Beam Instrumentation Performance and Plans

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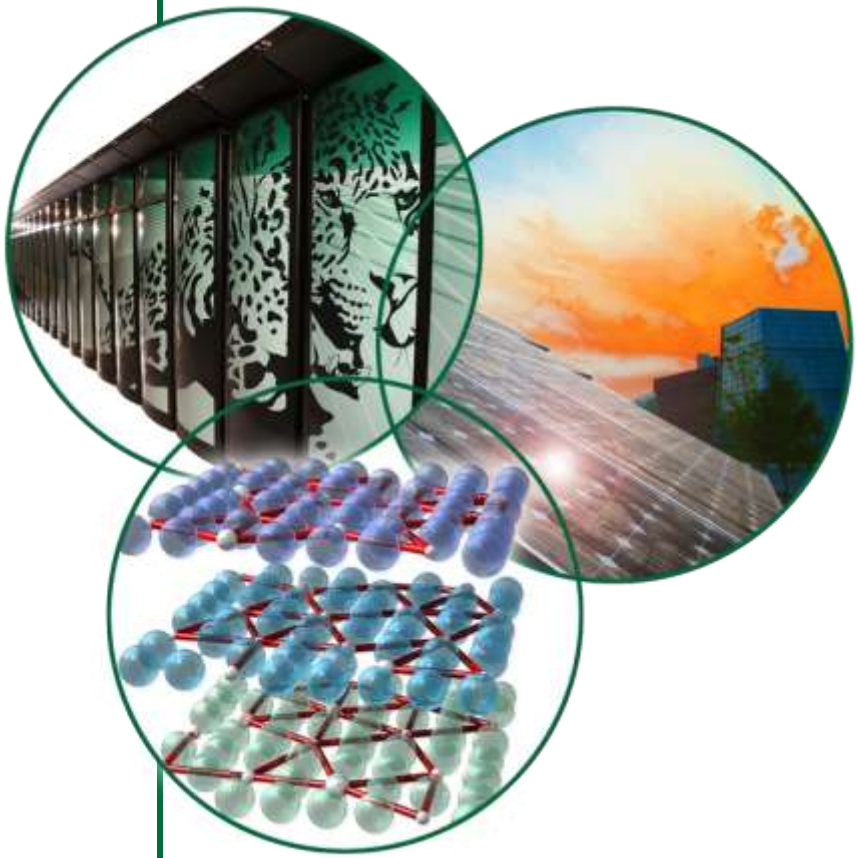
Beam Instrumentation
Team Leader

January 11, 2012



U.S. DEPARTMENT OF ENERGY

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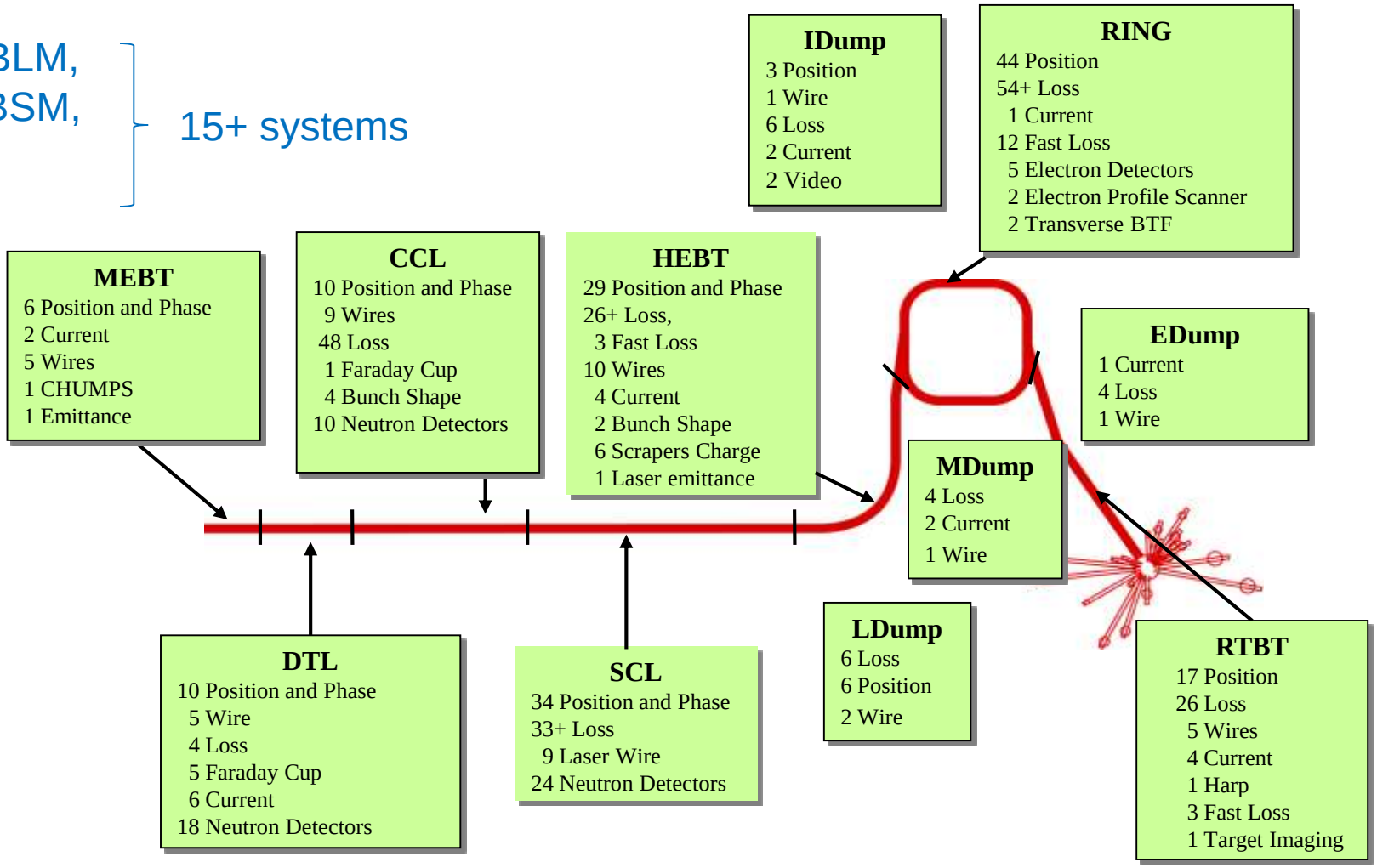
SNS Beam Instrumentation Systems are Numerous, Diverse and Growing in Number

BCM, BLM, BPM, BSM, WS….

