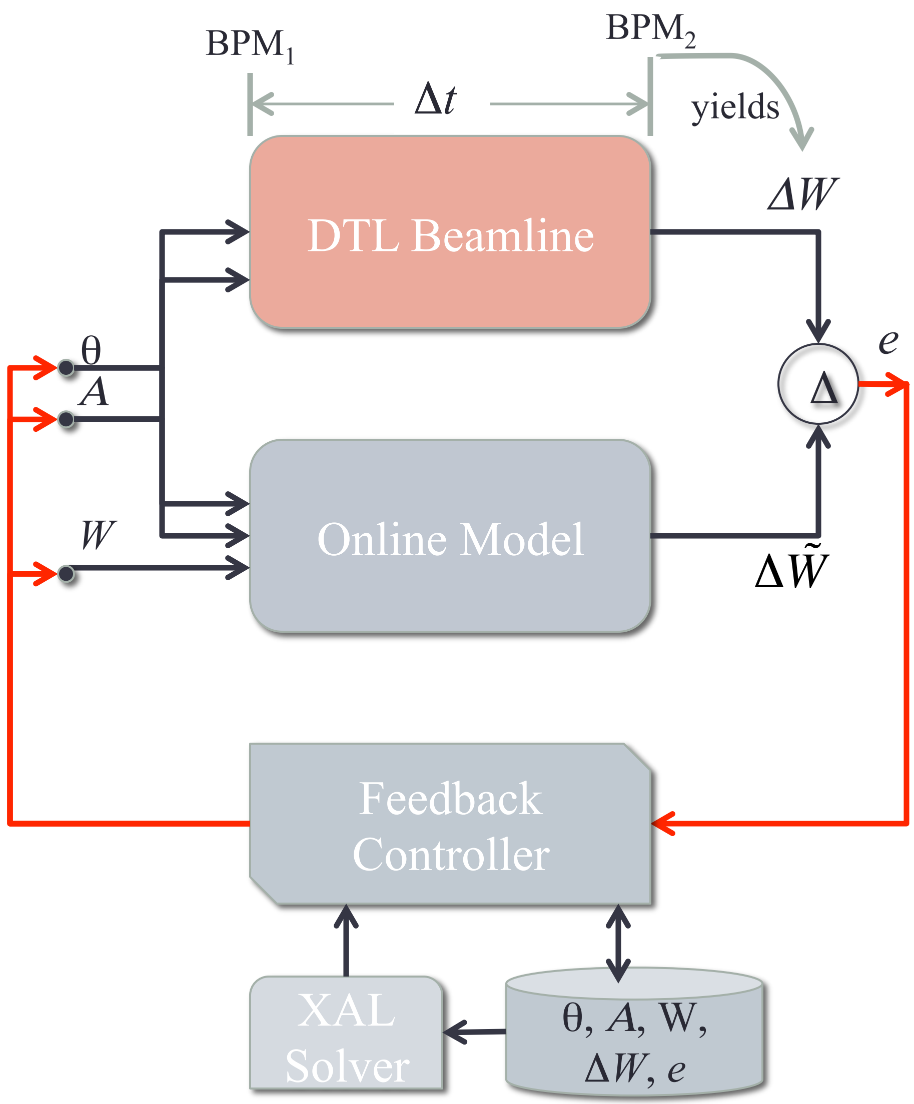
- Scan phase of DTL Tank for 2 amplitude values
- Measure the arrival time $\Delta t(\theta)$ at 2 downstream BPMs (red and blue)
- Uses the scan/measure tool in XAL
- Hard to interpret at this point



