Commissioning of the SNS Beam Instrumentation

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The Spallation Neutron Source Partnership

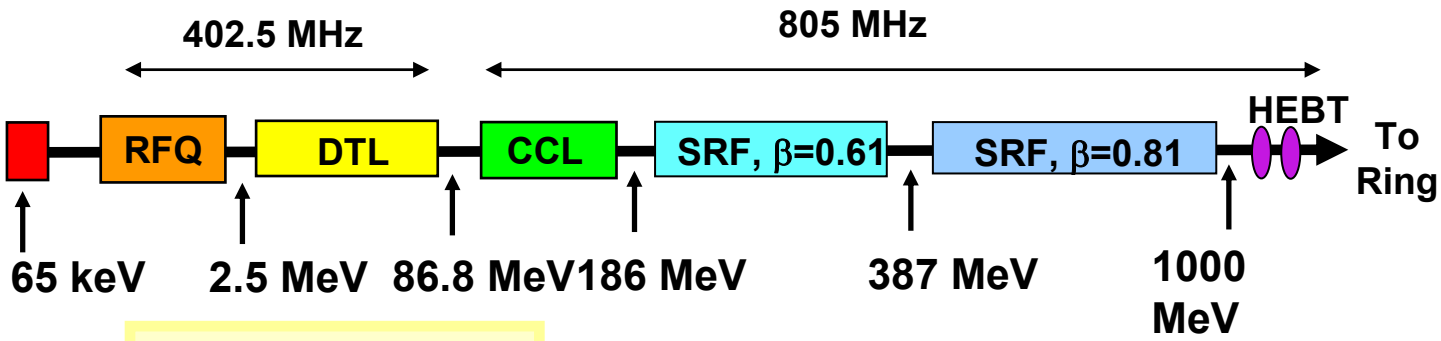
~113 M$

The SNS will begin operation in 2006

At 1.4 MW it will be ~8x ISIS, the world's leading pulsed spallation source

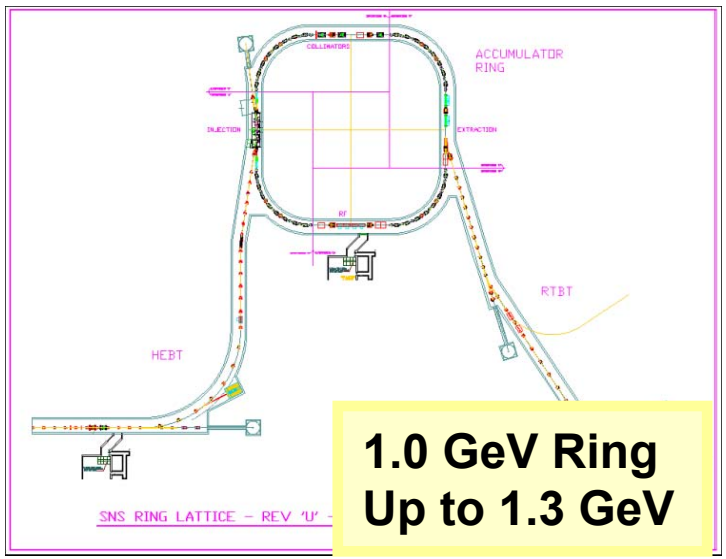
5000 hours per year at an availability of >90% …… (~ in 2009)

Accelerator Overview
Now Commissioned to 158 MeV through CCL



1 RFQ
6 DTL Tanks
4 CCL Modules

11 Medium-β Cryomodules - 3 Nb cavities each
12 High-β Cryomodules - 4 Nb cavities each



1.0 GeV Ring
Up to 1.3 GeV

Proton energy on target		1.0	GeV
Power on target		1.4	MW
Pulse repetition rate		60	Hz
Macro-pulse length		1	ms
Ave. current in macro-pulse		26	mA
H^- peak current front end	>	38	mA
Peak current in ring		52	A
Proton pulse width on tgt		695	ns
Energy per Pulse		>17	kJ
Uncontrolled beam loss		<1	W/m

Commissioning runs in parallel with installation

Run #1: **- RFQ at LBNL (2.5 MeV), Jan 25th through Feb 2002**
- beam stop for design beam power

Run #2: **- Front End at LBNL (2.5 MeV), Apr 4 to May 31, 2002**
- beam stop for design beam power

Run #3: **- Front End at ORNL (2.5 MeV), Nov 5, 2002 to Jan 31, 2003**
- beam stop for design beam power

Run #4: **- Front End, DTL tank 1, D-Plate (7.5 MeV), Aug 26 to Nov 17, 2003**
- beam stop and radiation shield for design beam power

Run #5: **- Front End & DTL tank 1,2,3 (39 MeV) Spring 2004**
- Beam stop and radiation shield for reduced beam power (50us, 1Hz)

Run #6 : **- Front End, DTL, CCL modules 1,2,3 (158 MeV) Fall 2004**
- Beam stop and radiation shield for reduced beam power (50us, 1Hz)

Run #7 : **- Front End, DTL, CCL, SCL (1 GeV), Fall 2005**

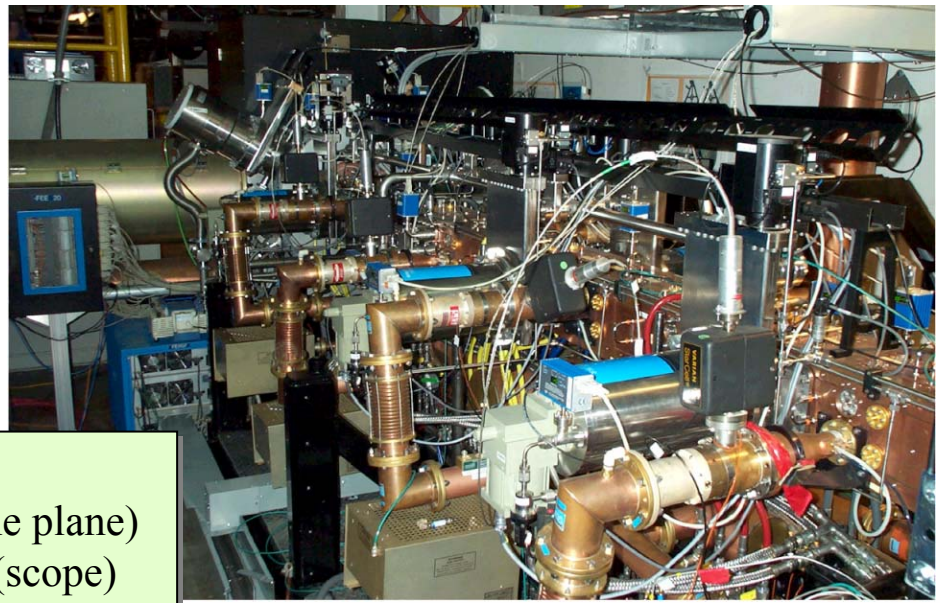
Run #8 : **- Front End, DTL, CCL, SCL, Ring (1 GeV), Early 2006**

Run #9 : **- Front End, DTL, CCL , SCL, Ring, Target (1 GeV), by June 30, 2006**

RFQ at Berkeley - 2 Diagnostic Devices Commissioning: Jan 25th through Feb 2002

1

2002 | 2003 | 2004 | 2005 | 2006



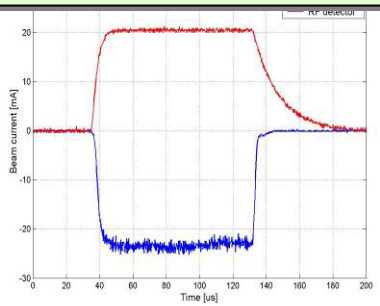
8 mA transmitted on first pulse, 24 mA current on first day

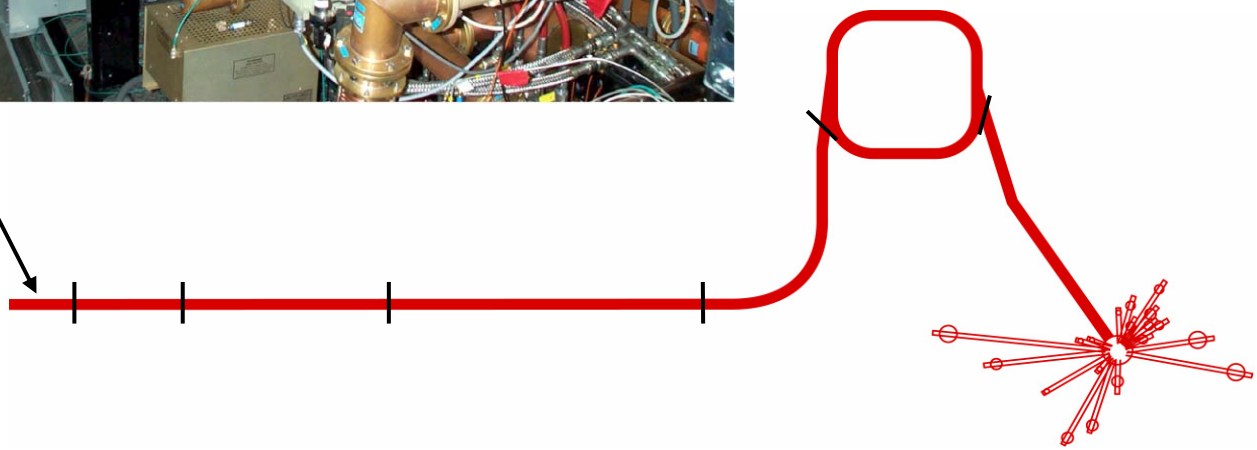
Emittance integrated with controls, all else via scopes