15+ systems

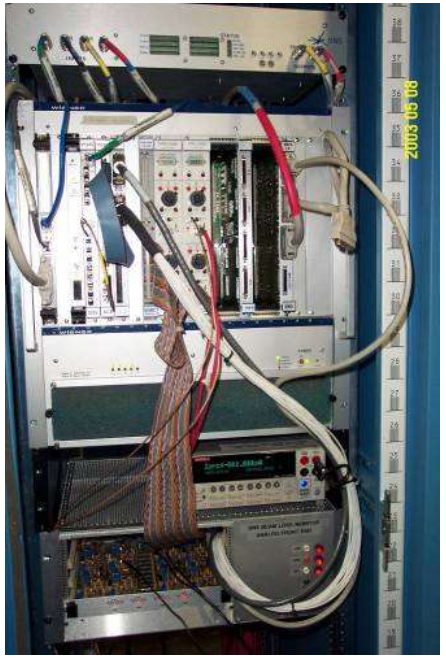


Outline

- Status and upgrade plans for selected systems:
  - Nominal Operation
    - Beam Loss Monitors
  - Machine Tuning
    - Beam Position and Phase Monitors
  - Beam Power Increase
    - Foil Image and Temperature
    - Ring Transverse Feedback and Beam Transfer Function Measurement
  - Machine Study and Loss Reduction
    - Transverse Profiles and Halo
    - Transverse Emittance
    - Longitudinal Profiles

Beam Loss Monitors (BLMs)

- Major tool for machine protection and tune up
- Ionization Chamber Detectors (307)
- Scintillation Detectors (55)
  - Neutron detectors
  - Fast loss detectors
- Multi-channel analog front-end VME cards
- Digital electronics in VME crate
- VxWorks software
- Very reliable



- Hardware obsolescence is looming problem
- Short term solution: stock up on spares
- Long term solution: new system

New BLM development

Courtesy of A. Zhukov

- **Guiding Principles:**
  - Compatible with existing EPICS and MPS infrastructure
  - Less custom, more off-the-shelf components
  - No major functionality changes
- **Analog Front End:**
  - Single channel Individual cards
  - Provision for analog background subtraction
  - Chassis satisfies “technical transparency”
  - Have had two chassis installed in SCL for testing
- **Digital Processing:**
  - Have not decided yet on what to use
  - National Instruments Compact RIO chassis is under consideration
  - New Compact RIO FPGA processor for HEBT scrapers is being installed
    - requirements are similar to BLM

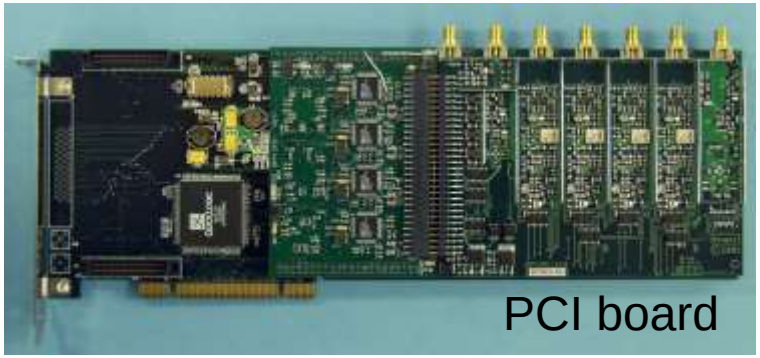
New analog front-end card

NI CRIO chassis

Beam Position and Phase Monitors (BPMs)

- Main tool for machine tune-up and troubleshooting
  - Phase measurements for linac tune-up
  - Position measurements for trajectory correction, injection set-up and centering beam on dumps and target
- 160 strip-line pick-ups
  - 96 “linac type” operate at 402.5MHz and 805MHz
  - 64 “ring type” operate at low frequency
- Custom made PCI analog front-end and digital cards
- LabView software under embedded Windows XP on individual PCs (one per pick-up), 6Hz trigger rate
- Meets all accuracy specs but reliability is not stellar


BPM pick up

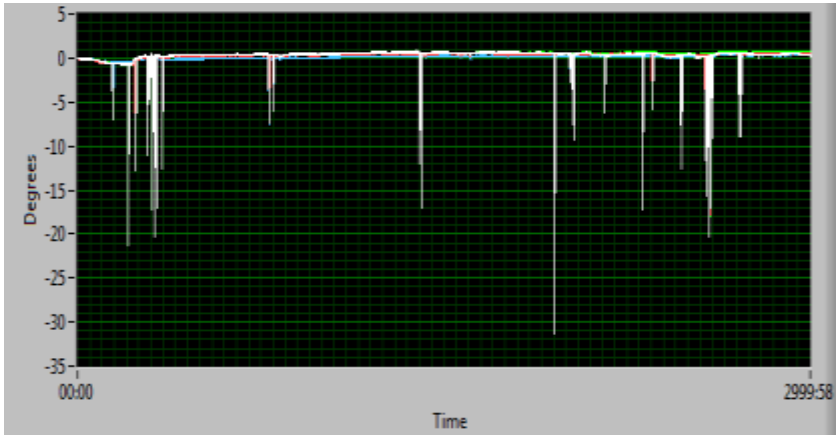

PCI board


BPM PC

- Hardware obsolescence is major problem
  - Parts, cards, PC motherboards, OS upgrades
- Short term solution: stock up on spares
- Long term solution: new system

New BPM development

- **Guiding Principles:**
  - Compatible with existing EPICS and Reference RF infrastructure
  - Less custom, more off-the-shelf components
  - No major functionality changes but 60Hz capable
- **Analog Front End:**
  - As similar to SNS LLRF front-end card as possible
  - Investigating need for continuous TDR self-calibration
  - Chassis satisfies “technical transparency”
  - Plan to have 1 chassis for testing by end of FY12
- **Digital Processing:**
  - Have not decided yet on
  - needs more processing power than BLM
  - National Instruments Flex RIO in PXIe chassis is under consideration
  - Plan to have 1 chassis for testing by end of FY12