RF Applications

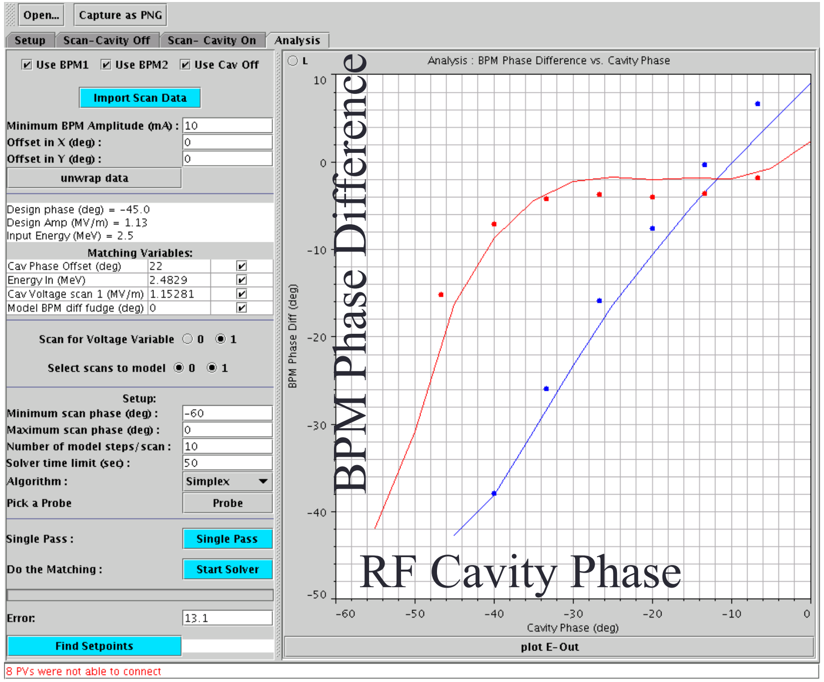
PASTA: Model Reference Control (MRC)

- The Δt Measurement
  - Using arrival time difference Δt between two BPMs eliminates position uncertainties RF cavity
  - The time difference Δt can be converted to an energy difference ΔW
- Model Reference
  - The model can accurately predict the observed behavior for correct input beam energy W, RF amplitude A, and phase θ
  - Design the MRC algorithm to find (W,A,θ)
- The model reference provides an estimator and error signal to do feedback control
  - The controller searches the parameter space (A,θ) to minimize e and adapts to parameter W since its value is unknown (adaptive control)
  - The controller uses the XAL Nonlinear Solver to search parameter space (W,A,θ)
- Steady state values of (W,A,θ) give the needed information to set the RF cavities
  - Error e is minimized, ΔW is maximized



RF Applications
PASTA: Accuracy of Application

- Application Graph
  - Lines are model, dots are measurements
  - Plots θ_{cav} versus $\Delta\theta_{RF} = \omega\Delta t$.
- Accuracy
  - RF Phase: ±1º
  - RF Amplitude: 1% of design
  - Input energy W: Estimate with unknown accuracy



RF Applications

RF Calibration Algorithm Critique

- NOTE:
  - Application PASTA is typically run in open loop, single iteration by the commissioner (feedback loop is the commissioner)
  - All data is collected first then the solver is used to "fit" model results to the data (this is a common strategy)

- Observations
  - The solver takes a few 10s of seconds to converge.
  - Small compared to setup time to perform the scan (all data taken *a priori*)

- Comments
  - Older techniques relied on linear approximations close to the design point
    - Fast, but required a good initial guess to converge
  - With modern computers, more general approaches are practical
  - Little application of control theory and automation