RFQ

1 Emittance (one plane)

1 Faraday Cup (scope)

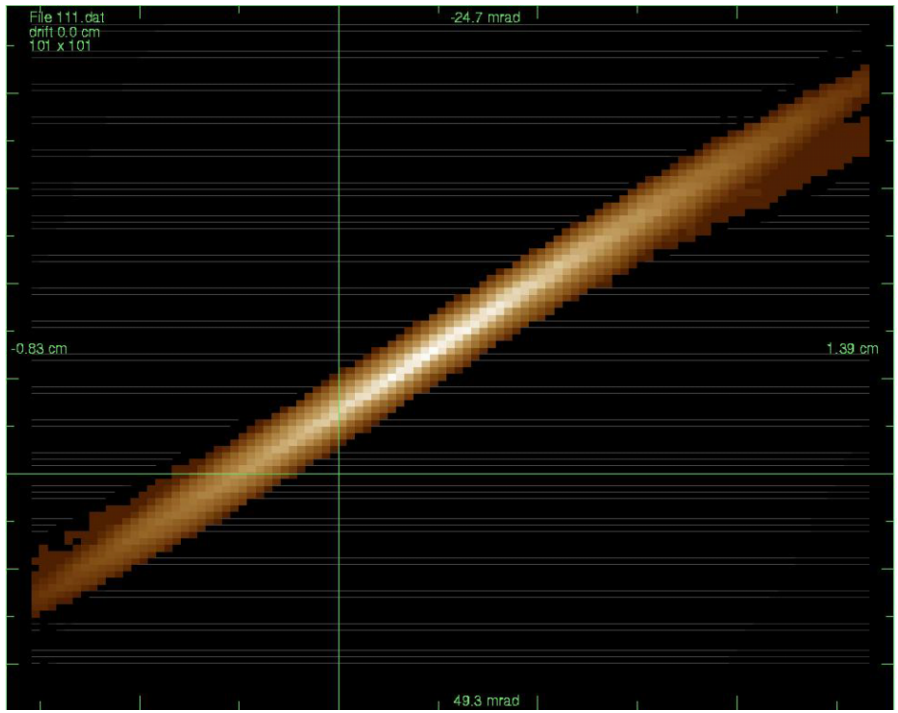


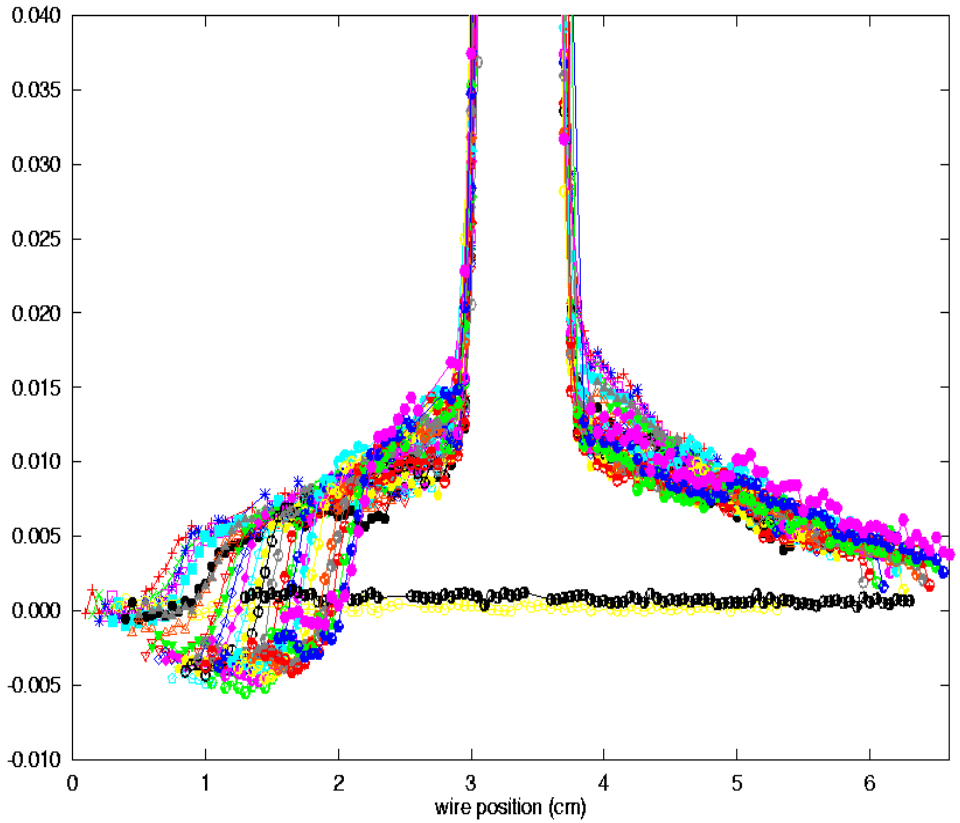


RFQ Commissioning at LBNL
Emittance

Vertical: 0.325 pi mm mrad (design goal: 0.3 pi mm mrad)

Distribution has about 1% floor most likely due to scattering (not emittance in this case)





Front End at Berkeley - 16 Devices
April 4, 2002 to May 31, 2002

2002 | 2003 | 2004 | 2005 | 2006

MEBT
6 Position
2 Current
5 Wires
1 Laser (test)
1 Emittance (0ne Plane)

All diagnostic systems were prototypes of linac systems

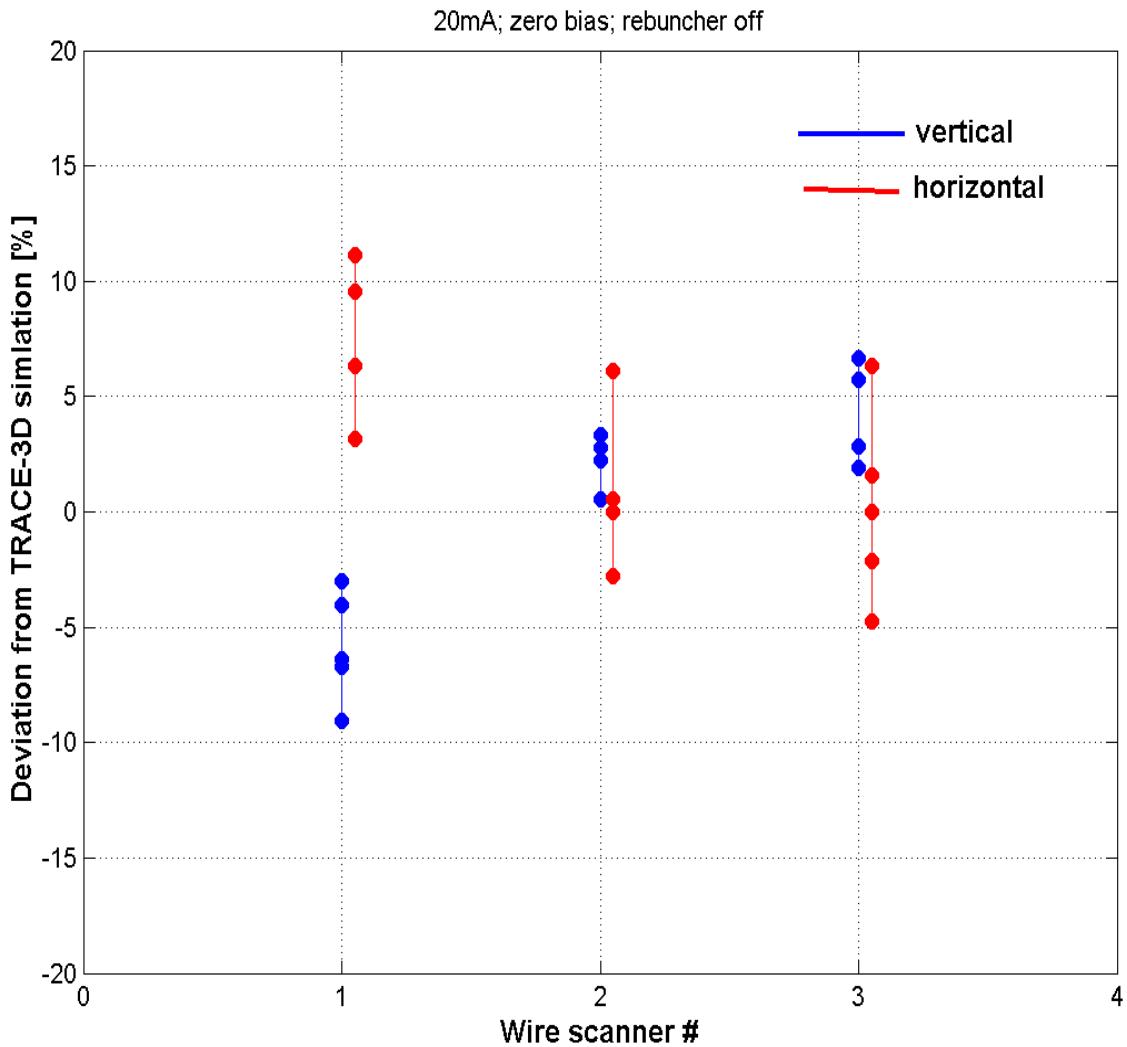
Integrated with EPICS via portable channel access

All integrated at LBNL within one week and delivered useful information for commissioning

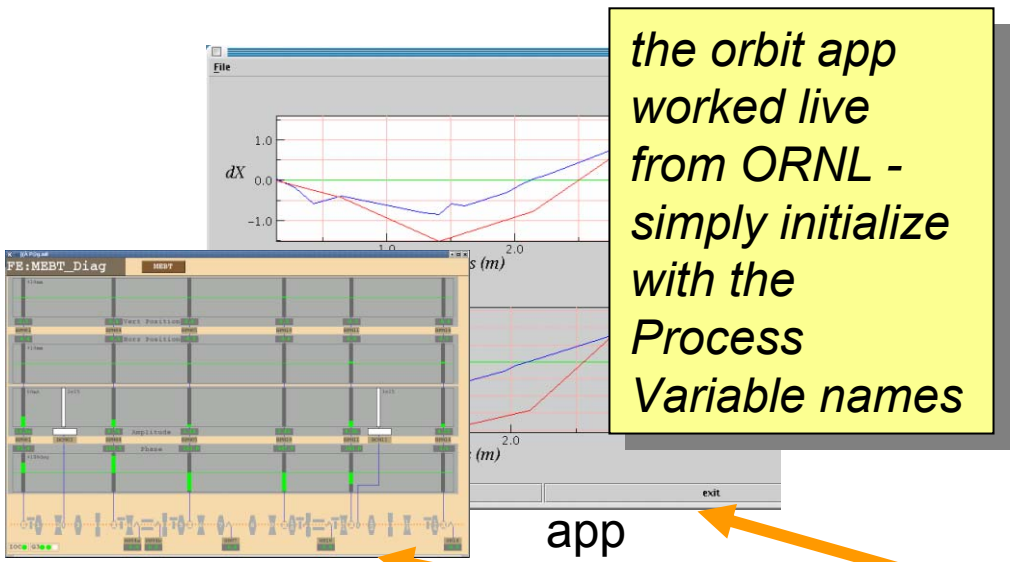
Photo Daryl Oshatz, LBNL

Carbon Wire Scanners

- This case: 20 mA debunched beam
- Compare measured rms transverse beam size to Trace3D simulation
- Virtually all measurements agree wi model to within 10%, mc within 5%