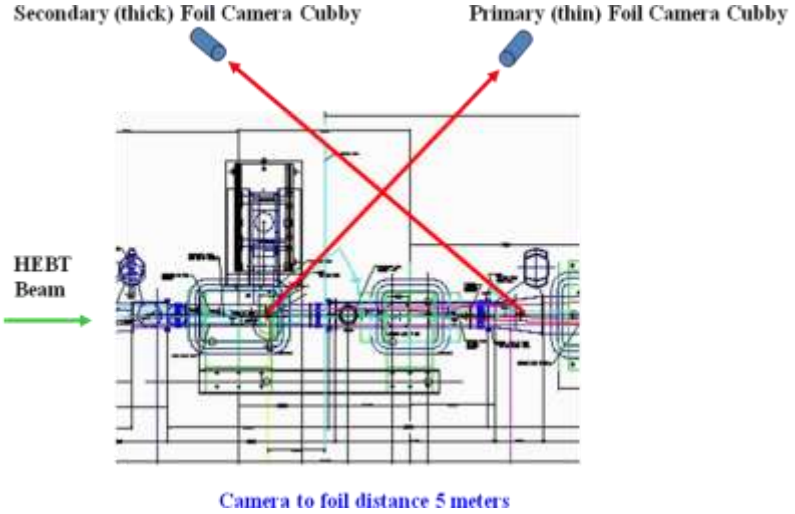


History of BPM TDR self-calibration data

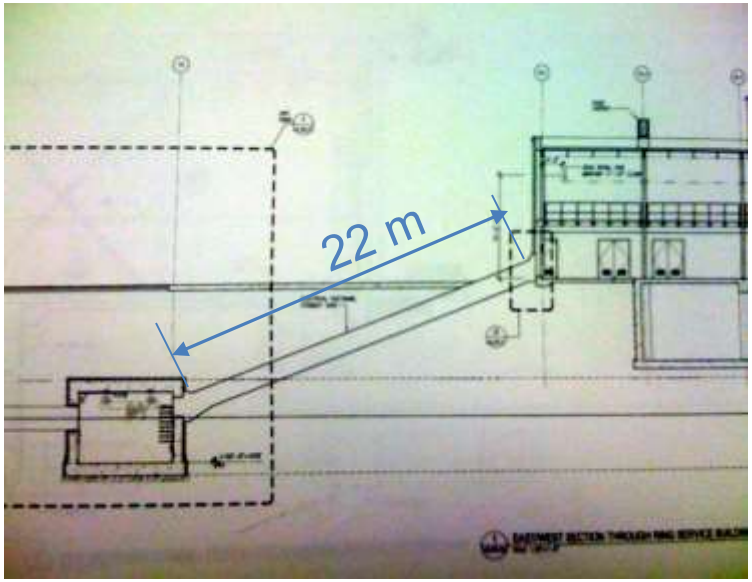
Goal: deploy 1 new ‘linac type’ BPM in FY12 summer shutdown for in-the-field performance evaluation

Injection Foil Imaging System

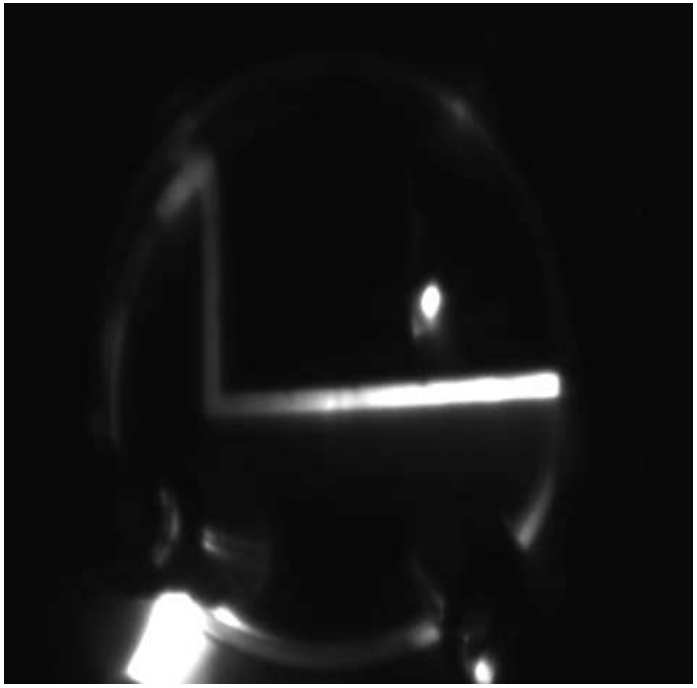
- Analog in-tunnel radiation hard camera has been used for injection foil imaging
  - Expensive maintenance
  - Not suitable for time-resolved optical pyrometry
  - Not optimal for foil shaking observation due to fixed and limited update rate (30Hz)



- New optical transmission line with digital camera outside of tunnel
  - High-End scientific cameras can be used
  - Infrared detectors can be used for temperature measurements
  - No maintenance in radiation areas



Optical transmission line

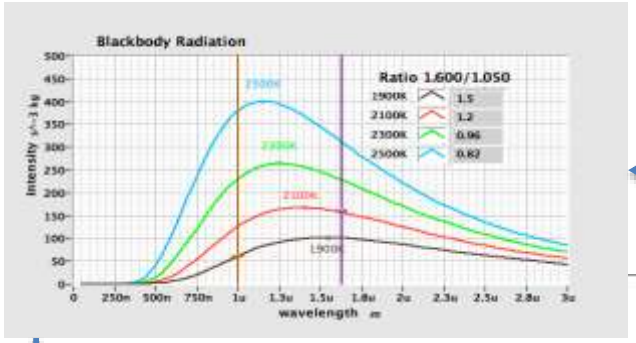


- Two 8” flat mirrors mounted on the wall in the tunnel
- A commercial off-the-shelf 6” telescope
- Digital scientific camera and/or other detectors

