Experience and Lessons with the SNS Superconducting Linac

Yan Zhang

on behalf of the SNS team

May 24, 2010, 1st IPAC, Kyoto, Japan

Managed by UT-Battelle
for the Department of Energy

OAK RIDGE National Laboratory

Acknowledgements

S. Henderson, J. Galambos, R. Campisi, J.G. Wang, S. Kim, Y. Liu, and all others of the SNS accelerator team

Outline

- Introduction to the SNS Linac
- Achievements and Lessons
- Transverse Beam Dynamics
- Longitudinal Beam Dynamics
- Summary

Introduction

SNS Accelerator Complex

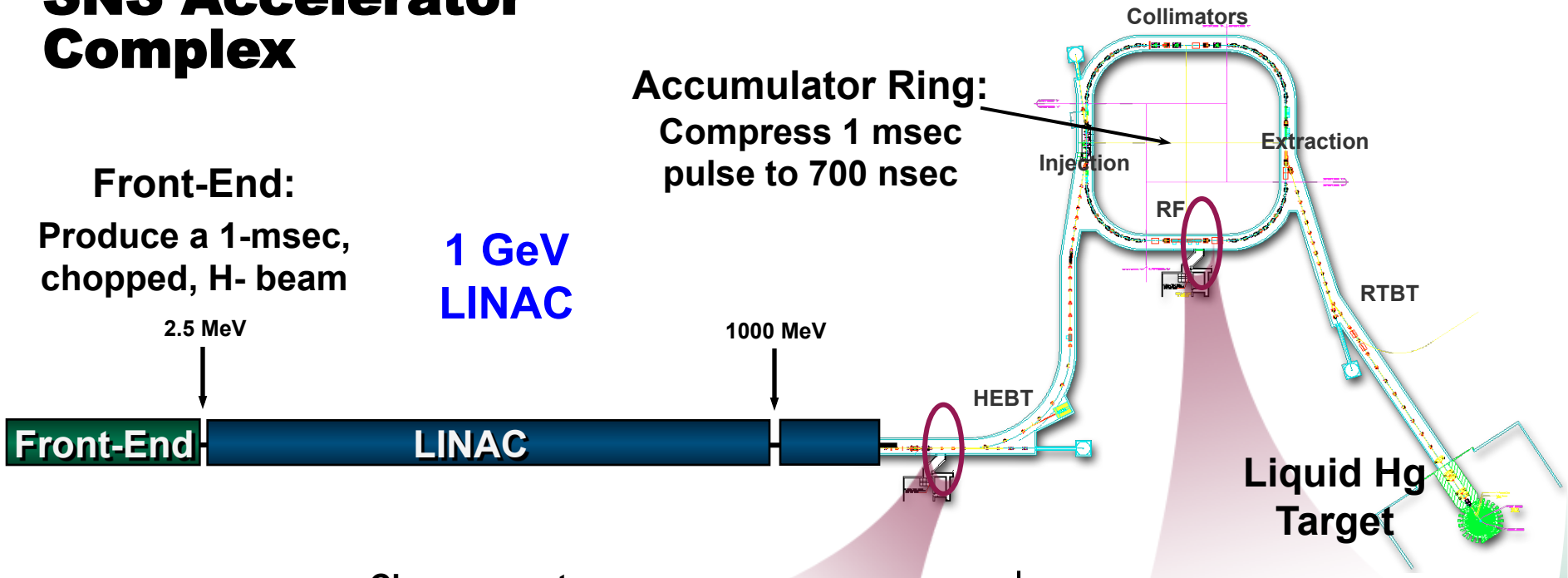
Front-End:

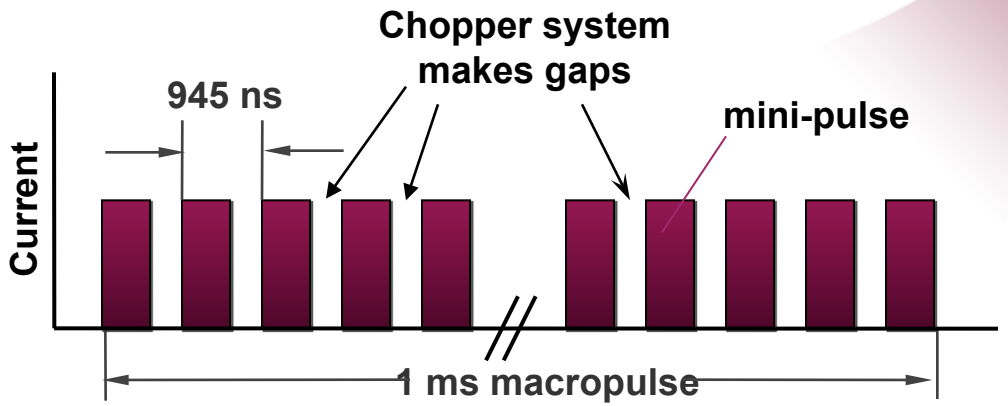
Produce a 1-msec, chopped, H- beam

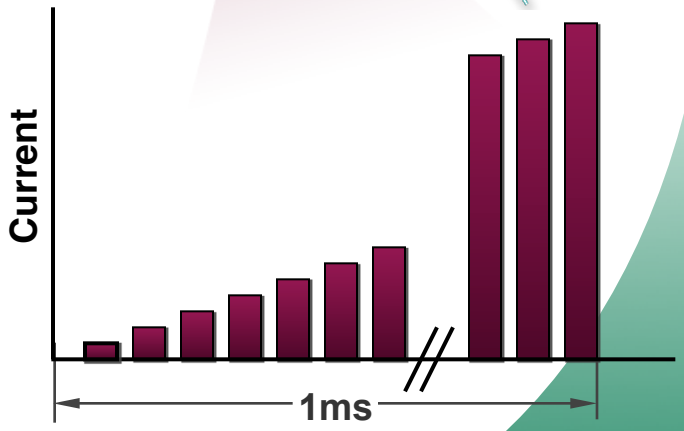
1 GeV LINAC

Accumulator Ring:

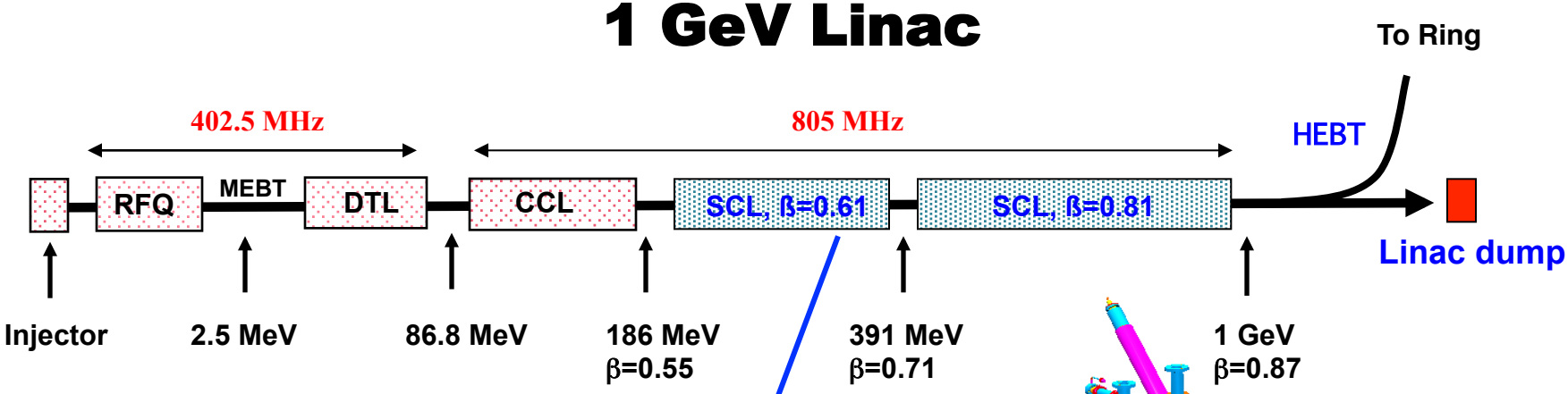
Compress 1 msec pulse to 700 nsec



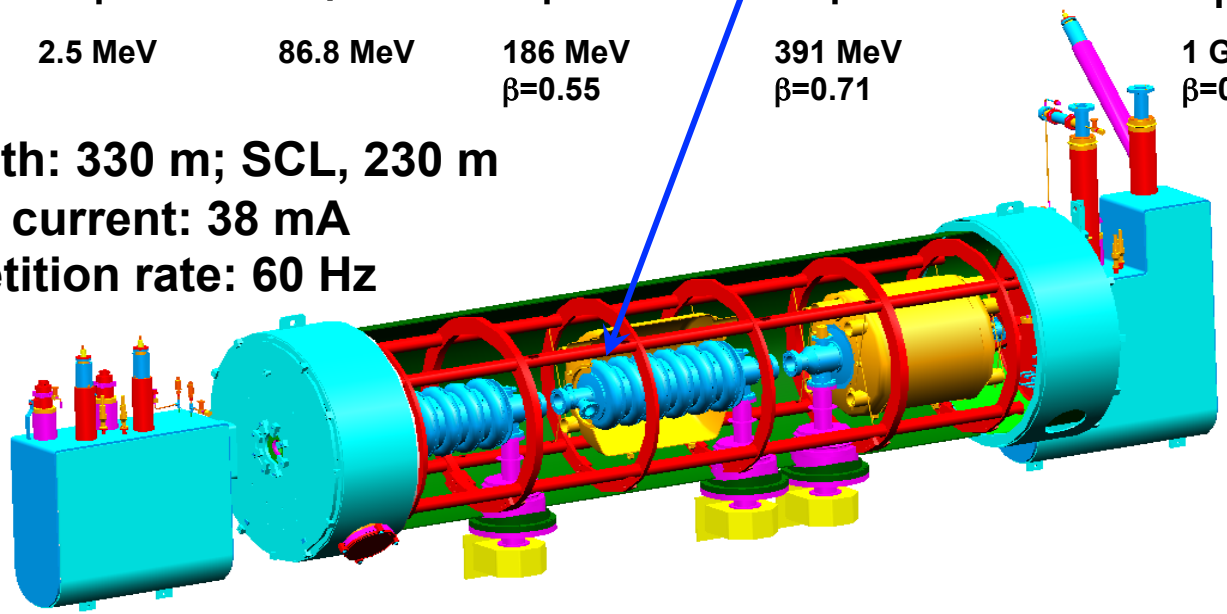




1 GeV Linac

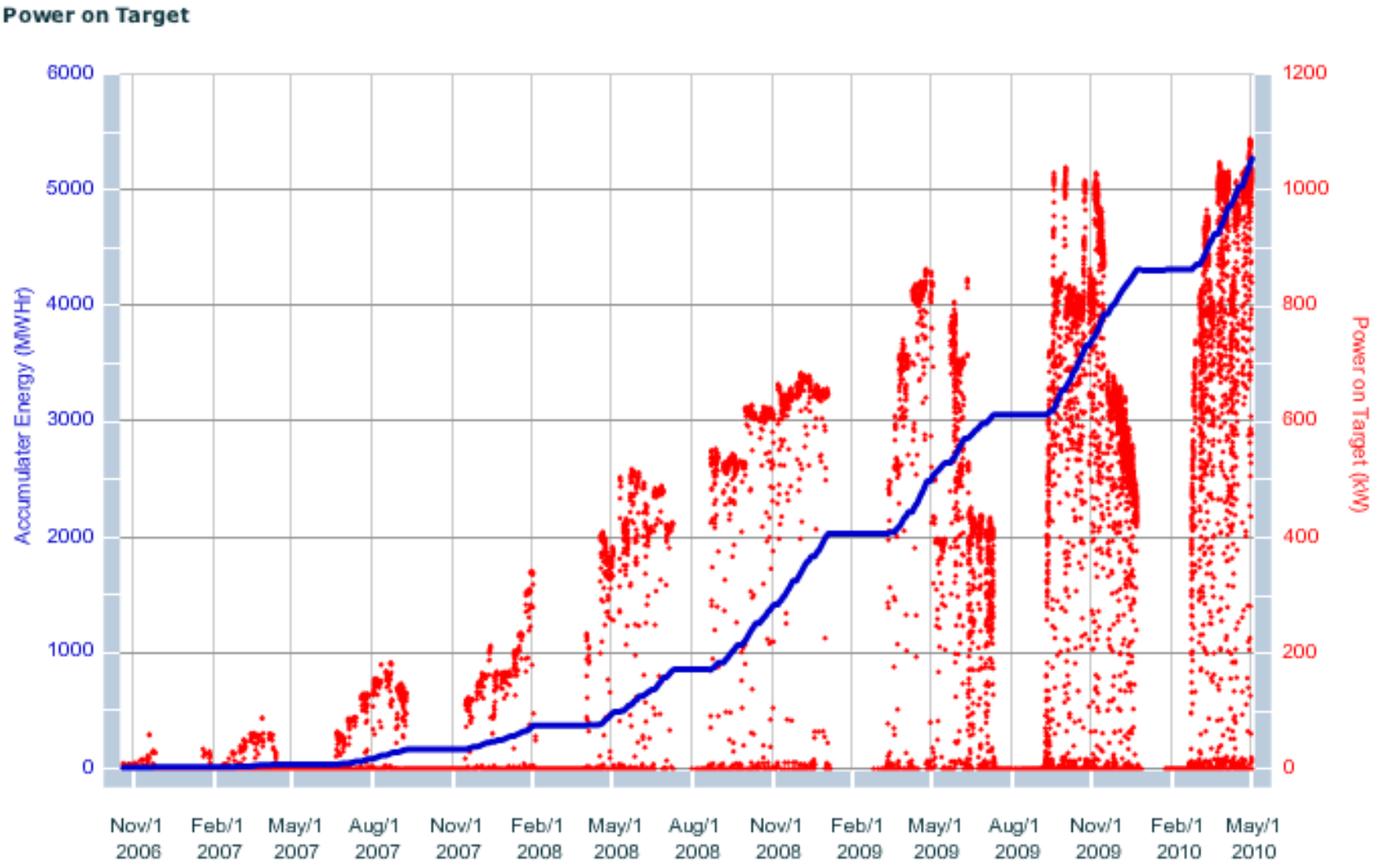


Length: 330 m; SCL, 230 m
Peak current: 38 mA
Repetition rate: 60 Hz



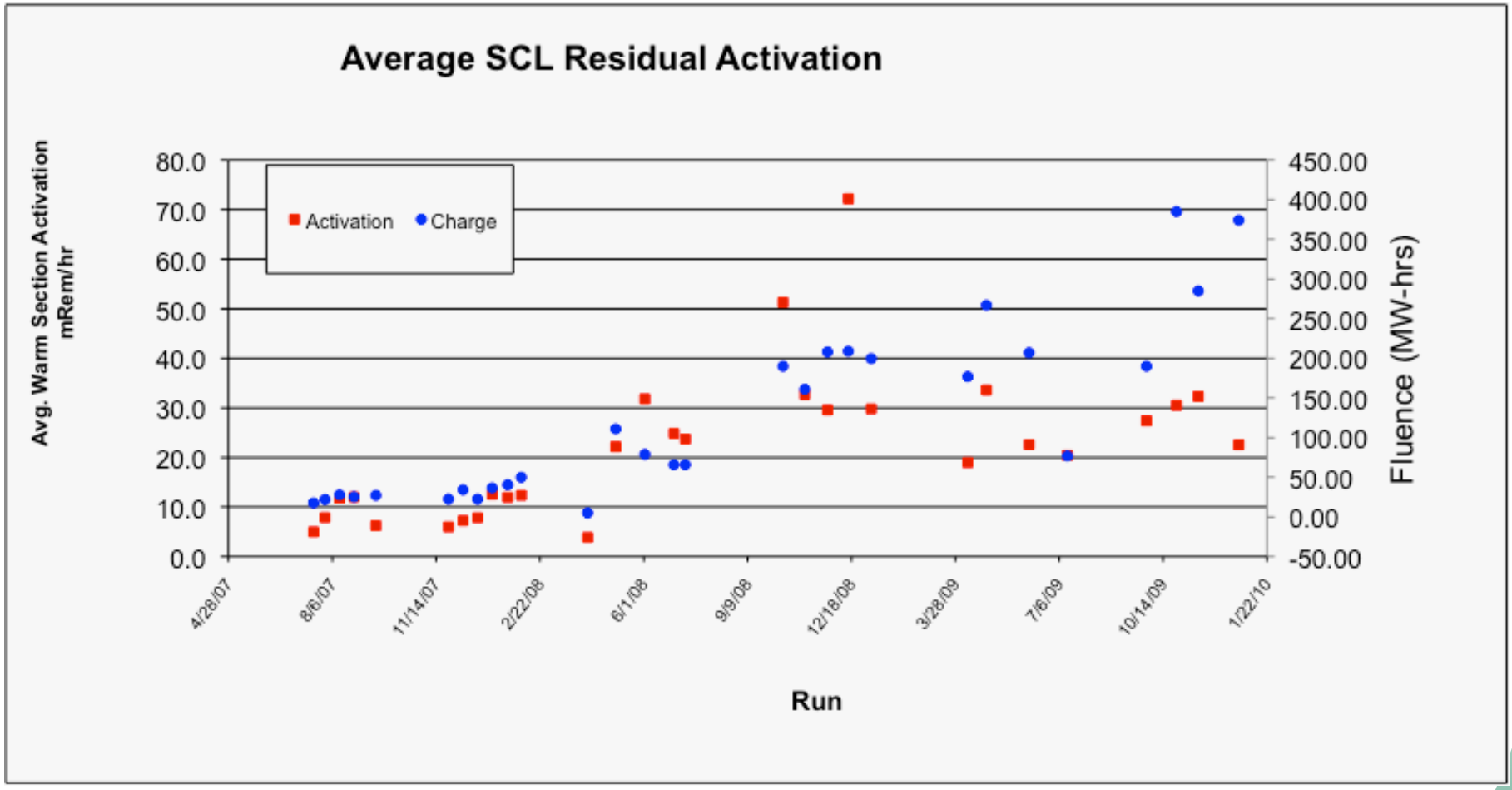
- **Medium Beta (β = 0.61): 11 cryomodules, 3 cavities/cryomodule**
- **High Beta (β = 0.81): 12 cryomodules, 4 cavities/cryomodule**
- **Each cavity is driven by a 550 kW klystron – totally 81 klystrons**
- **Quad doublets in warm sections for beam transverse focusing**
- **9 dummy sections (~70 m) reserved for future upgrade**

Achievements in the First 5-Year



- ✓ July-Aug. 2005, SCL beam commissioning
- ✓ Oct. 2006, neutron production, from 10 kW
- ✓ Sept. 2009, 1 MW production