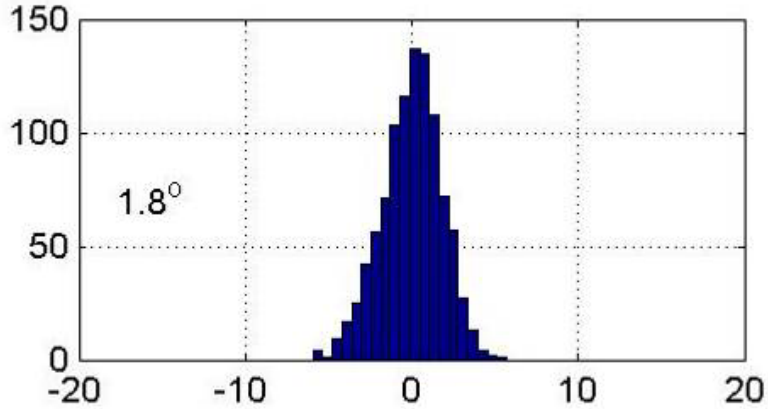
Beam Position Monitors
Position met spec; Phase was not quite there



the orbit app worked live from ORNL - simply initialize with the Process Variable names

app

EPICS screen



Histogram of BPM1– BPM2 phase difference (goal <<1deg)

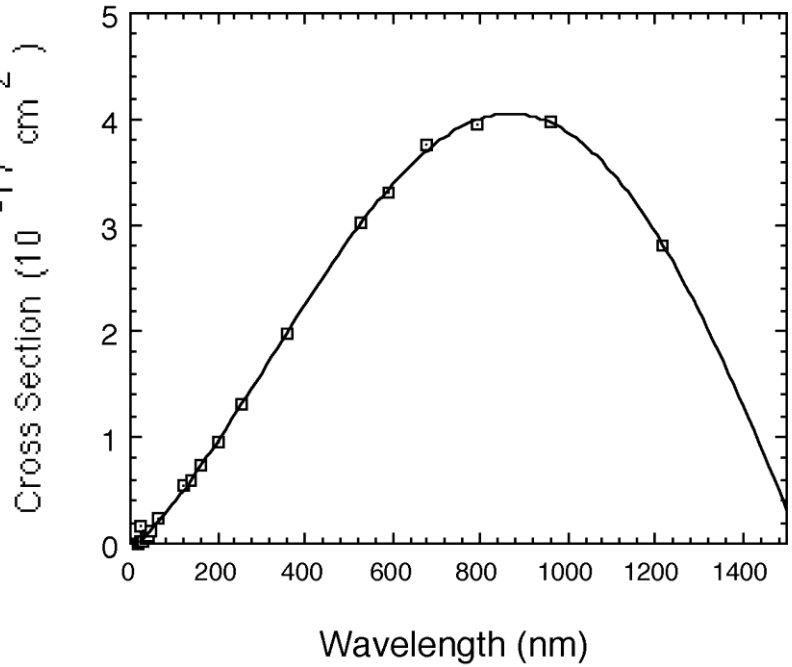
Channel Access

Electrodes - LBNL

Cables & install - LBNL

Electronics, NAD software - LANL

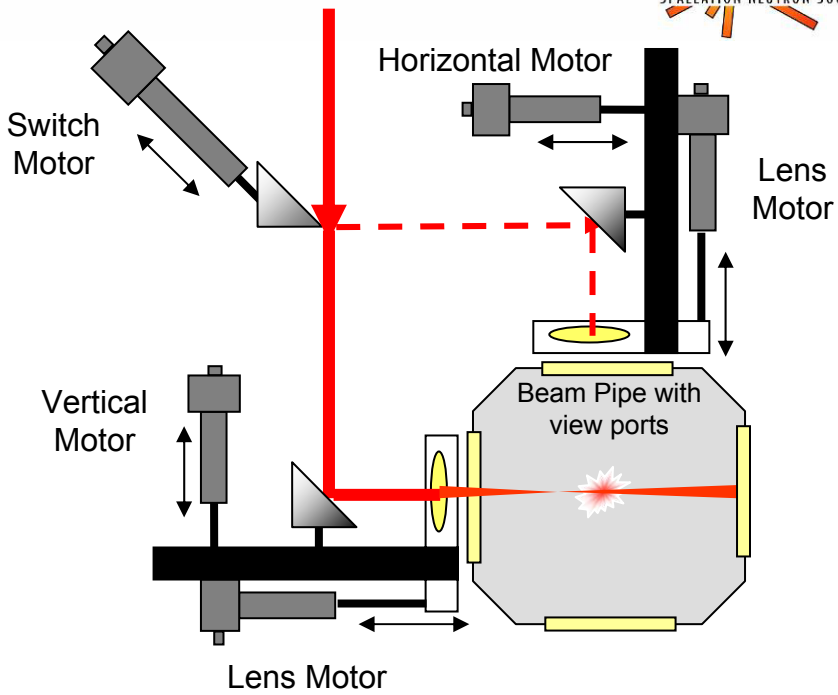
Laser Photo-neutralization of H- Ions



Calculated cross section for H- photoneutralization as a function of photon wavelength.*

Nd:YAG laser has λ=1064nm where the cross section is about 90% of the maximum.

*J.T. Broad and W.P. Reinhardt, Phys. Rev. A14 (6) (1976) 2159.

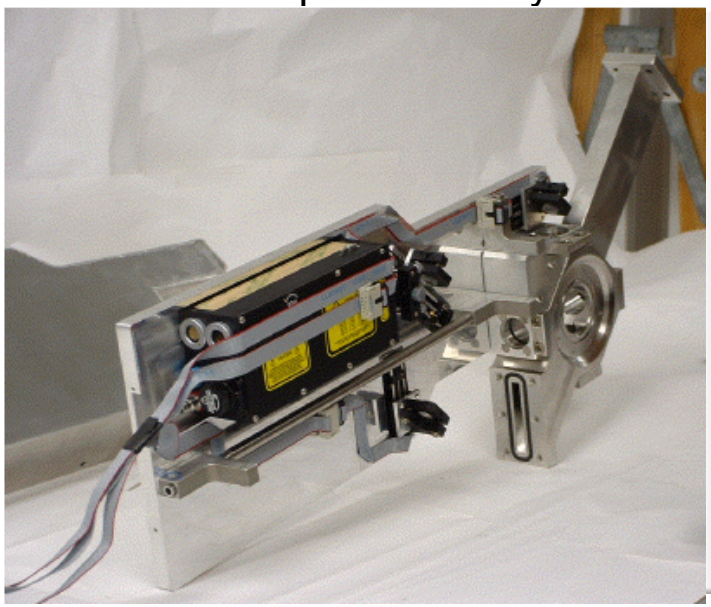


- Scan laser transversely across ion beam
- Plot one of the following vs. laser beam position:
  - Missing current in H- beam
  - Collected electrons liberated from H- beam

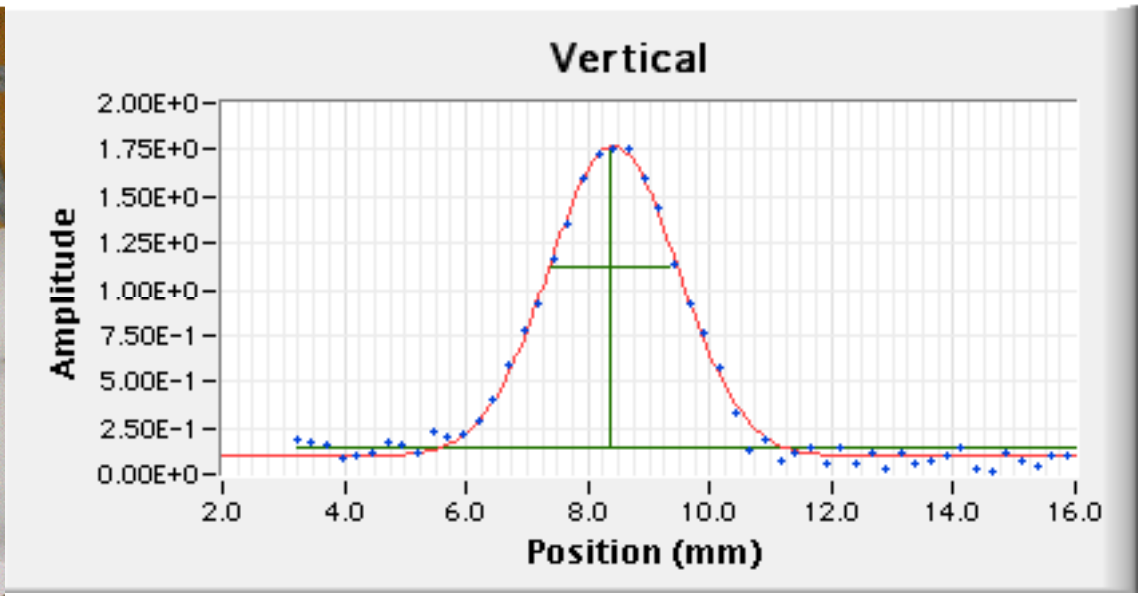
Transverse Profiles measured with Laser at LBNL

First measurement of SNS beam with by laser photo-neutralization

Small Nd YAG laser system provided by BNL and installed at LBNL, measurements performed by ORNL