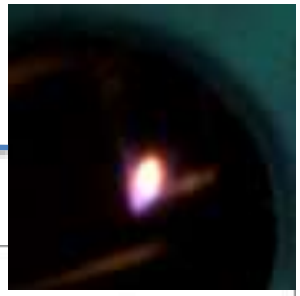
Foil Temperature Measurements

Two-color optical pyrometer

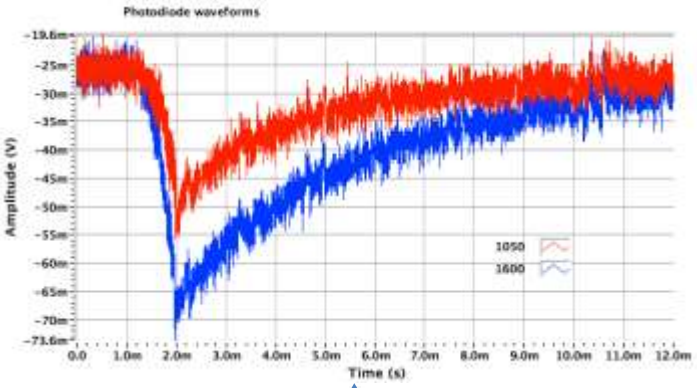
Courtesy of W. Blokland

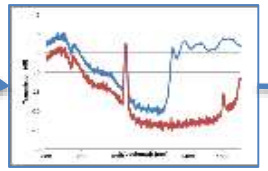


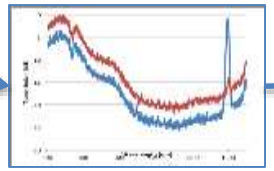
Black body radiation



Foil







Filters

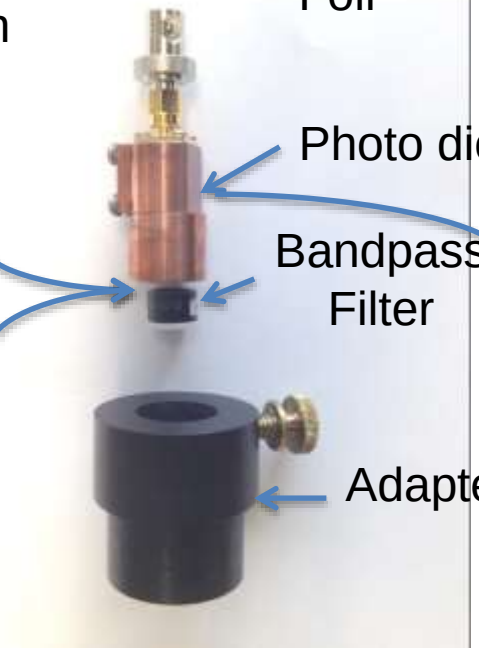


Photo diode

Bandpass Filter

Adapter

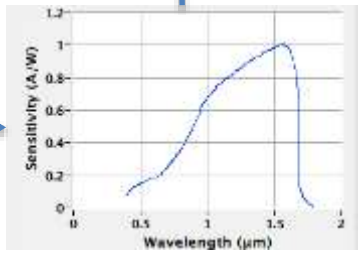
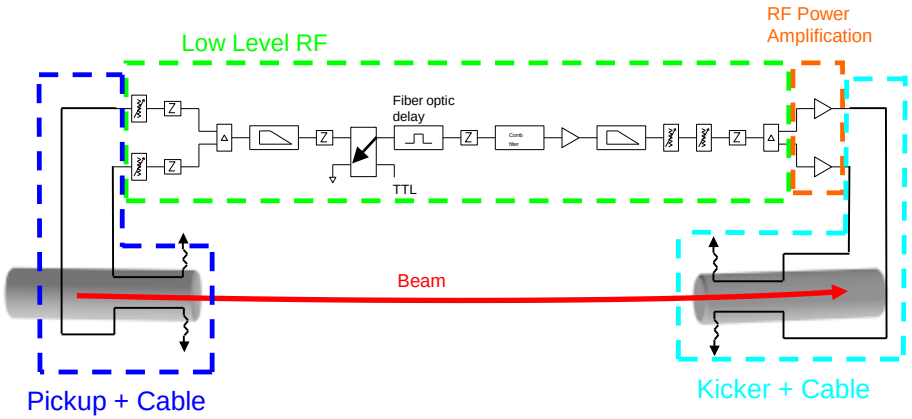


Photo diode

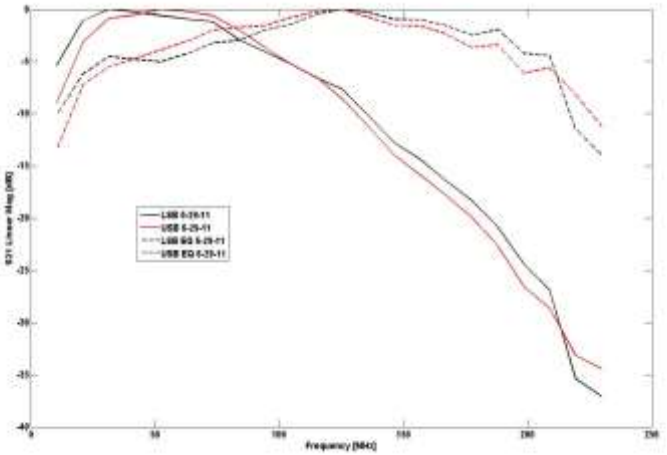
Ring Transverse Feedback System

- Suppressing e-p instability is primary goal
  - 1-300MHz bandwidth
  - 200/400 W/channel peak power
- Have analog LLRF system commissioned
- Digital LLRF is being commissioned