Beam Loss and Residual Activation

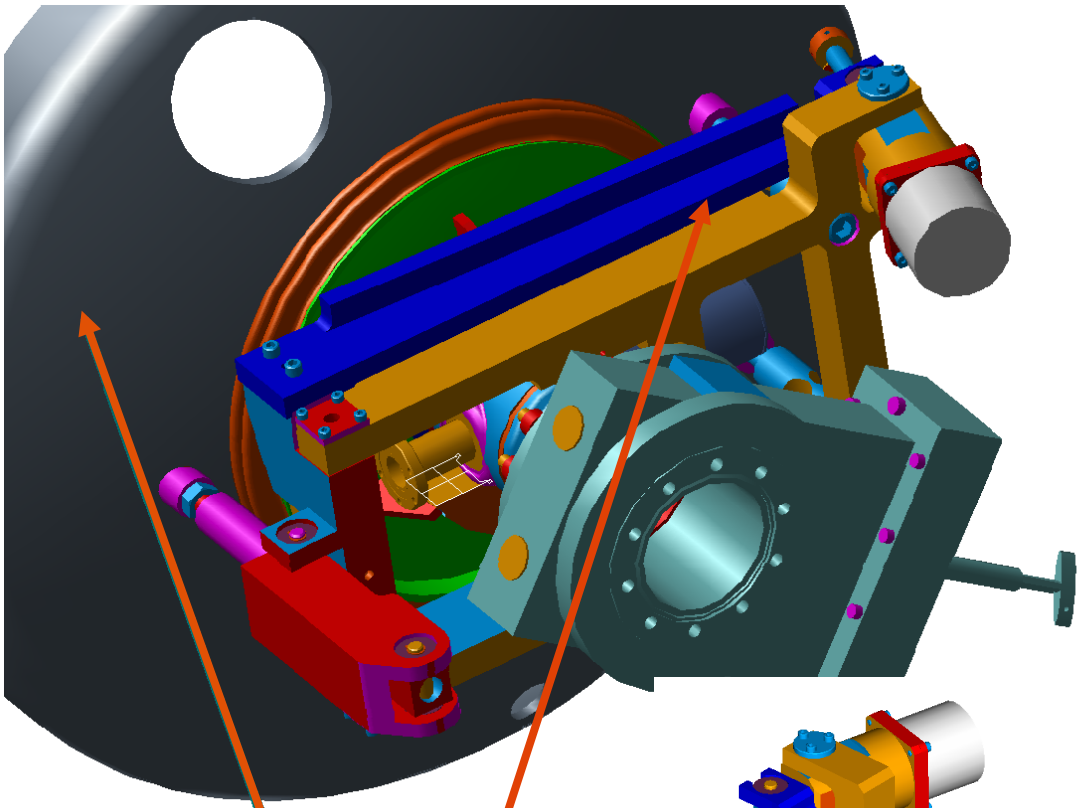


- ✓ We consider beam loss and residual activation very seriously
- ✓ Activation was once higher during the beam power ramp up
- ✓ Currently not beam loss limited, and may not - up to 1.44 MW

SNS Major Parameter

PARAMETER	Design	Best Achieved	Production
Beam Energy (GeV)	1.0	1.01	0.93
Peak Current (mA)	38	42	42
Repetition Rate (Hz)	60	60	60
Pulse Length (ms)	1.0	1.0	0.8
Proton per Pulse	1.5×10^{14}	1.55×10^{14}	1.1×10^{14}
Number of Cavities	81	80	80
RF Duty Factor (%)	8	7	7
Power on Target (MW)	1.44	1.08	1.08
Availability (%)	90	85	85

Lessons Learned with the SCL



Piezo Tuner

- Several failures
- Has not been used
- High-gain LLRF

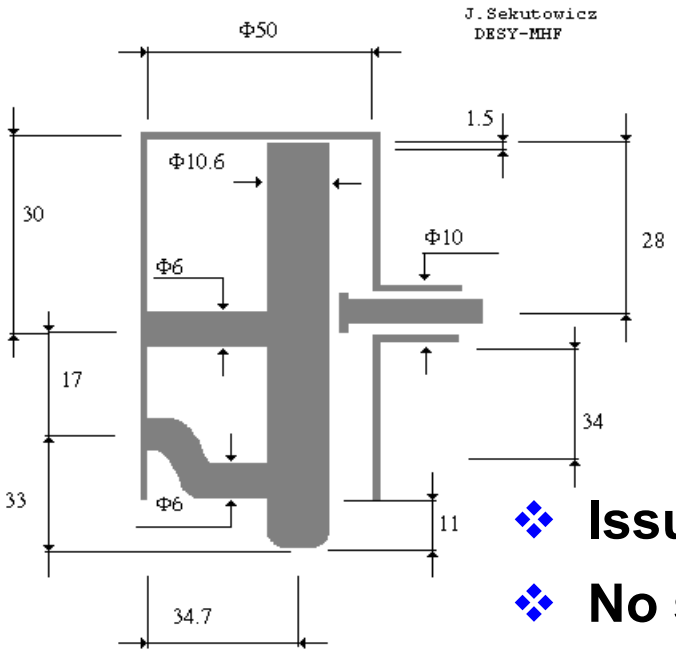
Helium Vessel

Piezo Actuator

Cavity Mechanical Tuner Assembly

HOM Coupler of SNS Cavity

High Beta (0.81) Cavity



Medium Beta (0.61) Cavity

- Issues with fundamental RF filtering
- No significant HOM power measured
- Costs more than potential benefits

Linac Beam Collimator

There is no beam collimator installed in the linac

- Multi-particle tracking simulations did not show loss, fractional beam loss was estimated to be < 1×10^{-5}
- Measured SCL beam loss might be 1×10^{-4}

  Some factors, e.g, residual gas and magnet stripping, were considered. But some others, not investigated

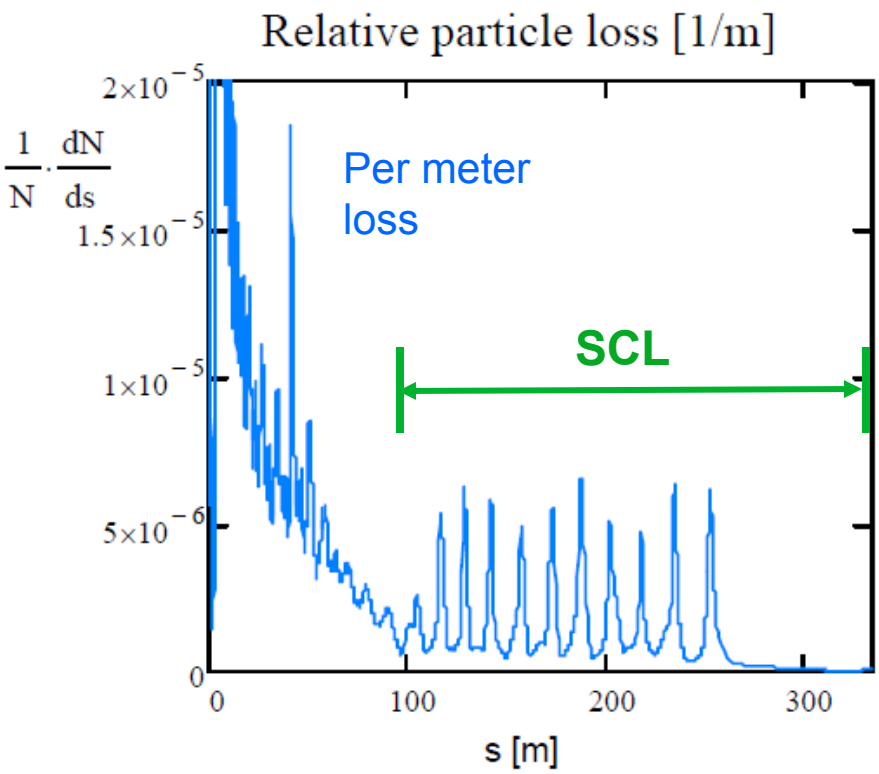
  1). Beam longitudinal halo

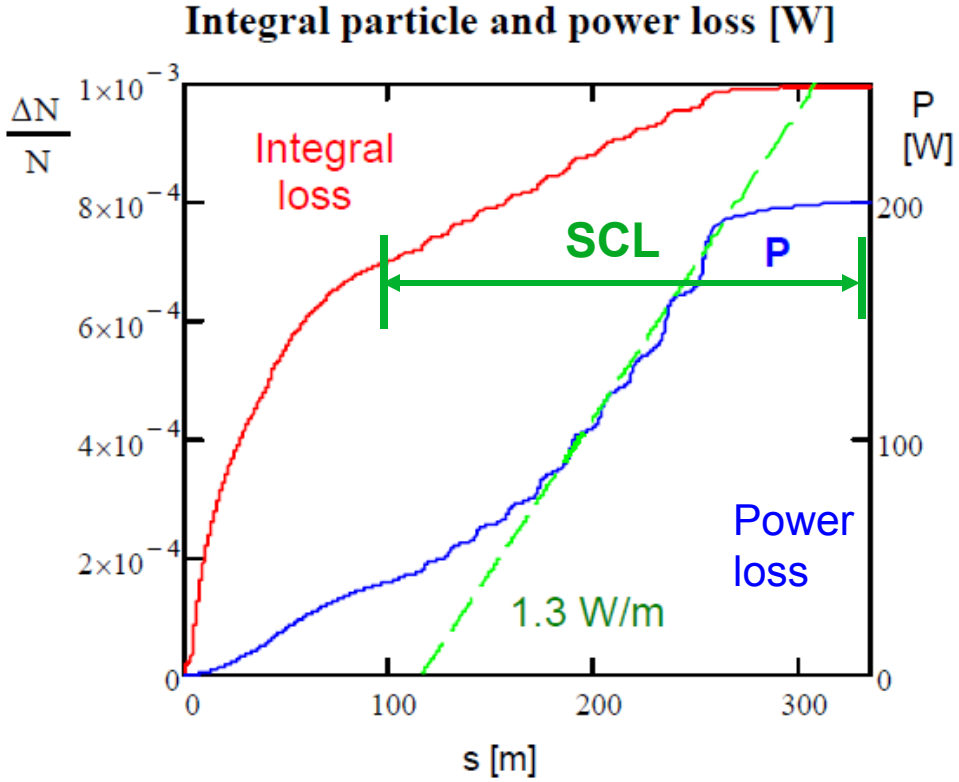
  2). Dodecapole components of linac quadrupole