Amplitude of missing beam current plotted vs Scanning mirror position

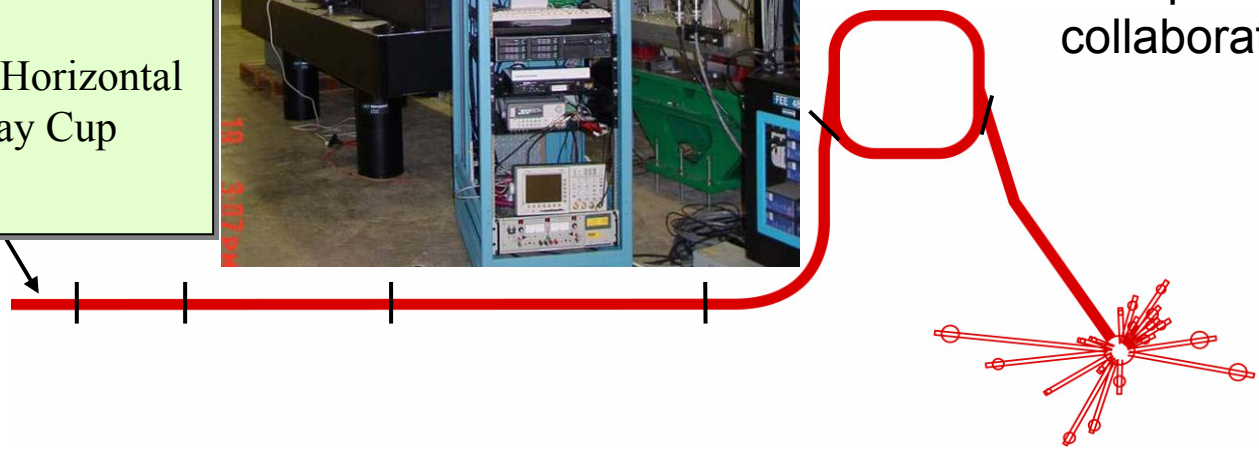


FE/MEBT at ORNL = 19 Devices
Nov 5, 2002 through Jan 31, 2003

2002 | 2003 | 2004 | 2005 | 2006

MEBT

6 Position
2 Current
5 Wires
2 Neutron
1 Emittance Horizontal
1 Fast Faraday Cup
1 SCL Laser

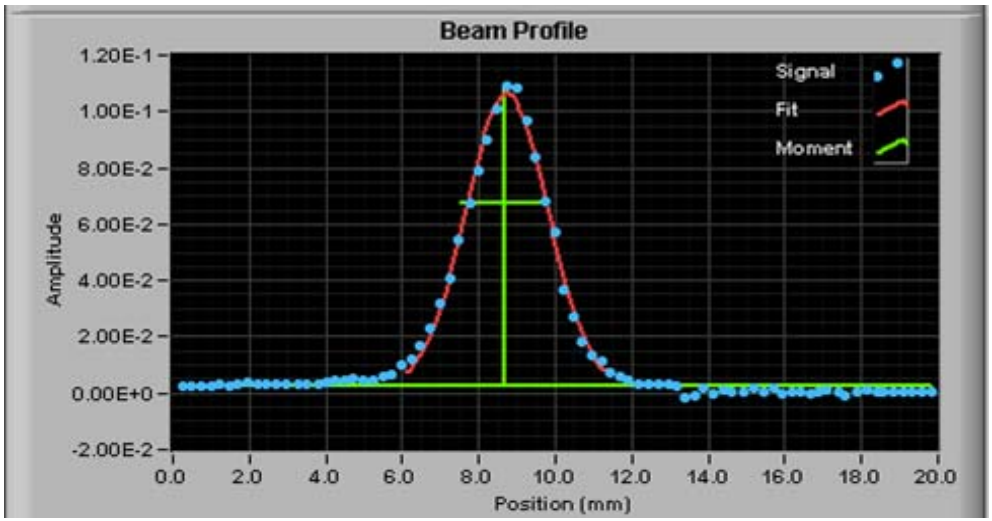


Test of SCL laser system, gap measurement

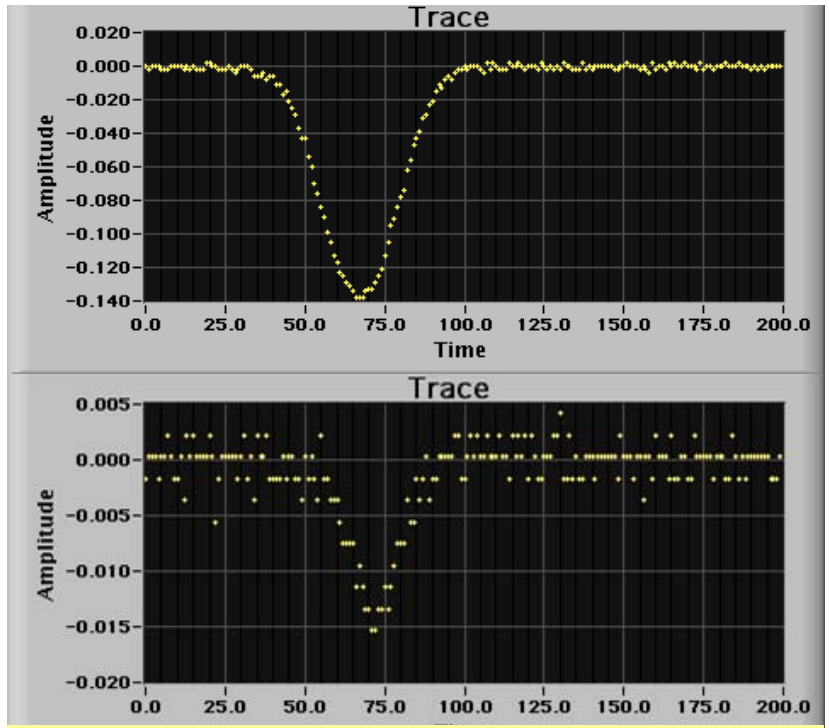
Based on LBNL experience, added neutron detectors (first borrowed from LBNL, then part of INR collaboration)

Front End at ORNL – Jan 2003
Laser Profile Monitor Results at 2.5 MeV

- Verification of **electron collection** for SCL laser profile monitor
- Reliable measurements to about **3 sigma**
- Anti-reflection coating for final windows.
  - May measure well beyond 3 sigma.



Horizontal Profile
1/25/2003 13:06
Gaussian fit plotted out to 2.5x Sigma
Sigma = 1.07 mm



Signal from electron collector
Top: laser intercepting beam core
Bottom: laser intercepting beam tail

Through DTL Tank 1/D-Plate: 31 Devices
August 26 through Nov 17, 2003

2002 | 2003 | **4** | 2004 | 2005 | 2006

last run at full power until beam on target

Diff BCM (analog)

Test BSM

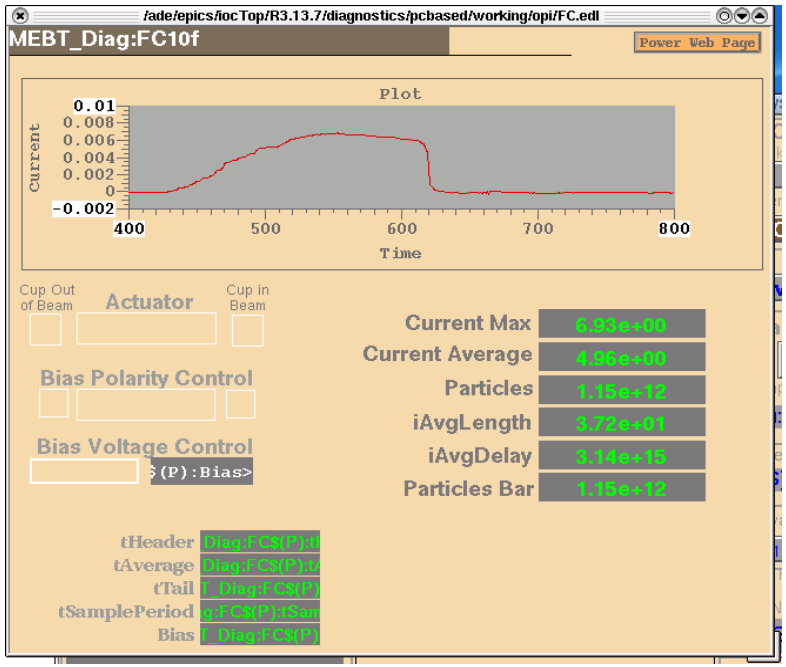
Migration to EPICS IOC core, structured LabVIEW

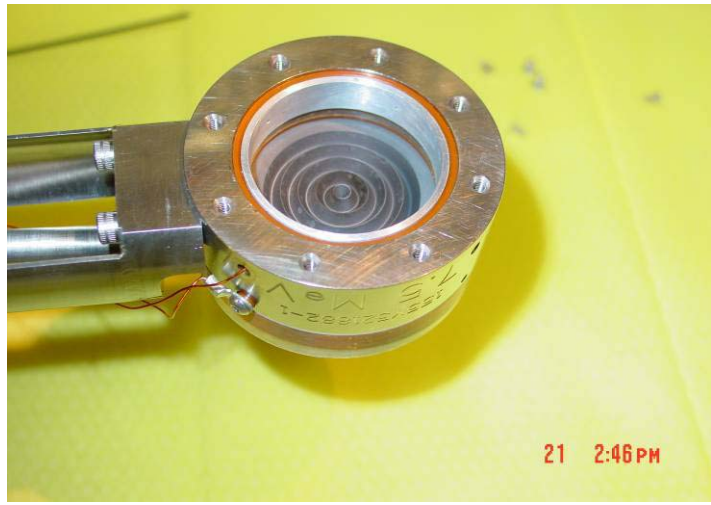
MEBT
6 Position
2 Current
5 Wires
2 Thermal Neutron
1 Fast Faraday Cup
1 Faraday/Beam Stop
Differential BCM

DTL/D-Plate
2 Position 1 Current 2 Wire 7 Ion Chamber 4 Thermal 3 Semi 2 Faraday Cup 1 Bunch
1 Video 1 Halo 3 Neutron 1 Beam Stop Faraday Cup
1 Emittance (Slit and Collector) Differential BCM

DTL Faraday Cup

- First beam through DTL-1 Tank was seen on console in control room.