BPM and kicker tuning

Feedback electronics



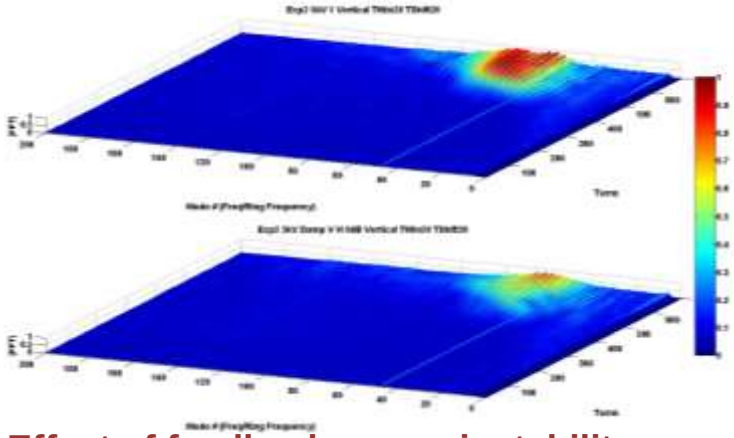
Measured system bandwidth

Courtesy of C. Deibele

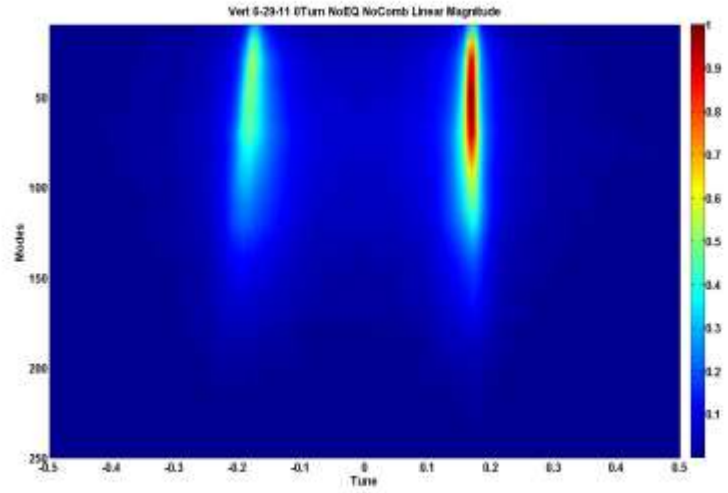
Ring Transverse Feedback / BTF Measurement System Performance

Courtesy of R. Hardin

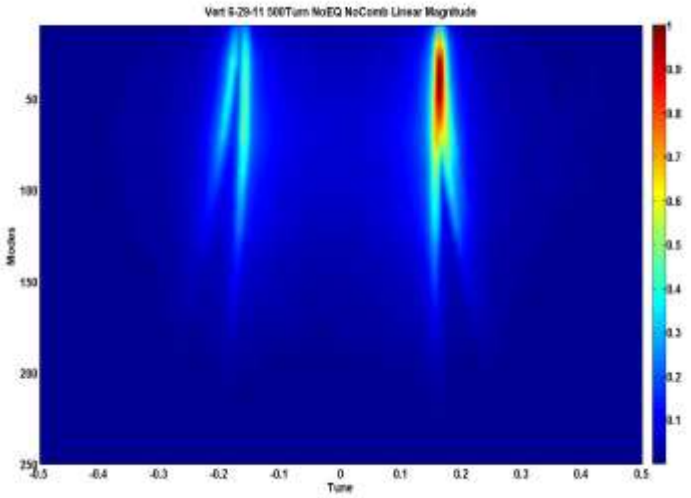
- Have demonstrated e-p instability suppression, but results are not repeatable and consistent
- Have implemented Beam Transfer Function (BTF) measuring technique
- Have observed unexpected, and so far unexplained beam response
  - Can be a key to successful e-p damping
- Digital LLRF promises more flexibility in system tuning



Effect of feedback on e-p instability



Low intensity beam BTF



High intensity beam BTF

Beam Study Diagnostics

- Improve performance through machine knowledge
  - Understand initial 6-d beam distribution
  - Understand beam dynamics in real machine
  - Tune / validate beam model
  - Optimize beam transport
- Demands to diagnostics
  - Complex beam pulse structure requires fine time resolution
  - Small beam loss requires large dynamic range
  - As many measured projections as possible: transverse profiles, longitudinal profiles, 2-d projections
    - Direct measurement of 6-d distribution is not practical
  - As many measurement locations as possible
- We can not meet all demands in one diagnostic – use variety of complimentary measurements

Transverse 1-D Profile Measurements

- Wire scanners in warm linac and transport lines (41)
  - Interceptive: max pulse width = 50us
  - 10us time resolution
  - Dynamic range = 10,000
- Laser Wire in super-conducting linac (9+1)
  - Non-interceptive
  - 10ns time resolution
  - Dynamic range = 100
- Electron beam scanner in accumulator ring (1)
  - Non-interceptive
  - 20ns time resolution
  - Dynamic range = 10