RF Applications

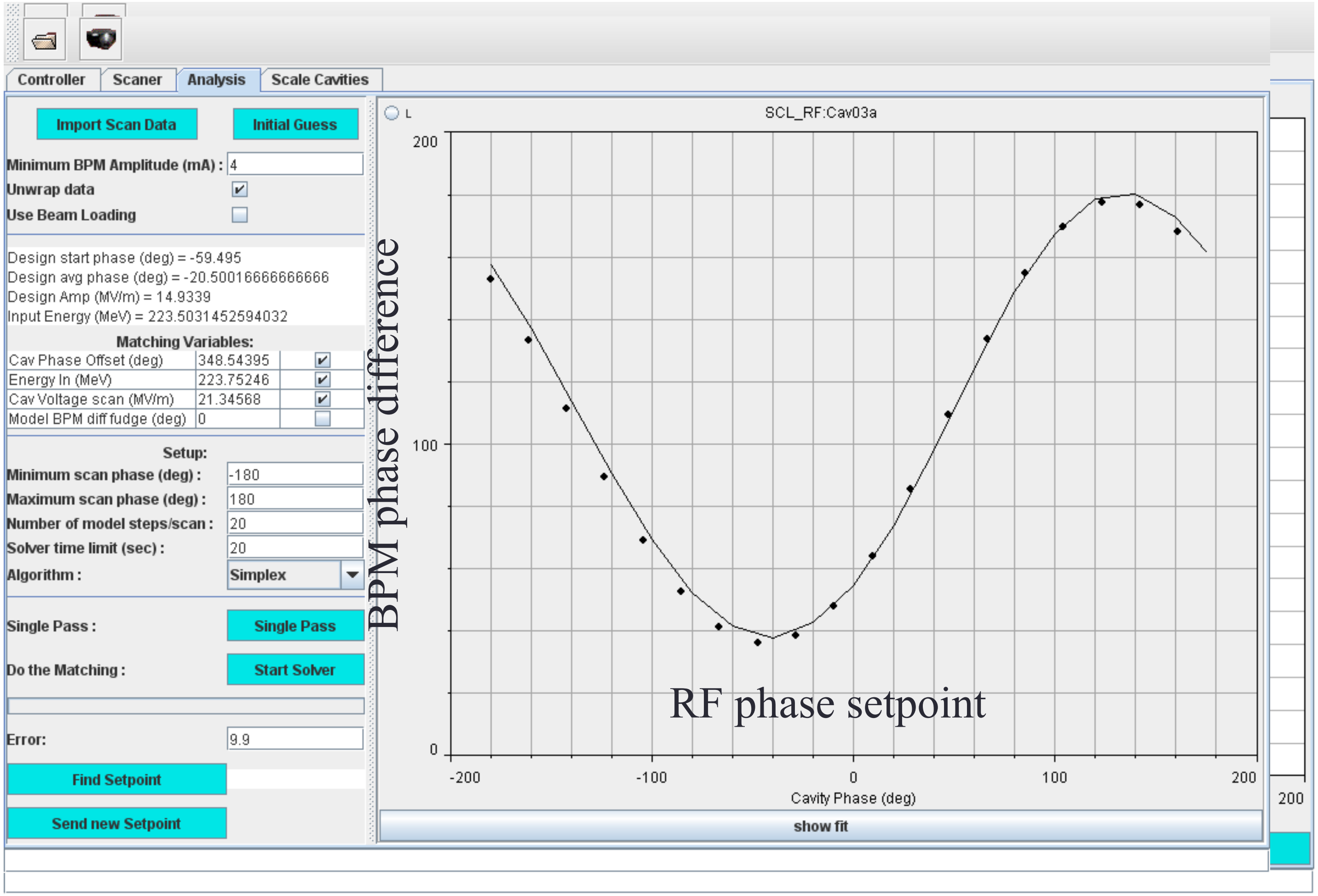
SLACS – Superconducting Cavity Phase Scan

- Super Conducting Situation
  - Minimal effect on the beam velocity β
    - Thus ΔW can change without significantly changing β
  - Cavity transmits the bunched beam for any RF setting (wide acceptance)

- SNS
  - The SNS Superconducting cavity is only 6 cells
  - Same concept as PASTA –
    - Scan the RF cavity and use model fits of the resulting measured effect on the downstream beam arrival times

RF Applications

SLACS – Superconducting Cavity Phase Scan



- With only a few cells and minimal change to the beam beta, this sort of cavity acts much like an ideal kick (sine-wave response)

Summary

- To determine how to set RF cavity phase and amplitudes, you can use the beam
  - Come up with a beam measurement technique that clearly identifies the effect of altering the energy gain
- Use a model to estimate how much the energy gain changed and predict response
  - Provides the needed information about the RF amplitude, the cavity RF phase relative to the synchronous beam, and the input beam energy
- Use of feedback for a closed loop search algorithm