Typical
Faraday
Cup (energy degrader removed)

Commissioning through first 3 (of 6) DTL Tanks: 54 Diagnostic Devices

D-plate removed

Added D-box to MEBT for inline emittance and others

Improved phase performance of all BPMs

MEBT
6 Position
2 Current
5 Wires
2 Thermal Neutron
1 Emittance Horizontal
1 Emittance Vertical
1 Faraday/Beam Stop
D-box emittance
D-box beam stop
D-box aperture
Differential BCM

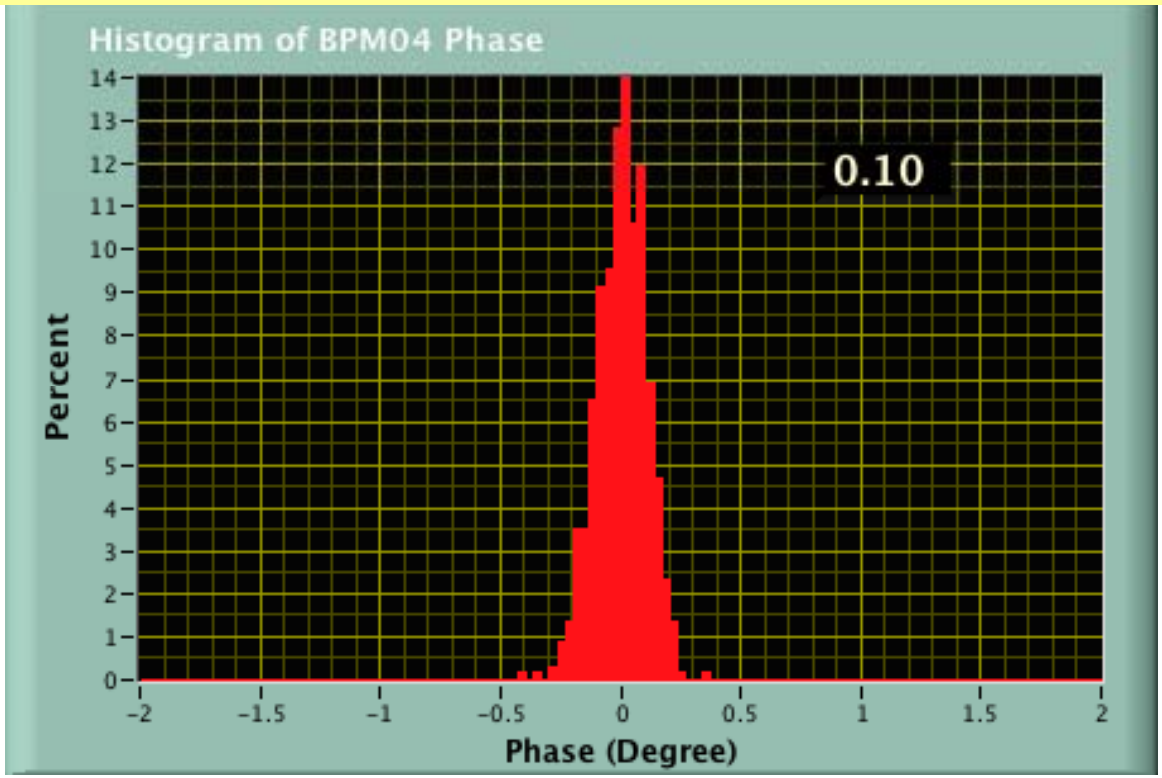
DTL
5 Position 3 Wire
3 Faraday Cup 3 Current
7 Loss Ion Chamber Differential BCM
4 Thermal 3 Semiconductor

BPM delivers Position and Phase
DTL3 Results Pulse-to-Pulse Phase Jitter

LLRF Goal: 0.5 degrees (at 402.5 MHz)

Measurements as low as 0.1 degrees at 805 MHz (0.05 deg @ 402.5) indicate that BPM/Phase diagnostics are meeting spec (also validates new LLRF systems)

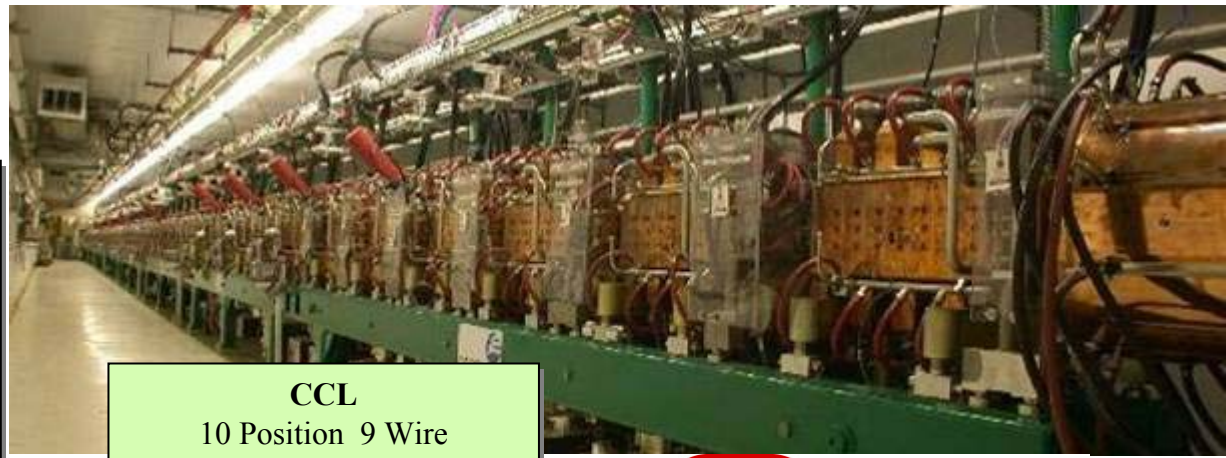
Histogram of measured beam phase with respect to RF reference



CCL commissioning: 136 Devices

2002 | 2003 | 2004 | 2005 | 2006

6



MEBT
6 Position
2 Current
5 Wires
2 Thermal Neutron
1 Emittance Horizontal
1 Emittance Vertical
1 Mode-locked Laser
1 Faraday/Beam Stop
D-box emittance
D-box beam stop
D-box aperture
Differential BCM

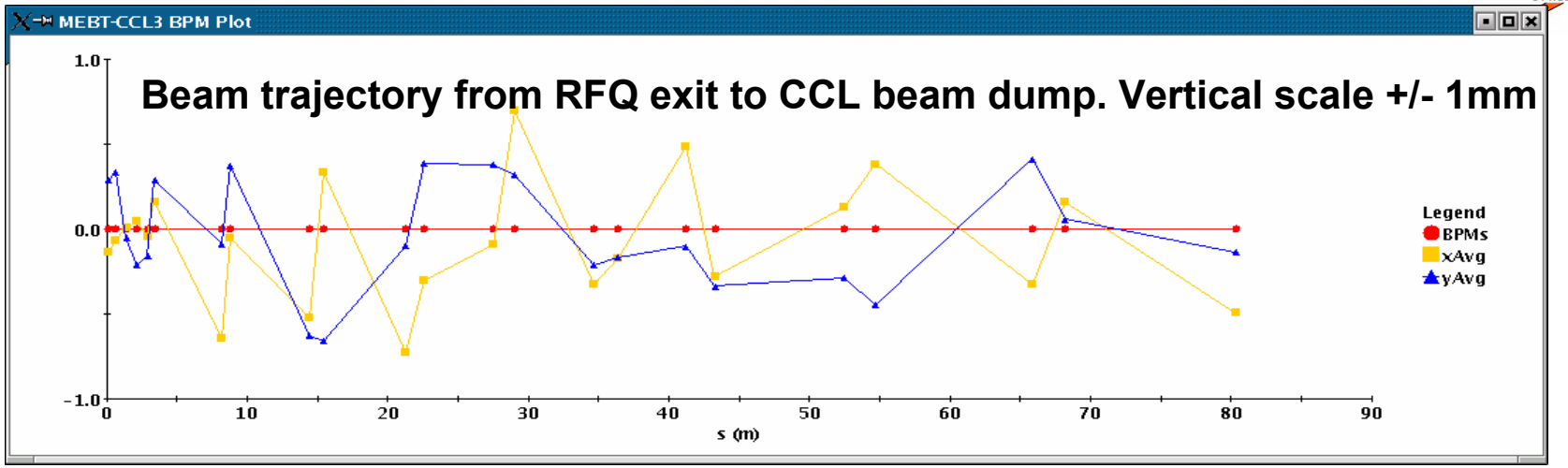
CCL
10 Position 9 Wire
8 Neutron, 3 BSM,
2 Thermal
28 Loss 3 Bunch
1 Faraday Cup 1 Current
1 Dump

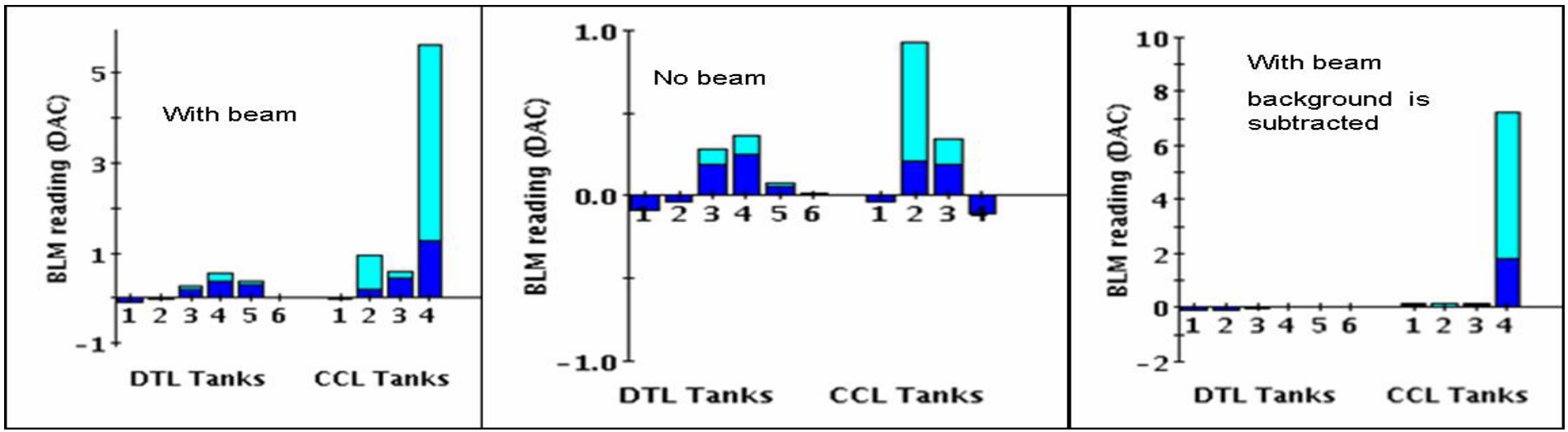
DTL
10 Position 5 Wire 12 Loss
5 Faraday Cup 6 Current
6 Thermal and 12 PMT Neutron
Differential BCM