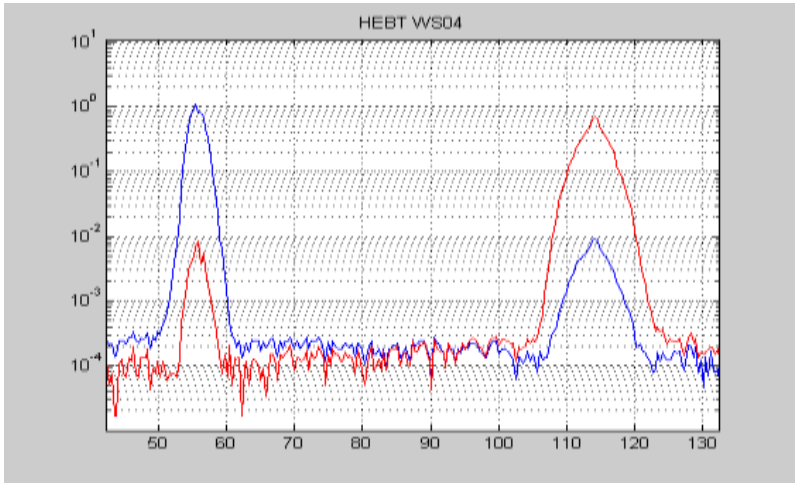

Wire scanner


Laser Wire station

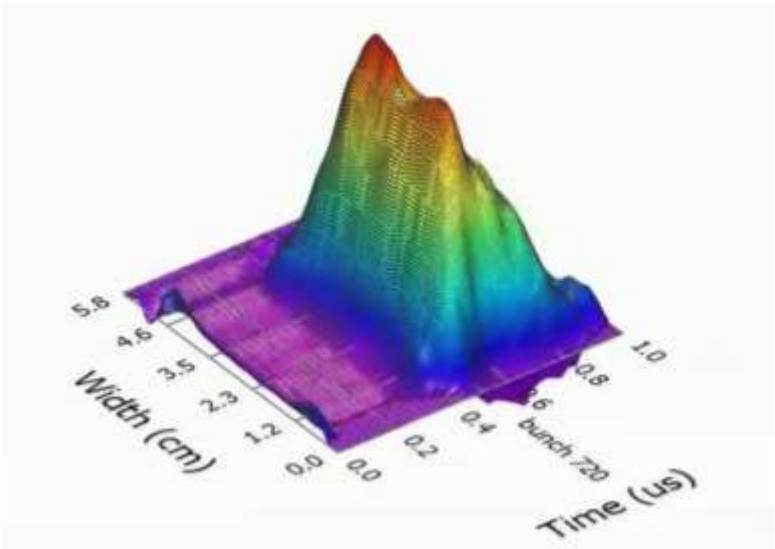

Ring electron beam scanner

Status and Plans

- **Wire scanners status**
  - Updated computers (PCs)
  - Upgraded LabView to 2009
  - Developed new software
- **Wire scanners plans**
  - Increase scan speed
  - Investigate and mitigate dynamic range limitations
- **Electron profile scanner status**
  - Expert run system
  - Limited scan aperture
  - Limited measured beam maximum intensity due to limited electron gun voltage
- **Electron profile scanners plans**
  - Improve electron beam optics
  - Develop user friendly software
  - Increase maximum electron gun voltage
  - Increase scan aperture



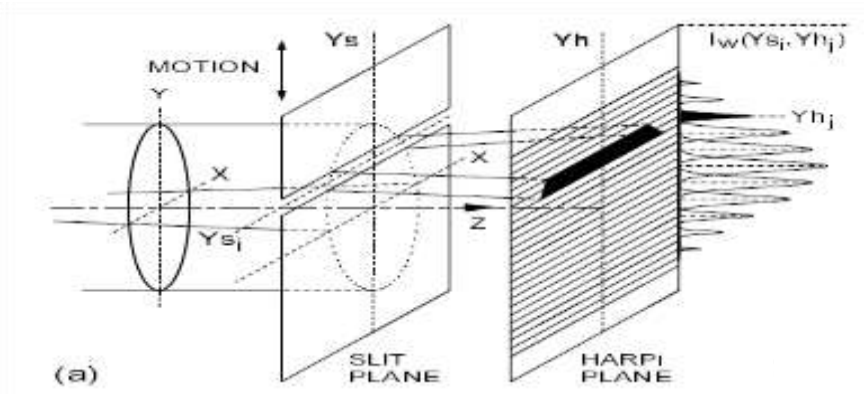
High resolution beam profiles in HEBT



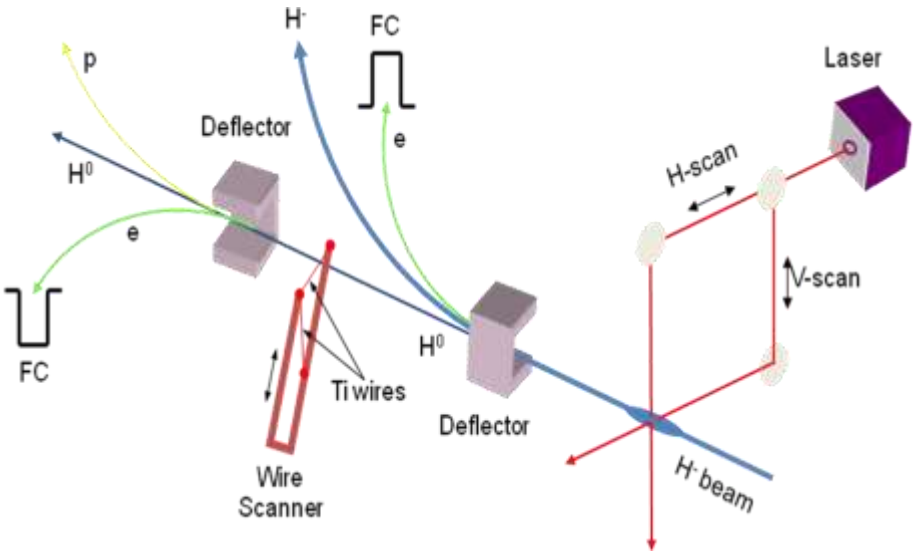
Time-resolved transverse beam profile in Ring

Transverse 2-D Emittance Measurements

- **Slit – harp emittance station in MEBT**
  - Interceptive: max pulse width = 50us
  - 10us time resolution
  - Dynamic range = 1,000
- **Laser emittance station in HEBT**
  - Non-interceptive
  - 10ns time resolution
  - Dynamic range = 100
- **Tomographic reconstruction using wire scanners**
  - Interceptive: max pulse width = 50us
  - 10 us time resolution
  - Dynamic range = ?



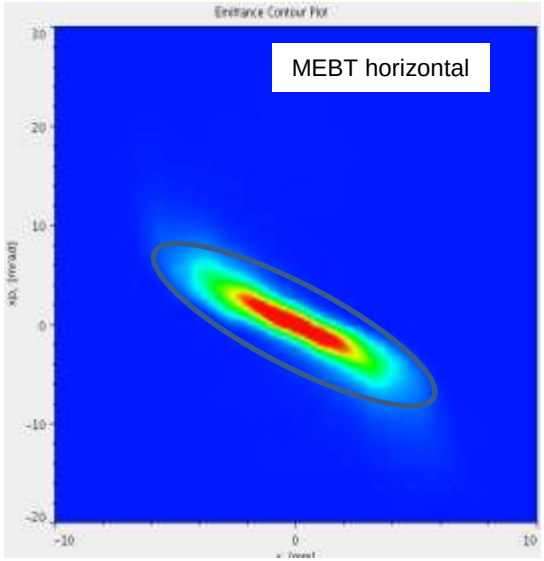
MEBT emittance scanner principle of operation