  3). Intrabeam stripping

- SCL is not loss limited, but collimator could be helpful

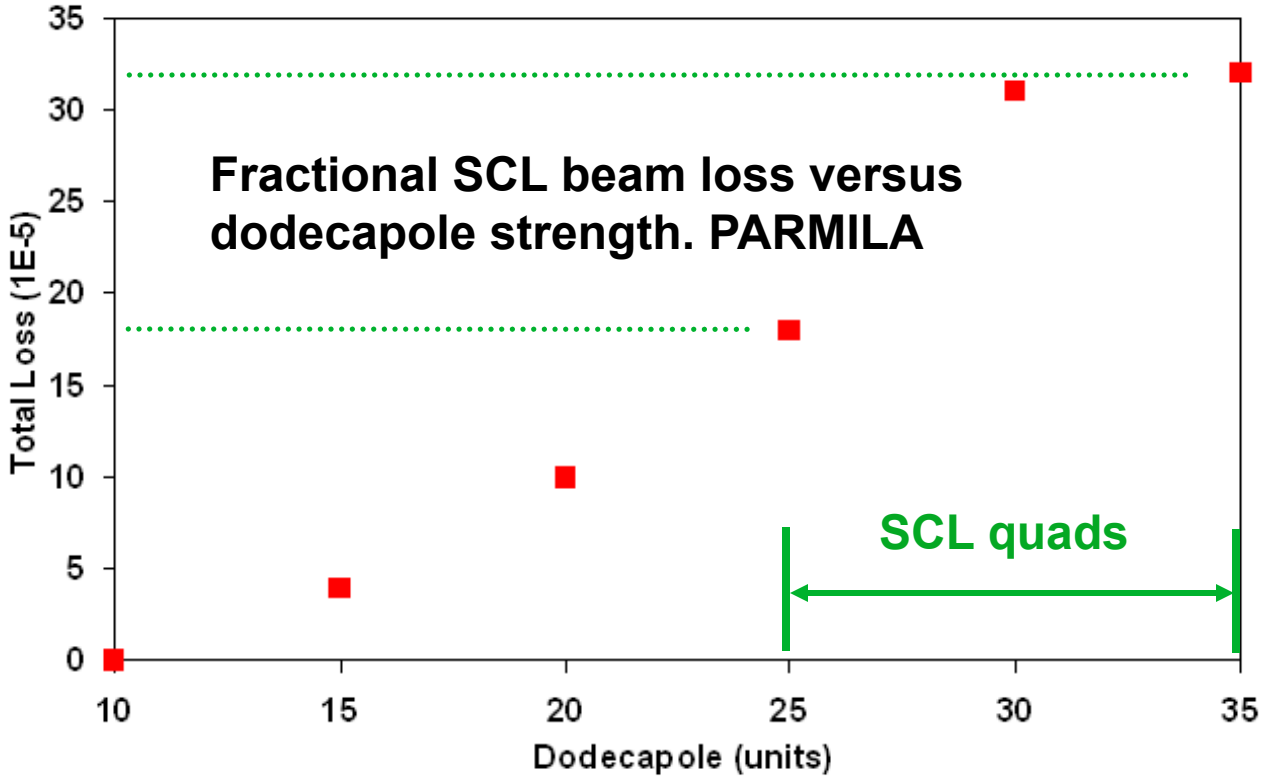
Intrabeam Stripping (V. Lebedev, FNAL)





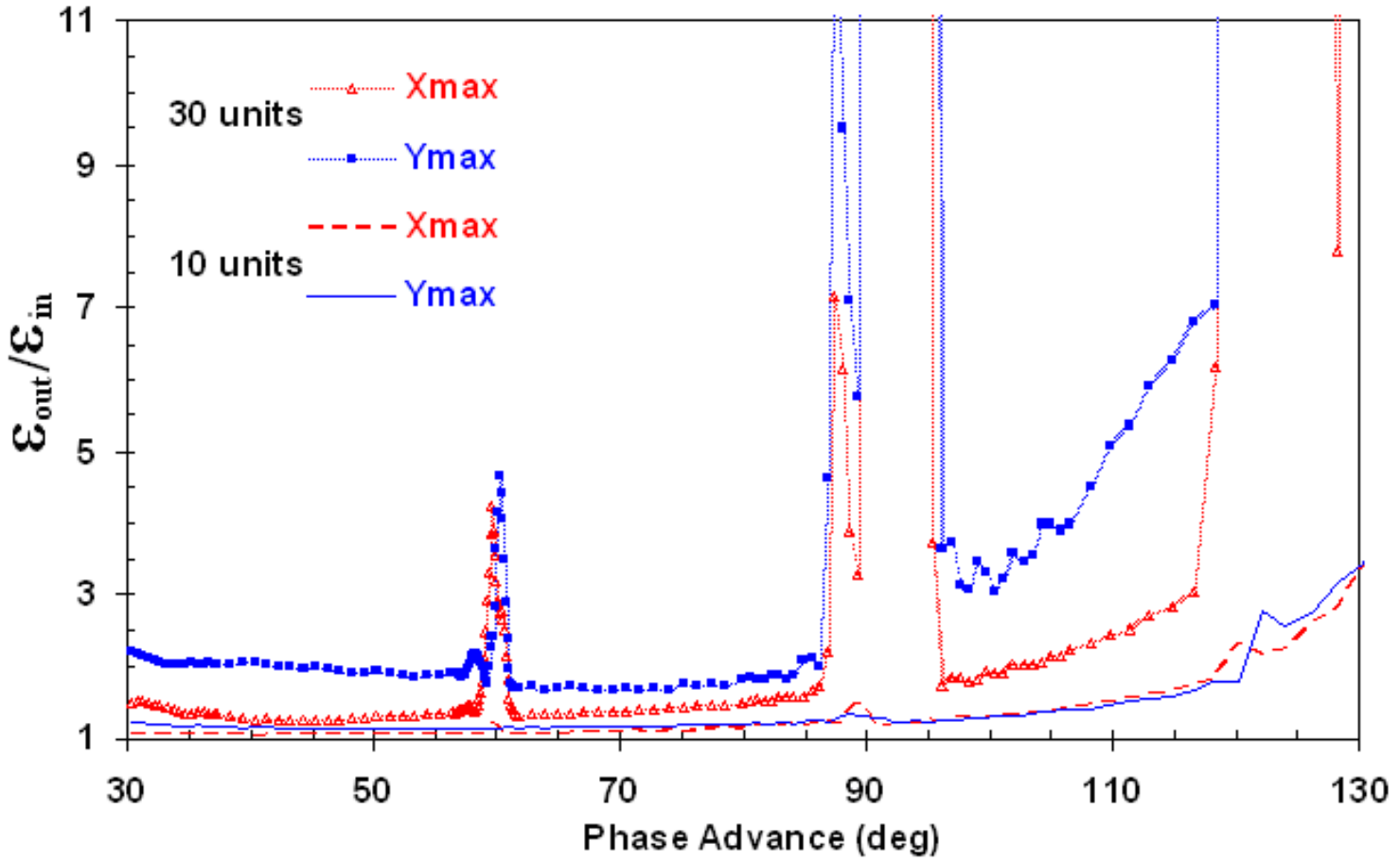
- Binding energy only 0.75 eV, beam-beam stripping loss
- Estimated total fractional beam loss in the SCL ~ 3×10^{-4}

Dodecapole Field of SCL Quadrupole



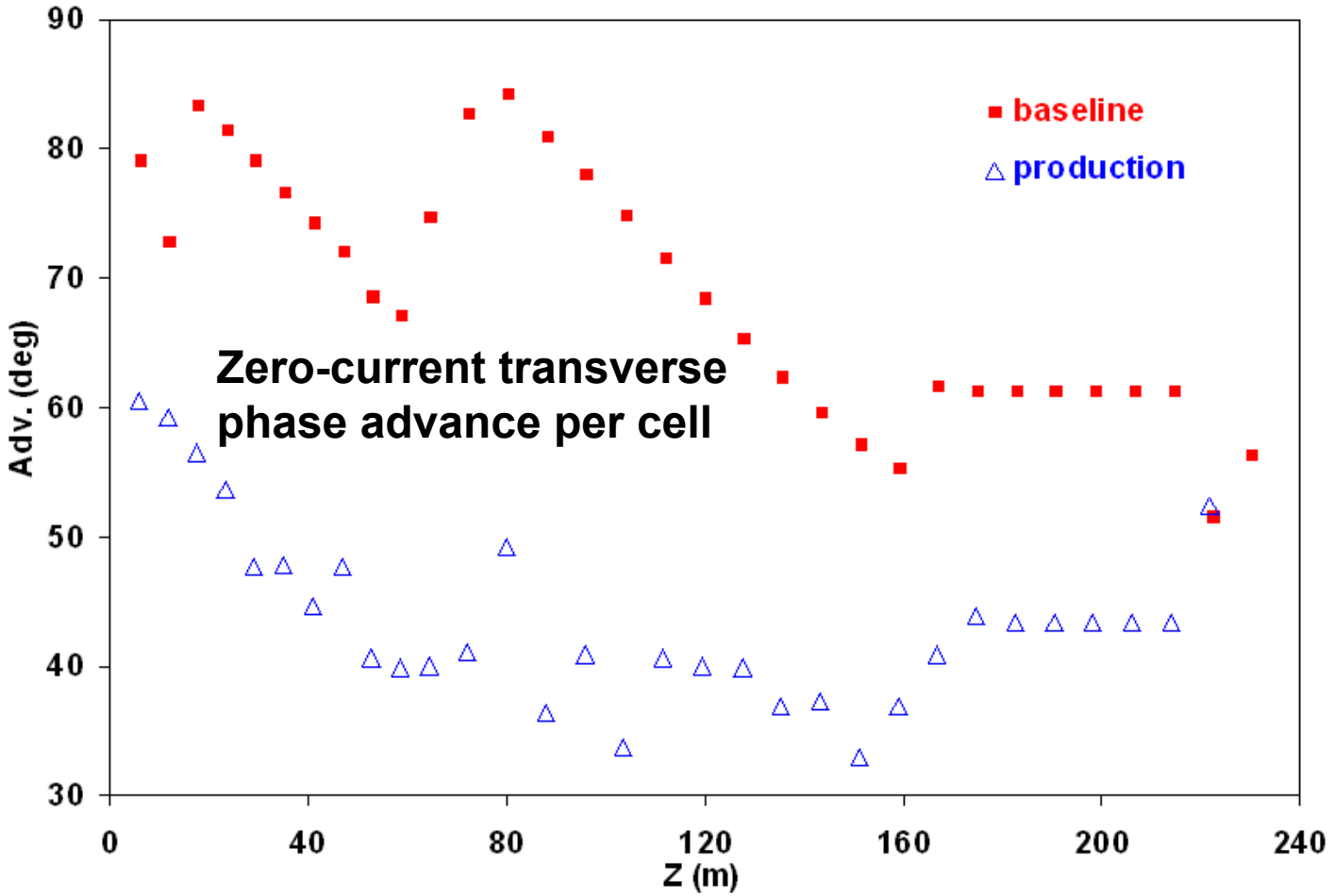
- 1 unit dodecapole equals to 1×10^{-4} of quadrupole field
- Measured SCL quadrupole is approximately 30 units
- They may cause ~ 3×10^{-4} fractional beam loss in SCL