Tools to support large scale deployment: database configuration control, Altiris, Windows XP, collaboration with IT

Migrate to fiber distribution of Diagnostics RF reference

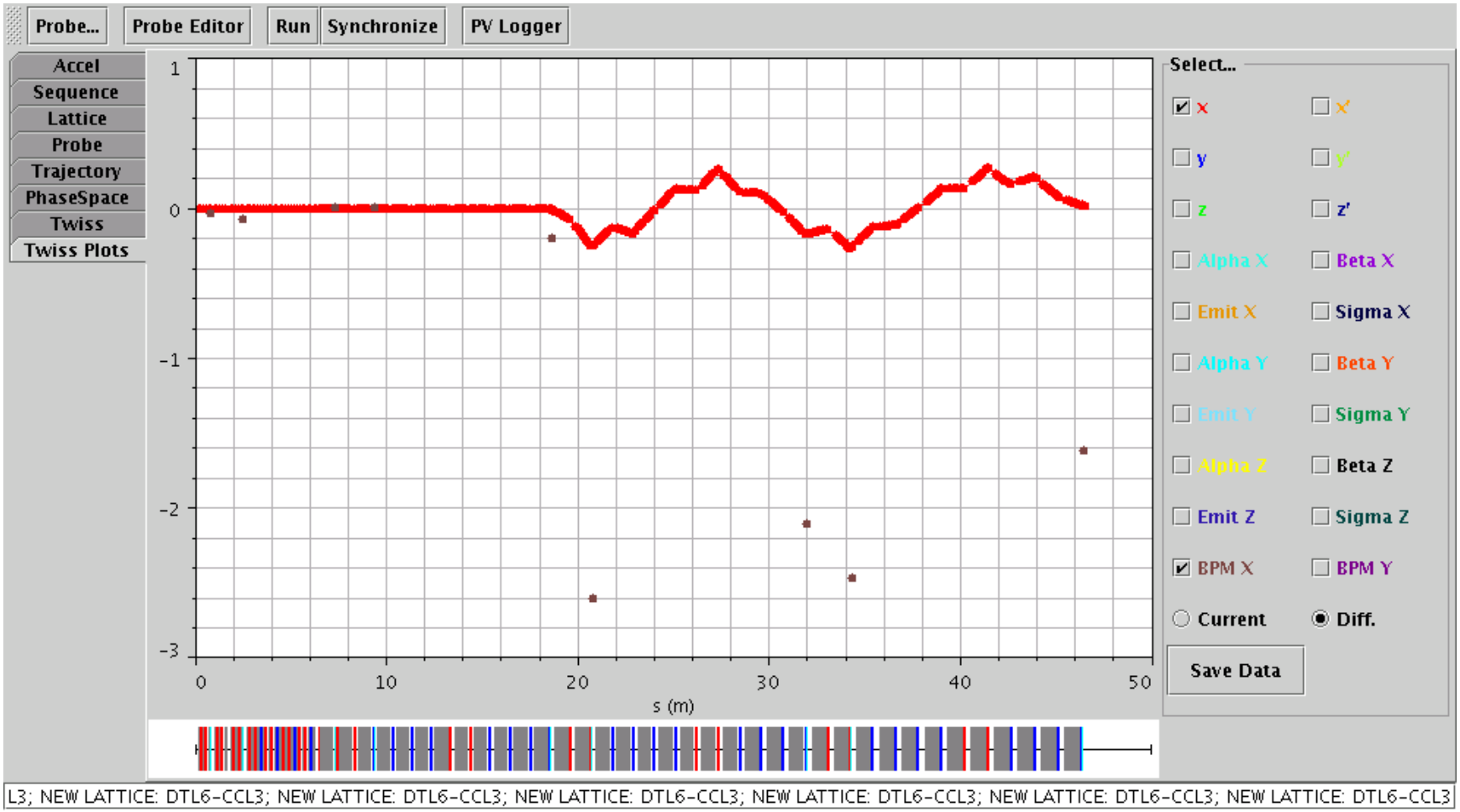
Position and loss measurements through CCL





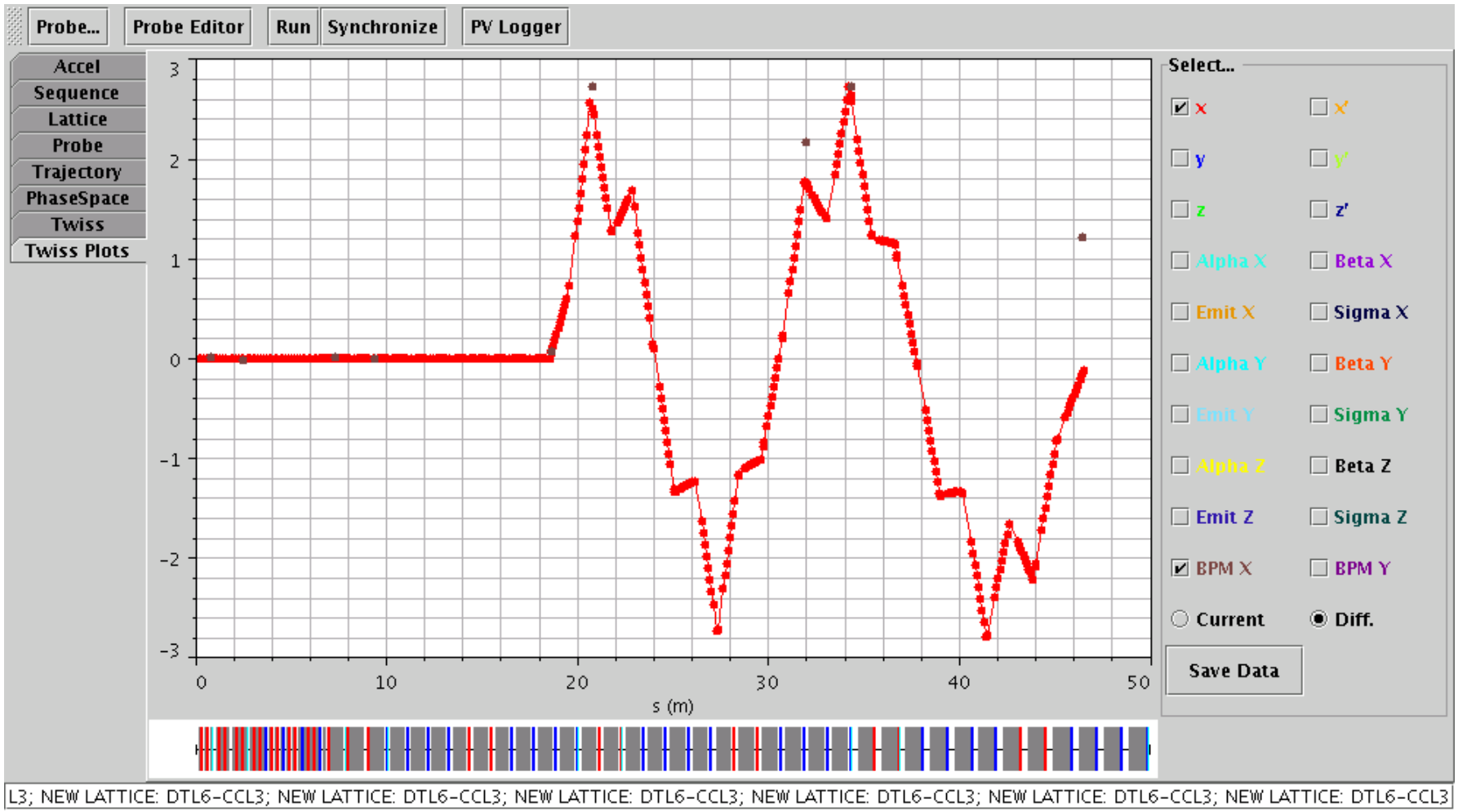
Beam loss distribution along the linac. Raw data with beam on (left), no beam (center), With beam on and subtracted background (right). Now integrated with machine protect system.