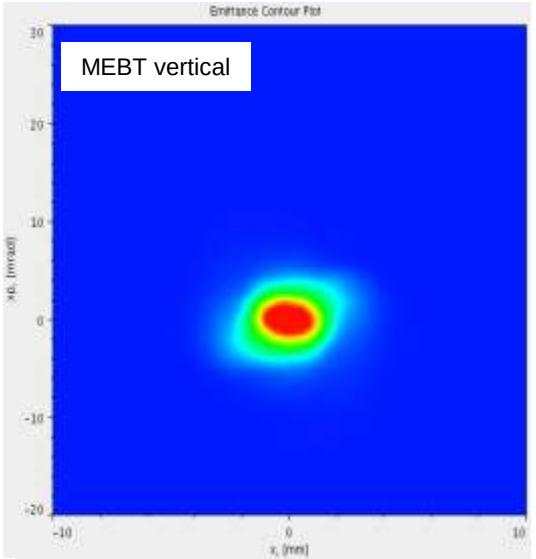


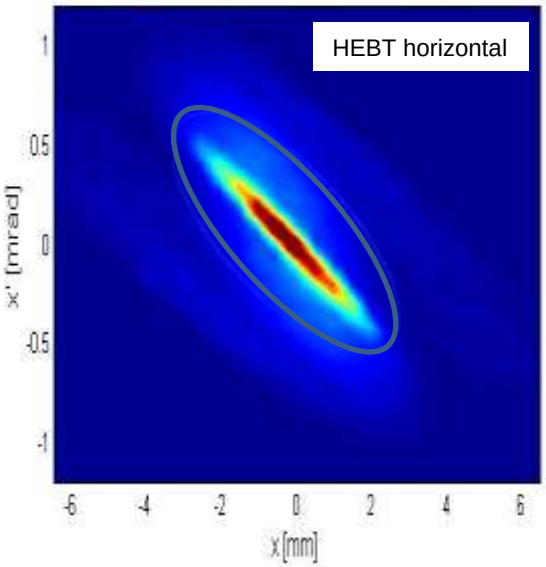
HEBT laser emittance scanner principle of operation

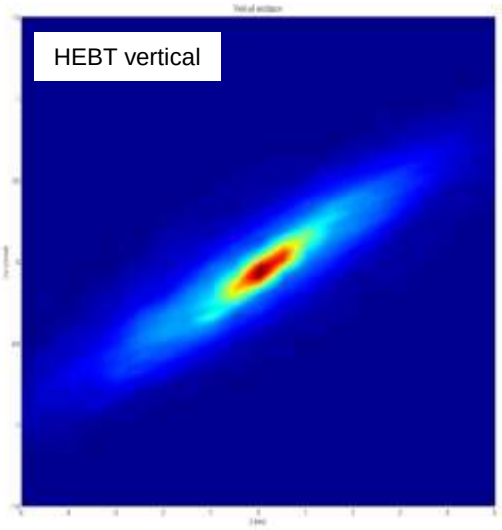
Emittance Measurements Status and Plans

- **MEBT emittance status**
  - Updated computer (PC)
  - Upgraded LabView to 2009
  - Developed new software
- **MEBT emittance plans**
  - Increase dynamic range to ~ 10,000
  - Reduce integration time to < 1us
- **HEBT laser emittance status**
  - Recently commissioned
  - Details in next presentation
- **HEBT laser emittance plans**
  - Finalize EPICS GUI
  - Unify data analysis software with MEBT
  - Investigate and mitigate dynamic range limitations



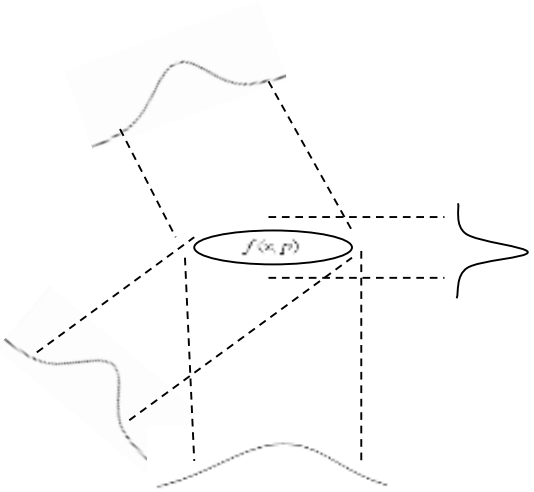


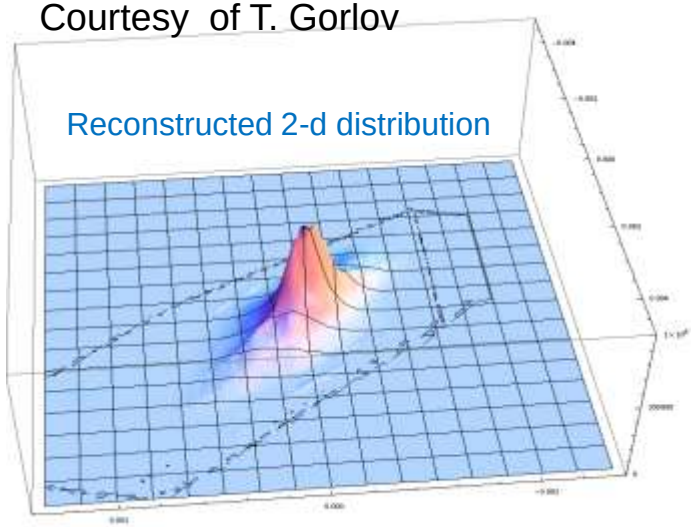




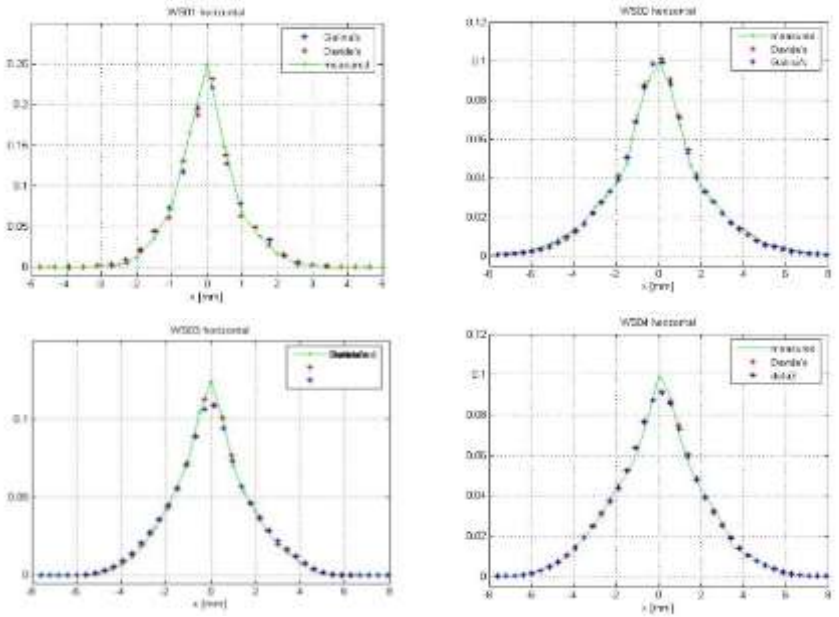
MEANT Tomographic Reconstruction of 2-D Emittance from 1-D Profiles