Transverse Beam Dynamics



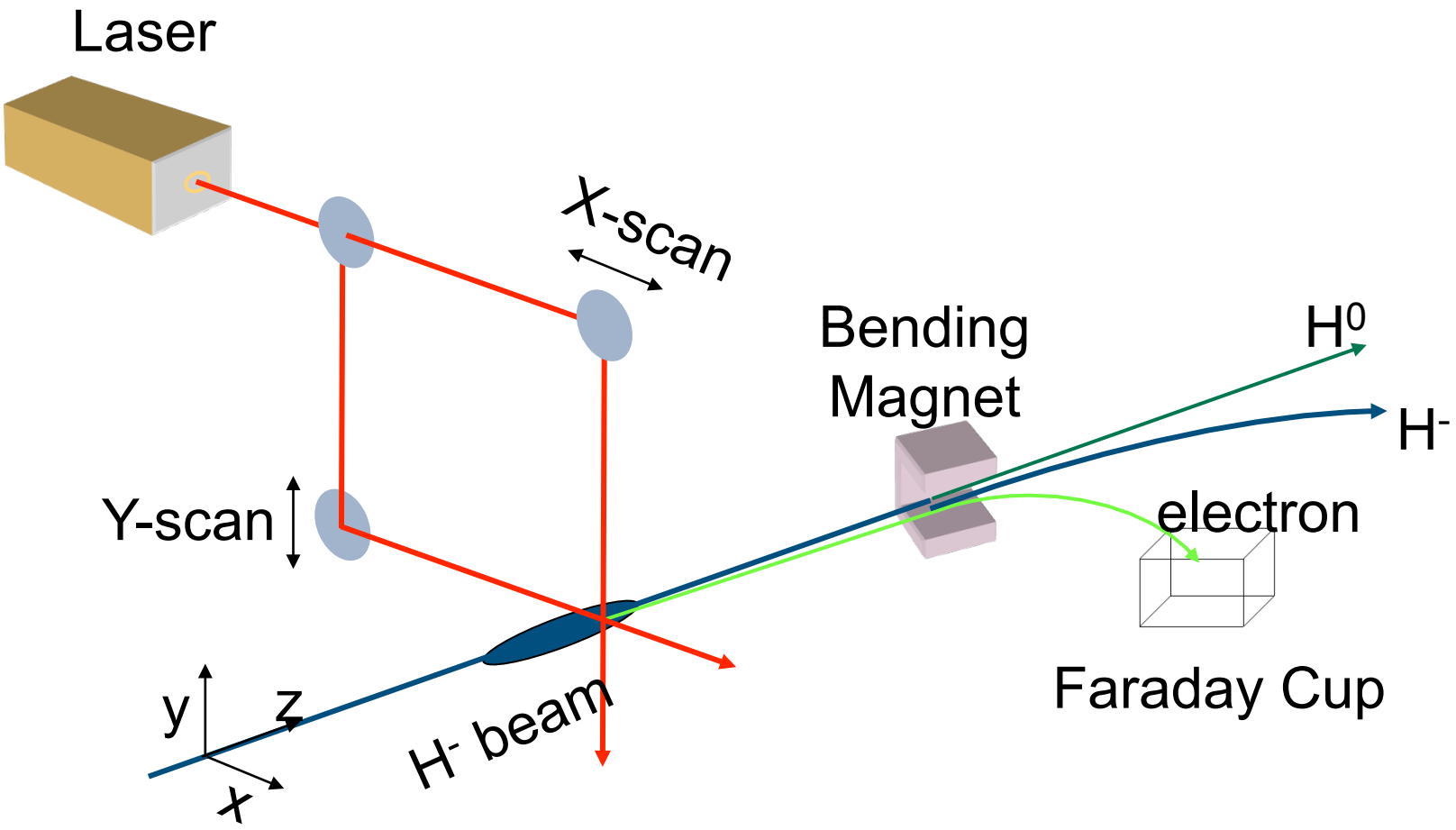
- Maximum emittance in doublet lattice, no space charge, no cavity
- The weak resonance appears only when dodecapole is significant

Baseline Versus Production



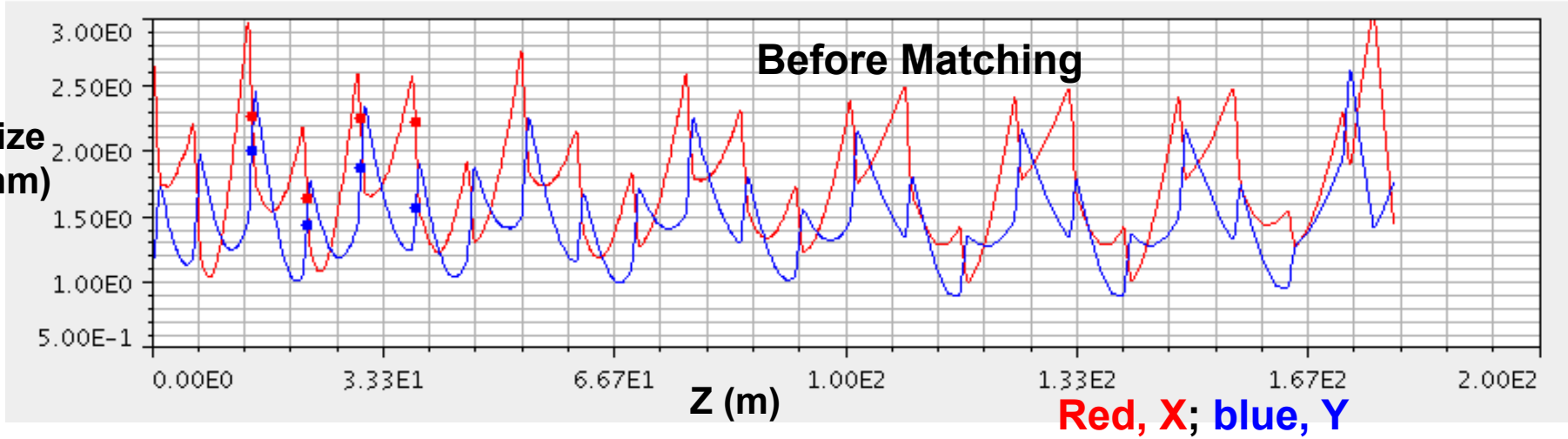
- Quadrupoles in production are 20 to 30% lower than the design
- Manual adjustment for beam loss results a non-smooth lattice
- All the three beam loss mechanisms favor strong focusing

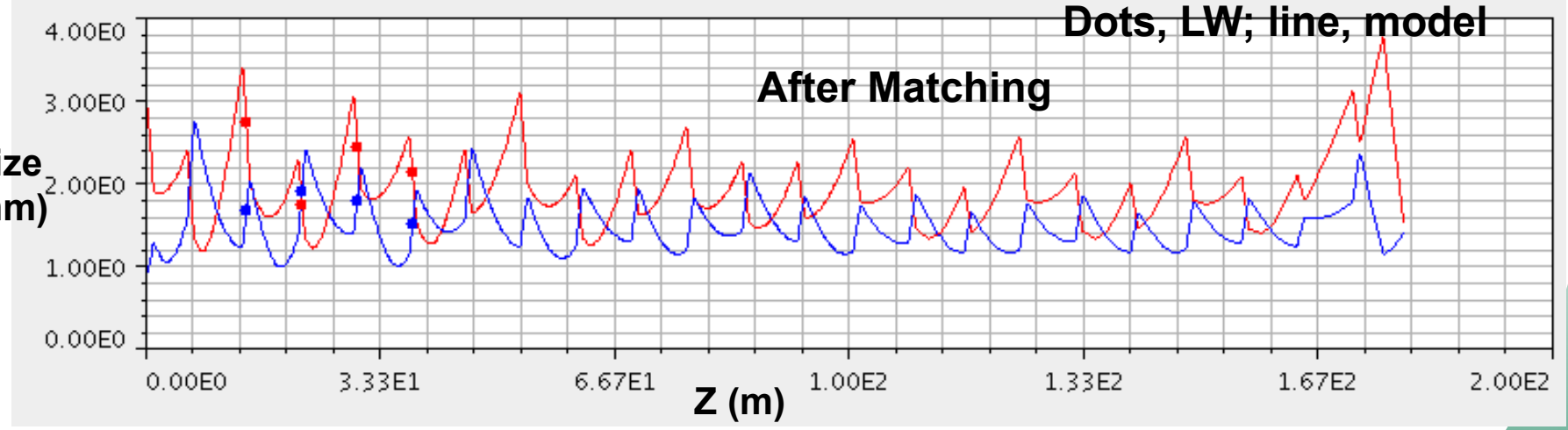
Laser Wire Beam Profile Monitor (Y. Liu, MOPE101)



- **Intercepting beam diagnostic devices are not allowed**
- **9 laser wire profile monitors are installed and used**