Difference orbit through CCL first try
Model vs measurements



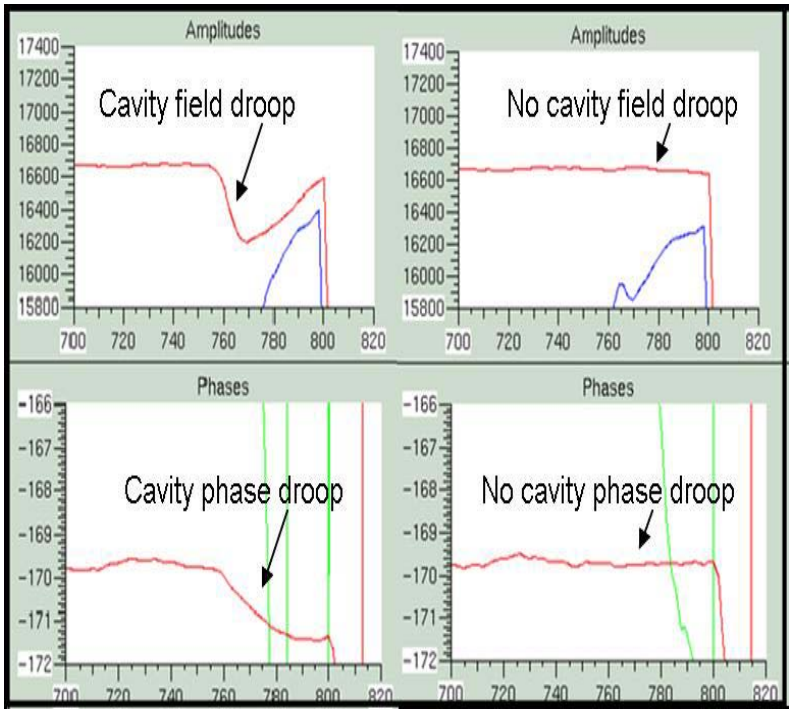
Plots by P. Chu

Difference orbit after correcting integrated field values in model

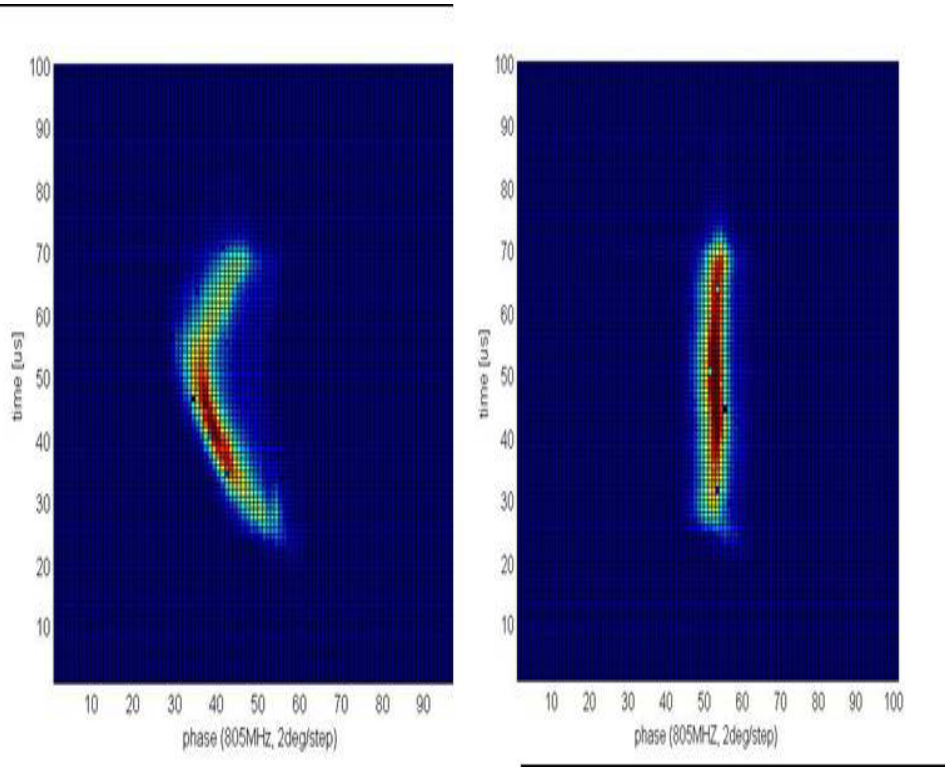


Plots by P. Chu

Effect of beam loading in the Linac Bunch Shape Monitor results



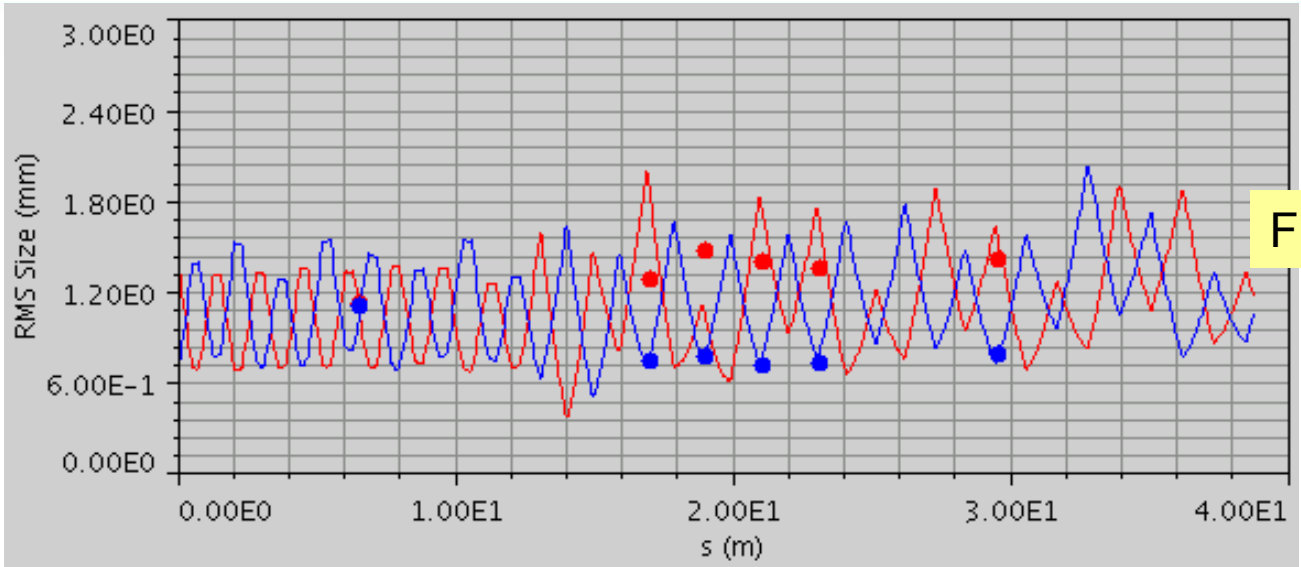
Cavity field and phase droop with feedback alone (left) and feedback + feedforward (right) beam loading compensation.



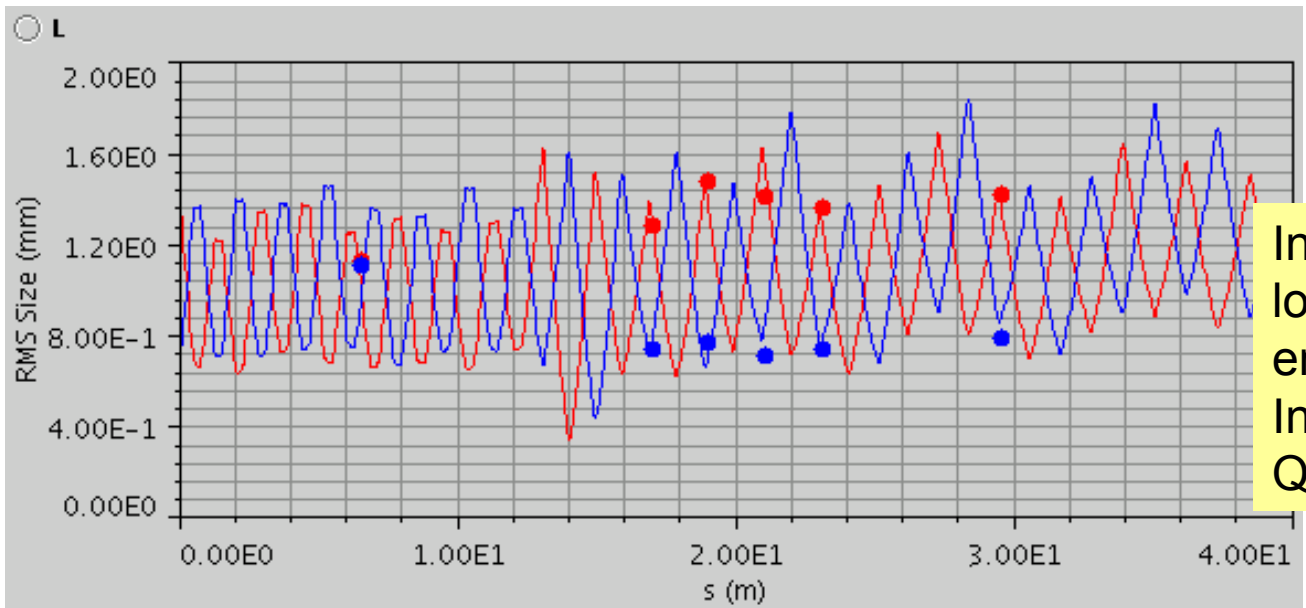
Phase width of the bunch along the pulse with feedback alone (left) and feedback + feedforward (right).

Phase width in CCL is larger than design value.

Simulated beam envelope compared to Carbon wire scanners results in DTL and CCL



First try

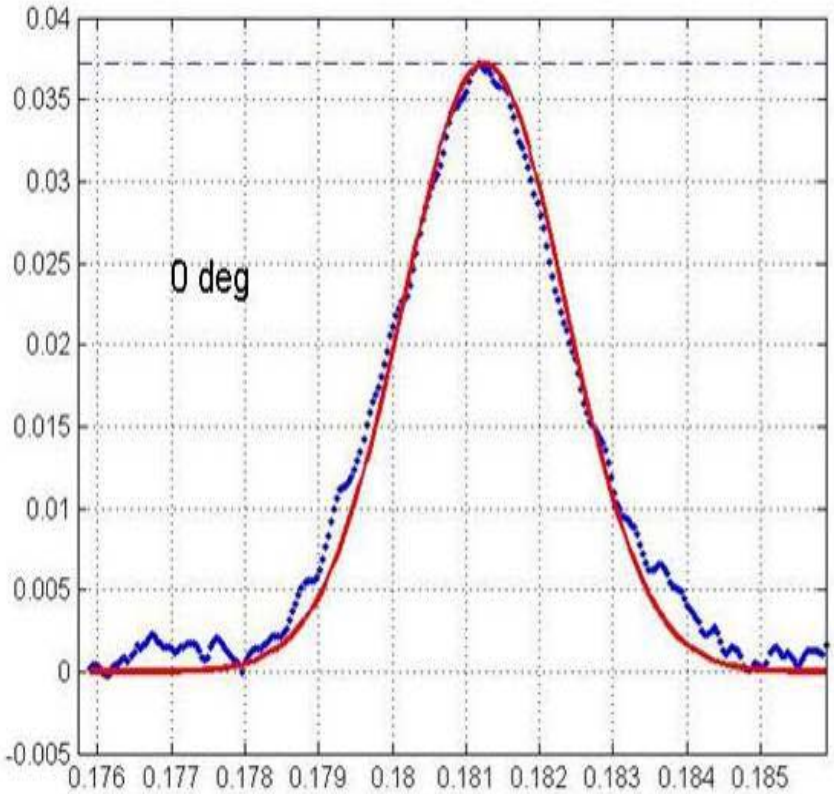


In model, increase longitudinal emittance x 3 and Increase Quad QH102 by 6%:

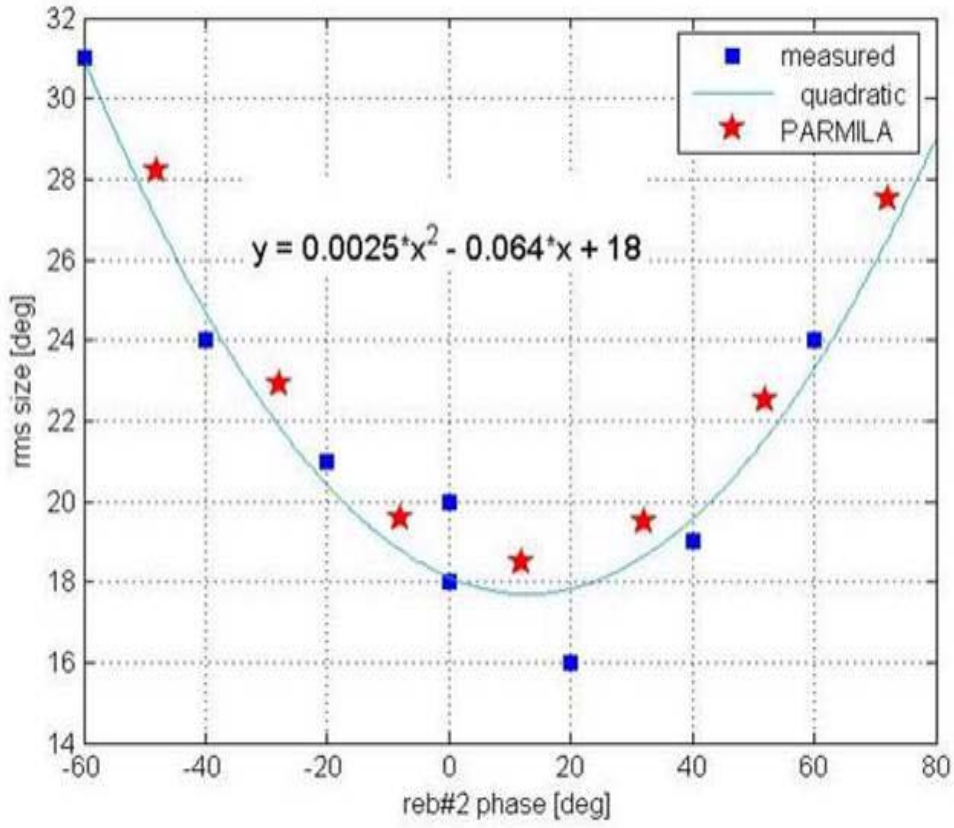
Plots by J. Galambos

Mode Locked Laser
First Longitudinal Measurements

2.5 MeV H-, 402.5 MHz bunching freq, TiSapphire laser phase-locked @ 1/5th bunching freq;

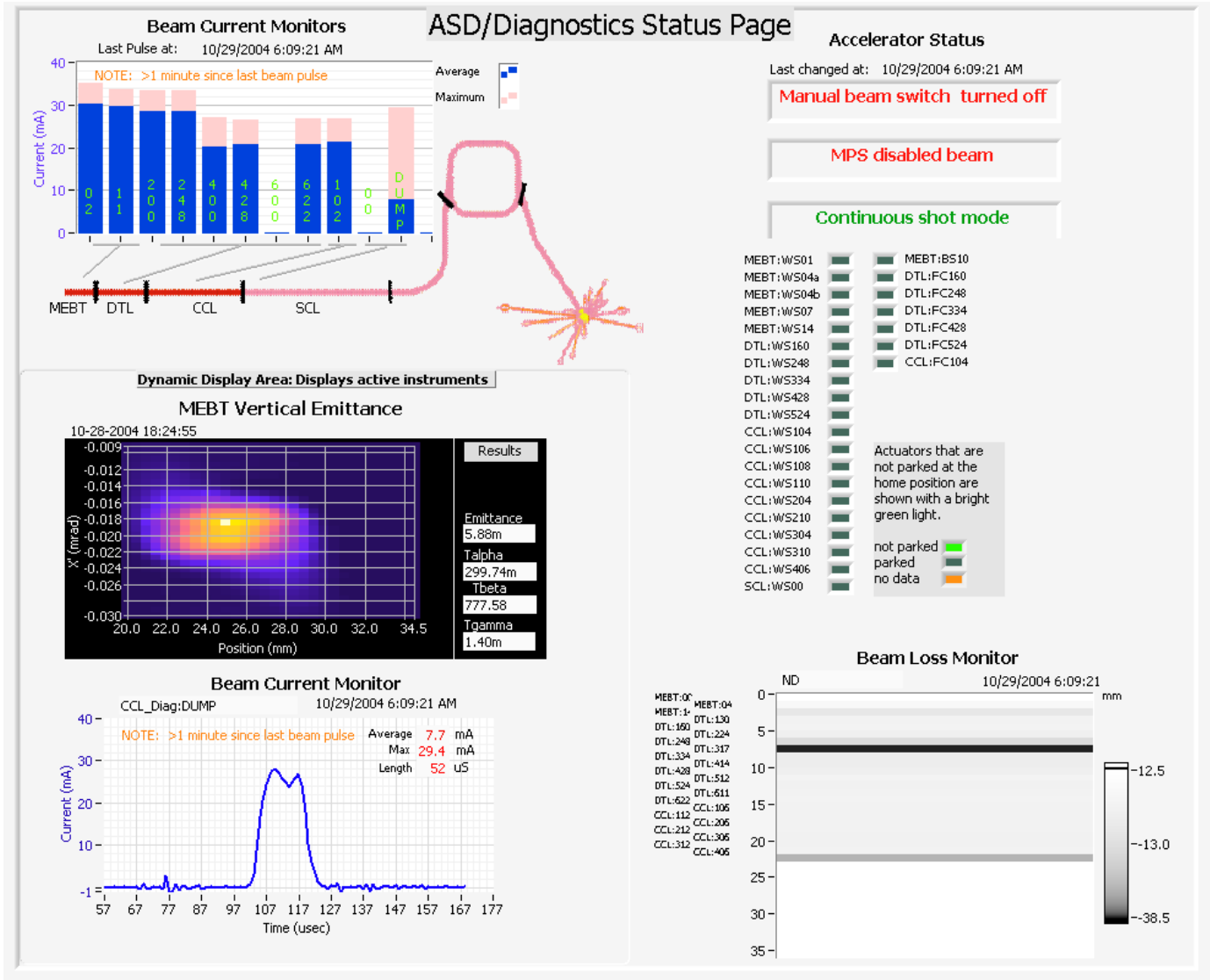


collected electron signal plotted vs. phase



Measured and predicted bunch length vs. cavity phase setting

Global view provided by Channel 13
An example supervisory layer application



W. Blokland
M. Sundaram
C. Long

Complete Linac: 326 Devices
Commissioning begins late summer 2005

2002 | 2003 | 2004 | 2005 | 2006

MEBT
6 Position
2 Current
5 Wires
2 Thermal Neutron
1 Emittance Horizontal
1 Emittance Vertical
1 Fast Faraday Cup
1 Mode-locked Laser
1 Faraday/Beam Stop
D-box video
D-box emittance
D-box beam stop
D-box aperture
Differential BCM

CCL
10 Position 9 Wire
8 Neutron, 3 BSM,
2 Thermal
28 Loss 3 Bunch
1 Faraday Cup 1 Current
1 Dump

DTL
10 Position 5 Wire 12 Loss
5 Faraday Cup 6 Current
6 Thermal and 12 PMT Neutron
Differential BCM

CCL/SCL Transition
2 Position 1 Wire
1 Loss 1 Current

SCL
32 Position 86 Loss
8 Laser Wire
7 PMT Neutron

HEBT
11 Position
5 Wire
17 BLM, 3 FBLM
2 Current

LDump
6 Loss
6 Position
1 Wire ,1 BCM

Ring then to Target: 602 Devices Commissioning in first half of 2006

MEBT
6 Position
2 Current
5 Wires
2 Thermal Neutron
1 Emittance Horizontal
1 Emittance Vertical
1 Fast Faraday Cup
1 Mode-locked Laser
1 Faraday/Beam Stop
D-box video
D-box emittance
D-box beam stop
D-box aperture
Differential BCM

IDump
1 Position
1 Wire
1 Current
6 BLM

RING
44 Position 2 Ionization Profile
70 Loss 1 Current
5 Electron Det. 12 FBLM
2 Wire 1 Beam in Gap
2 Video 1 Tune

CCL
10 Position 9 Wire
8 Neutron, 3 BSM,
2 Thermal
28 Loss 3 Bunch
1 Faraday Cup 1 Current
1 Dump

EDump
1 Current 4 Loss
1 Wire

RTBT
17 Position
36 Loss
4 Current
5 Wire
1 Harp
3 FBLM

DTL
10 Position 5 Wire 12 Loss
5 Faraday Cup 6 Current
6 Thermal and 12 PMT Neutron
Differential BCM

CCL/SCL Transition
2 Position 1 Wire
1 Loss 1 Current

SCL
32 Position 86 Loss
8 Laser Wire
7 PMT Neutron

HEBT
29 Position 11 Wire
46 BLM, 3 FBLM
4 Current

LDump
6 Loss
6 Position
1 Wire ,1 BCM

Summary

- The SNS Diagnostics Team has deployed a variety of instruments that is unprecedented at this stage of commissioning.
- Interleaving commissioning and installation has been challenging, but based on experience from early commissioning runs, several systems have already been added or upgraded.
- System readiness, controls integration, and general performance has been outstanding.
- 50% of our beam instrumentation is installed; 25% is commissioned with beam.
- All partner laboratories have completed their work and Oak Ridge now has full responsibility.

- It will be a busy year.