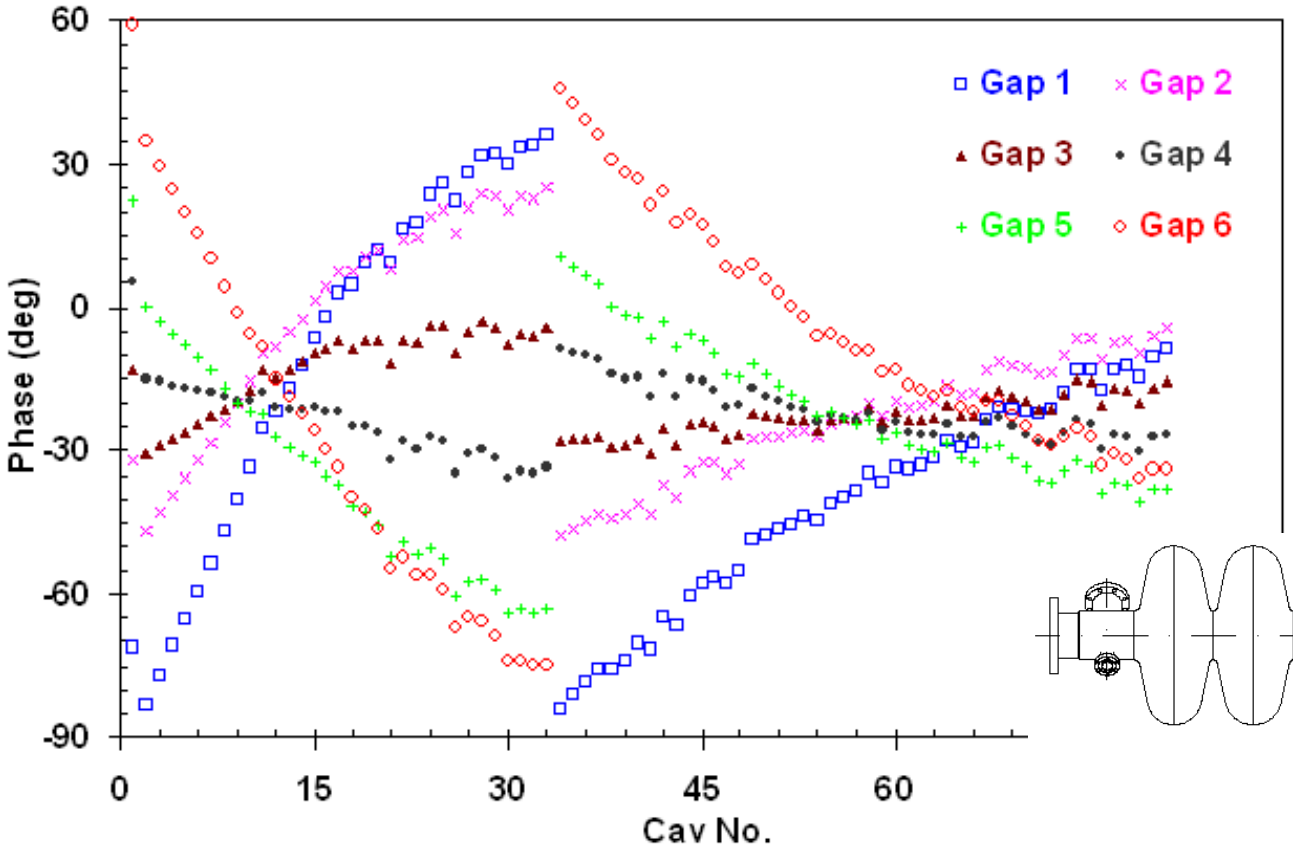
Transverse Matching

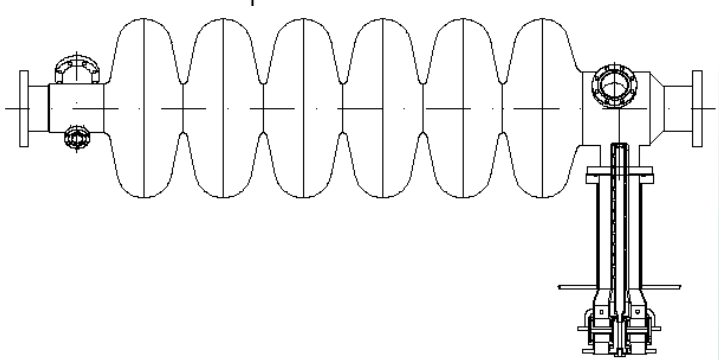




- Online beam matching with the control room envelope model
- Very time consuming, and the online model is not so accurate
- A well matched beam does not necessarily reduce beam loss

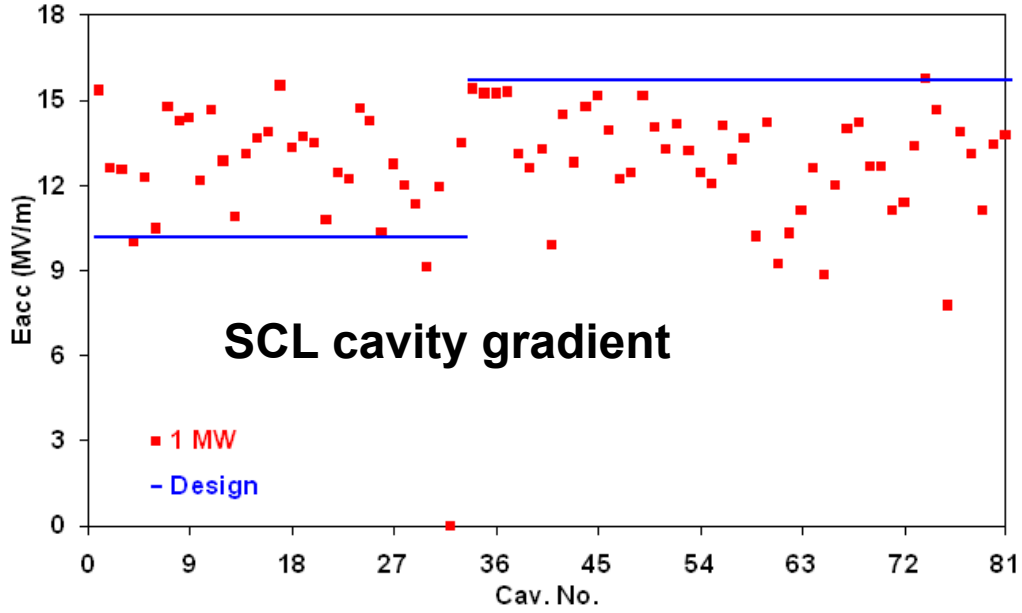
Beam Phase For the 6 Cells in Each Cavity

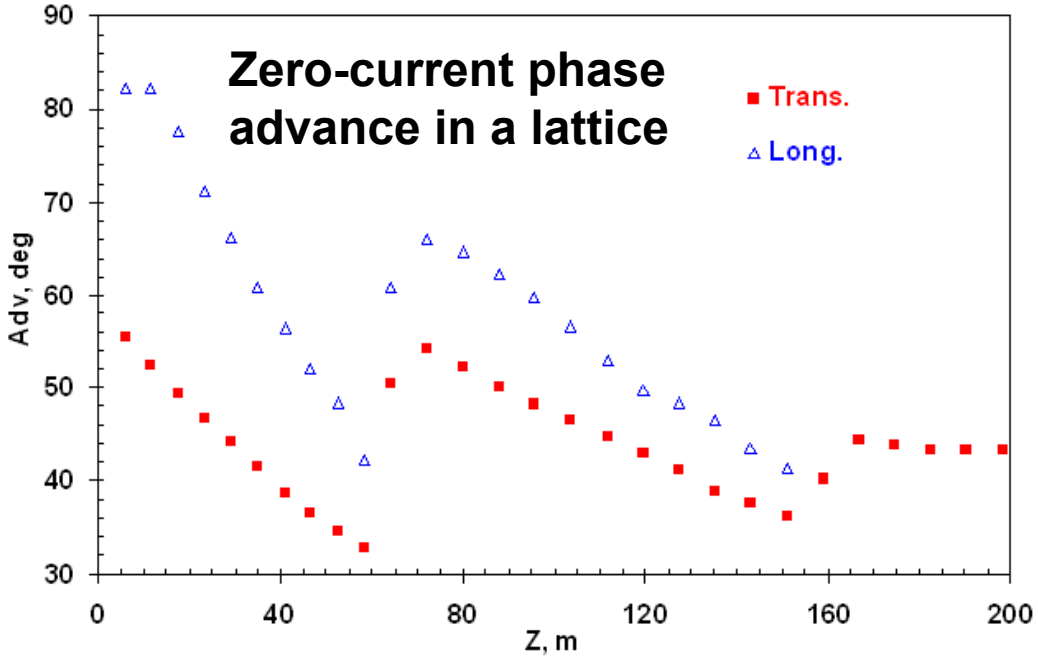




- Many cells are close to the RF crest, not a linear defocusing
- High-gradient SC cavity has a large aperture, not a thin-lens
- Multi-particle tracking is too slow, not for online application

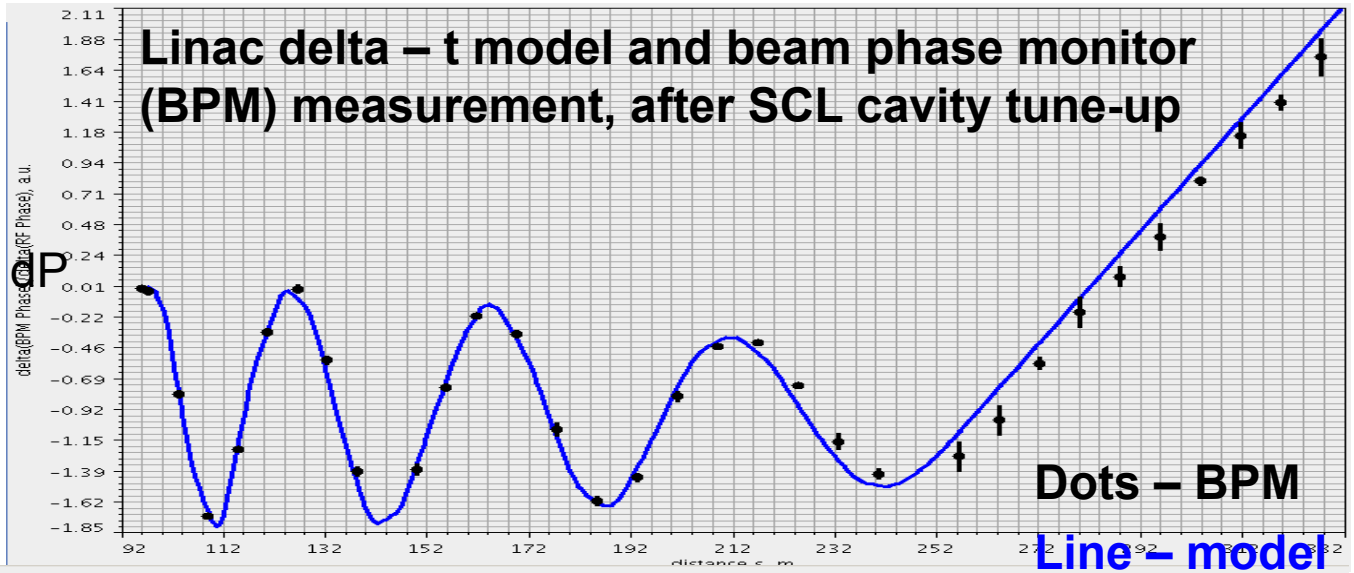
Longitudinal Beam Dynamics

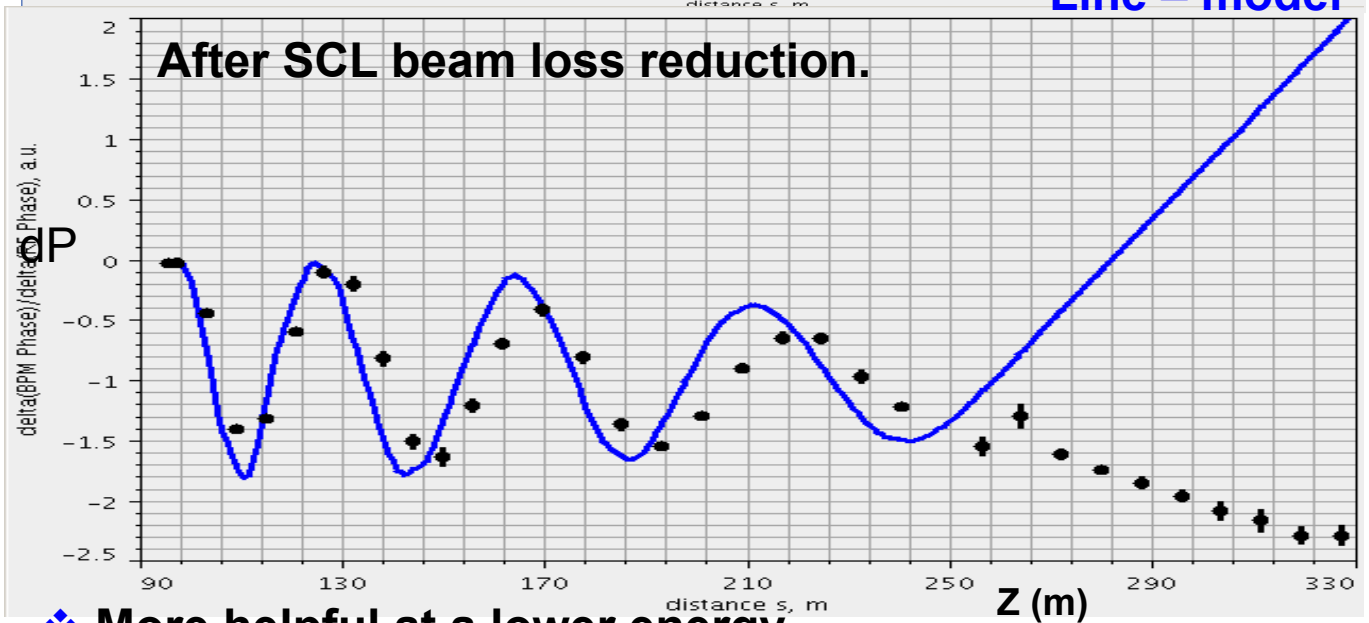




- Constant focusing
- Smooth quadrupole
- May not for loss

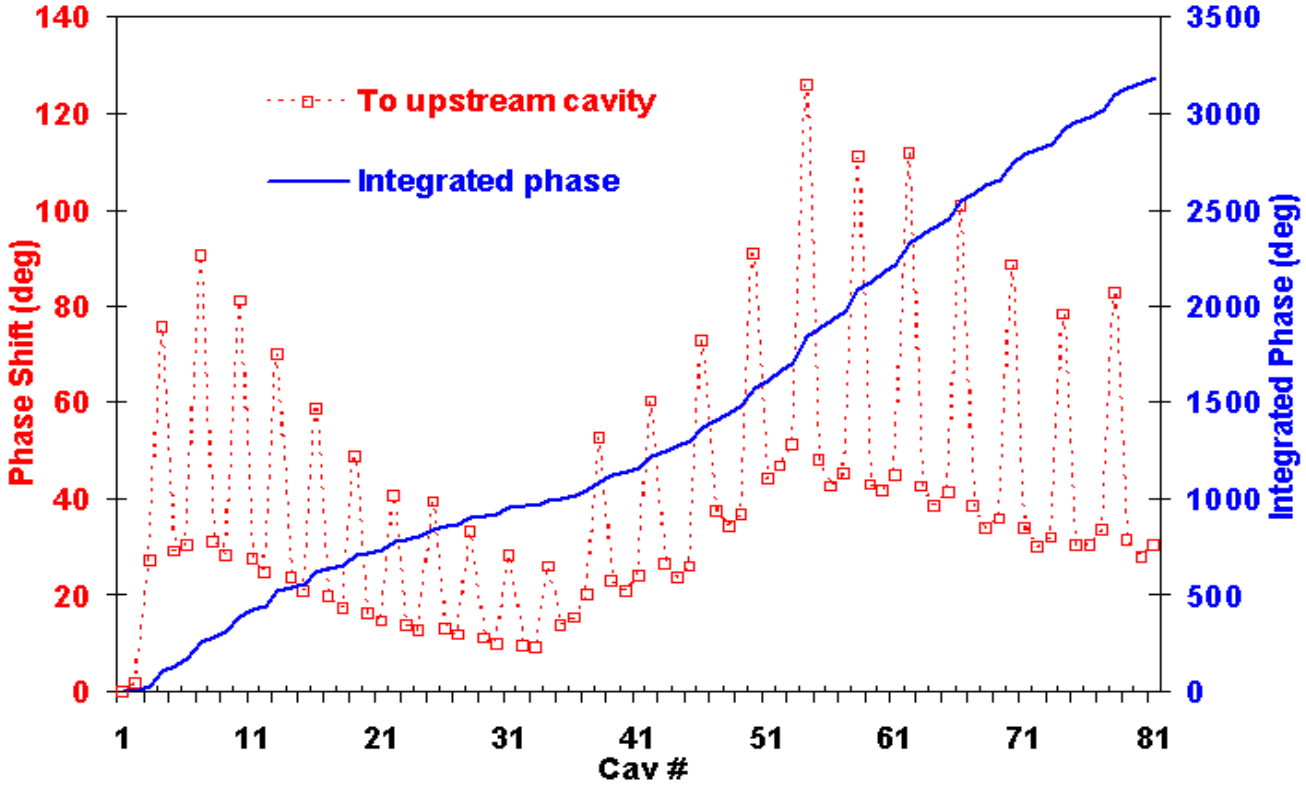
Phase Damping





- More helpful at a lower energy
- May or may not for beam loss

Phase Scaling



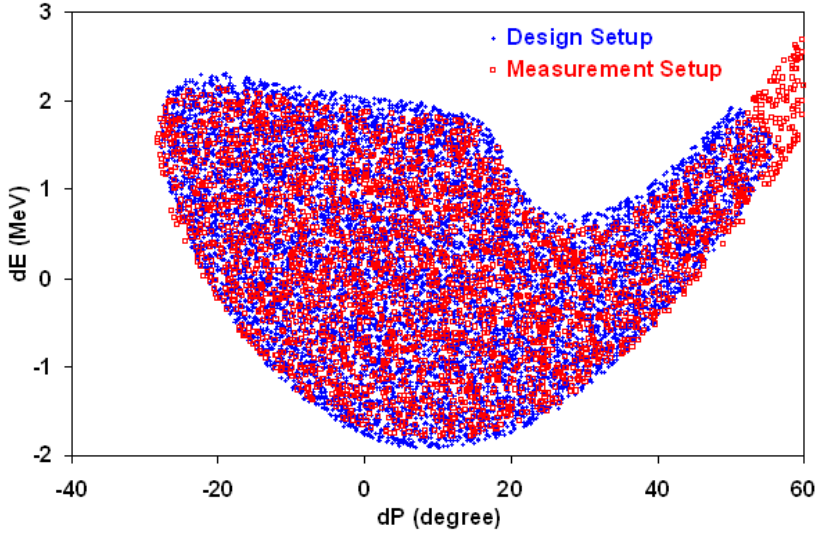
Model based RF phase scaling technique

From 900 MeV to 1 GeV, the acceleration gradient of many cavities change, integrated shift of beam phase is > 3000°.

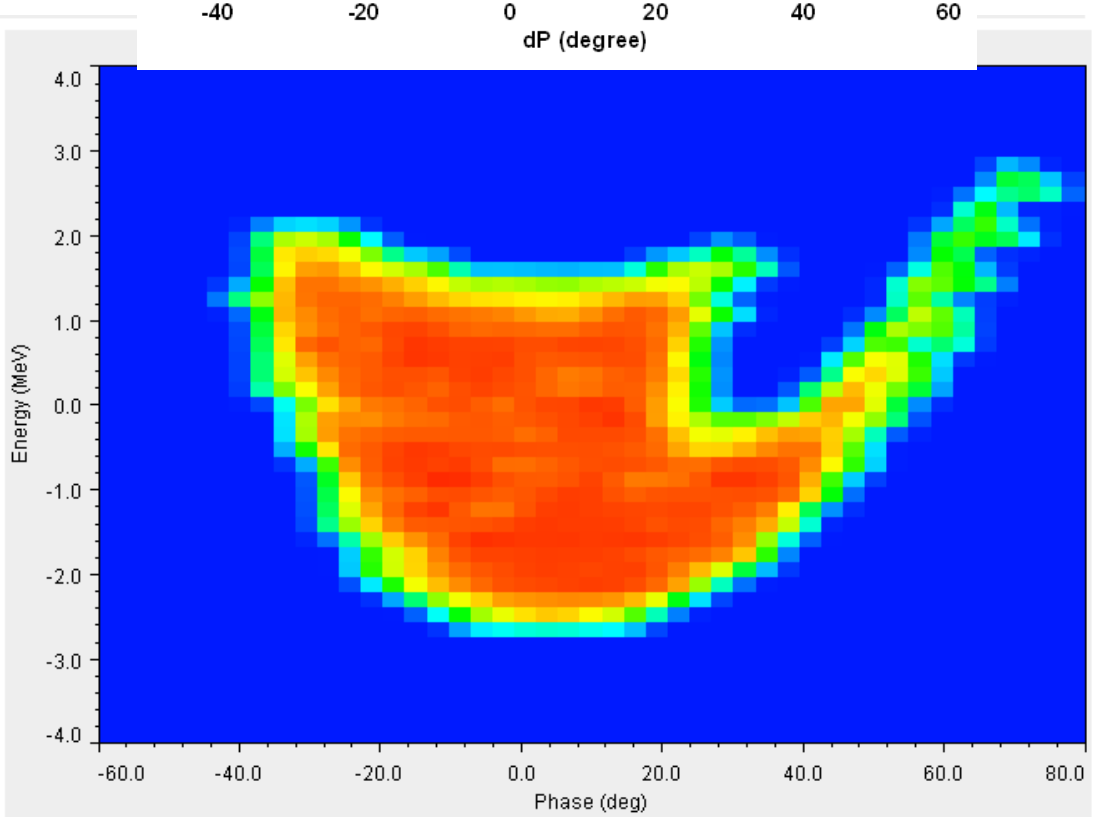
- **SCL cavity and RF failure recovery**
- **Application in other longitudinal beam dynamic study**

Longitudinal Acceptance

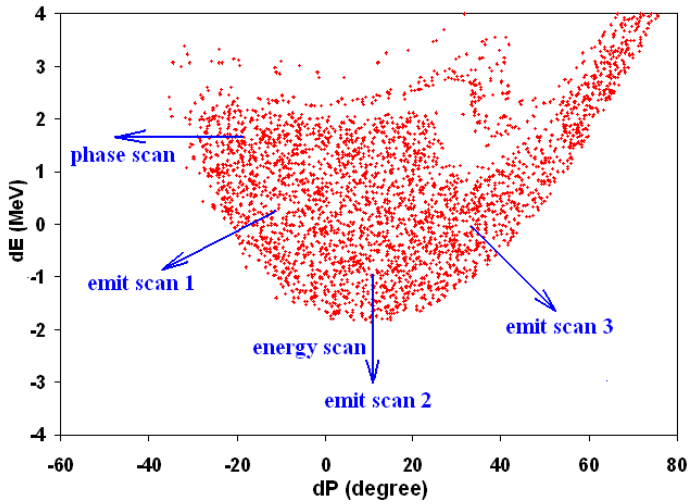
Model



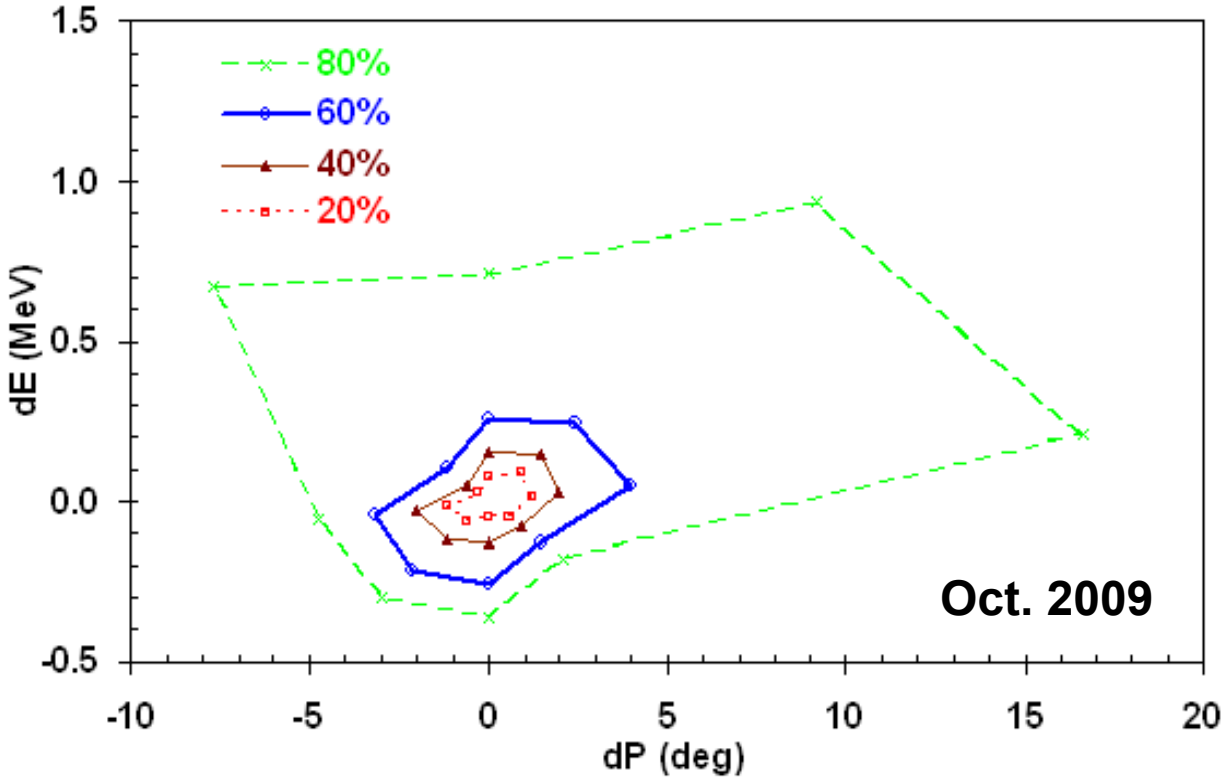
Measurement



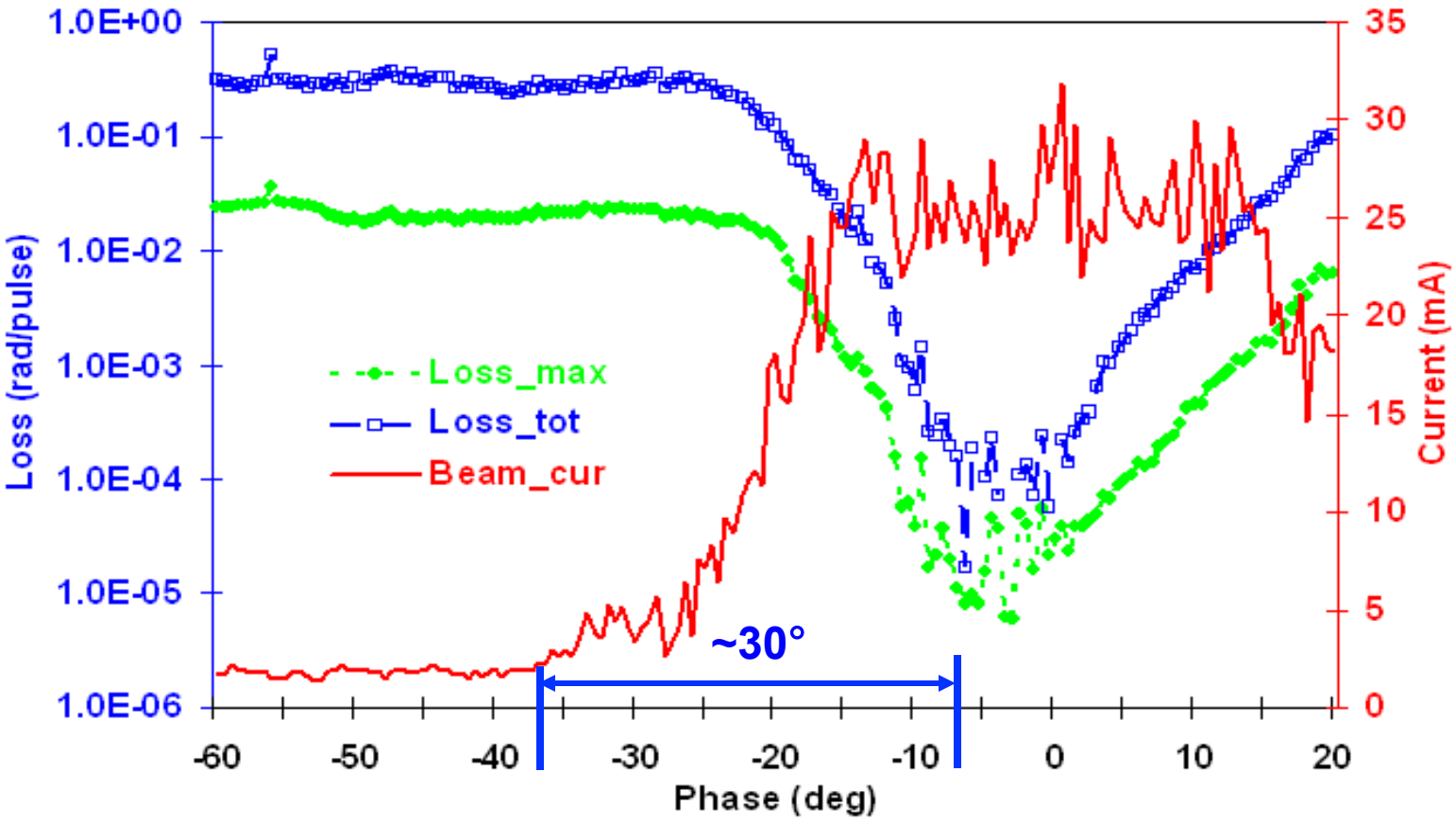
Longitudinal Emittance



- Phase and energy scans: bunch size and energy spread
- Beam emittance scans: isodensity contours
- Design: ~0.3 mm*mrad; measurements: 0.4 to 0.9



Longitudinal Halo



SCL injection beam phase scan

- **Beam current monitor and beam loss monitor measurements**
- **Scan in different directions, such as, beam phase and energy**
- **Measured halo size is usually comparable to the acceptance**

Summary

- The first 5-year of beam commissioning and operation of the SNS superconducting linac has been a great success.
- Hardware:
  1) Keep every component simple
  2) System reliability rather than individual performance is important to a success
- Beam dynamics:
  1) Small level (1×10^{-4}) of beam loss is observed
  2) Very difficult to accurately model or measure
  3) Need more works, both simulation and experiment