Courtesy of T. Gorlov





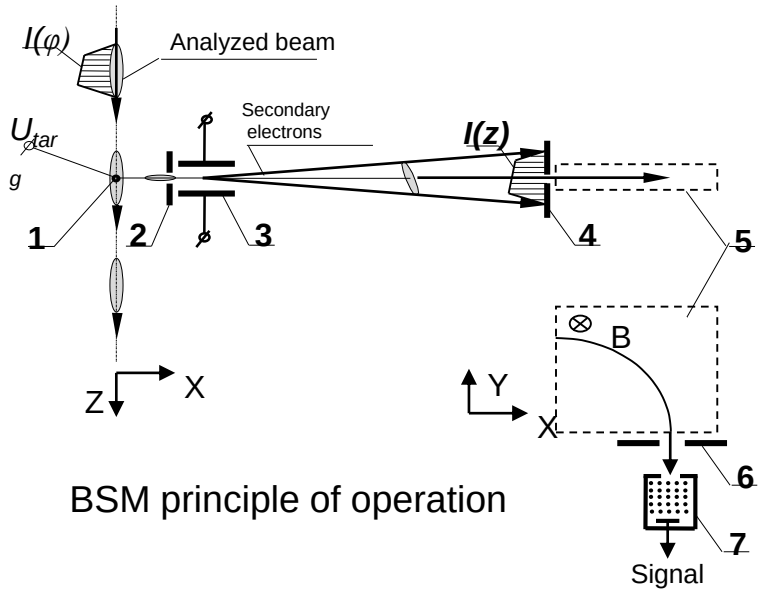
- **Reconstruction seems to works very well in HEBT**
  - **Need to verify using laser emittance measurements**
  - **High resolution of wire scan data help with algorithm convergence**
- **Plan to extend to SCL, Warm Linac, MEBT**
  - **Requires good transport model**
  - **Problem of space charge**



Comparison of measured and reconstructed profiles

Longitudinal 1-D Bunch Profile Measurements

- **Beam Shape Monitors (aka Feschenko monitor) in CCL and HEBT (4+3)**
  - Interceptive: max pulse width = 50us
  - ~1° @805 MHz (3.5 ps) intra-bunch resolution
  - 10us averaging time
  - Dynamic range = 10,000

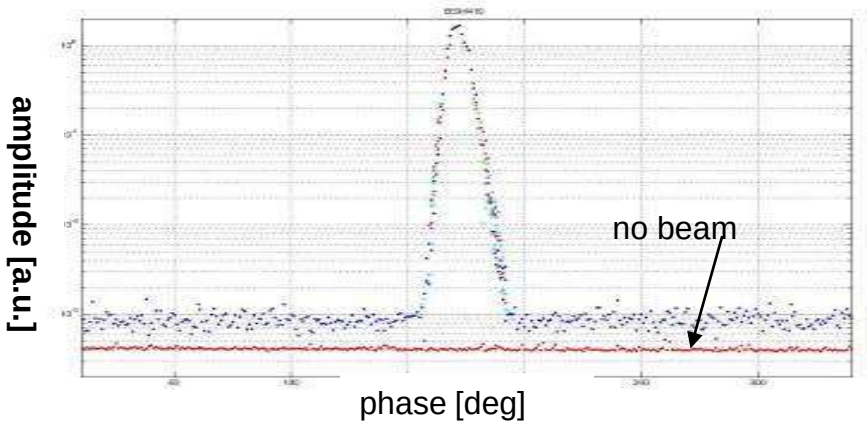


BSM principle of operation

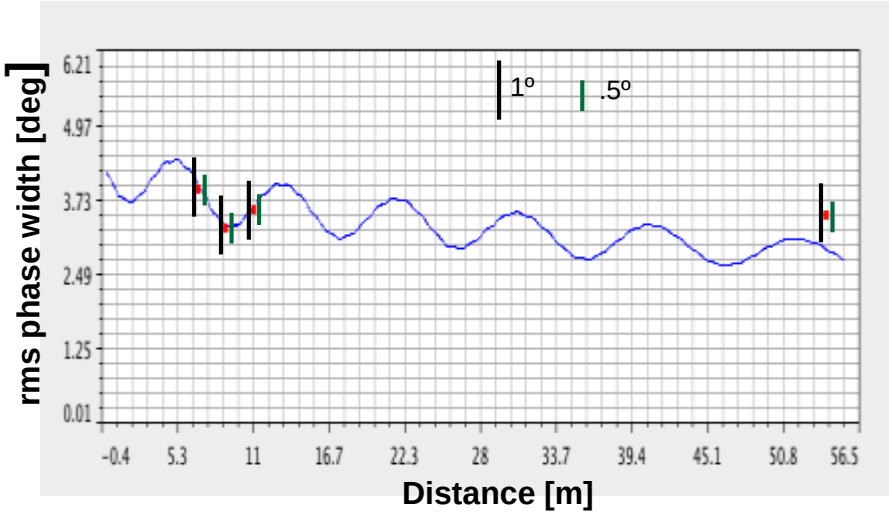
- **Mode-lock-laser monitor in MEBT (1)**
  - Non-interceptive
  - ~ 3° @402.5 MHz (20ps) intra-bunch resolution
  - 10us averaging time
  - Dynamic range = 100
  - Non-operational currently
  - Status and plans in next talk

BSM Status and Plans

- **Beam Shape Monitor status**
  - Upgraded computer hardware (PC)
  - Upgraded LabView to 2009
  - New software
  - Upgraded BSM hardware on 2 CCL BSMs to improve resolution to ~.5°
- **Beam Shape Monitor plans**
  - Upgrade remaining BSMs hardware
  - Study and mitigate resolution limitations
  - Collaborate with INR (Feschenko) on laser BSM development

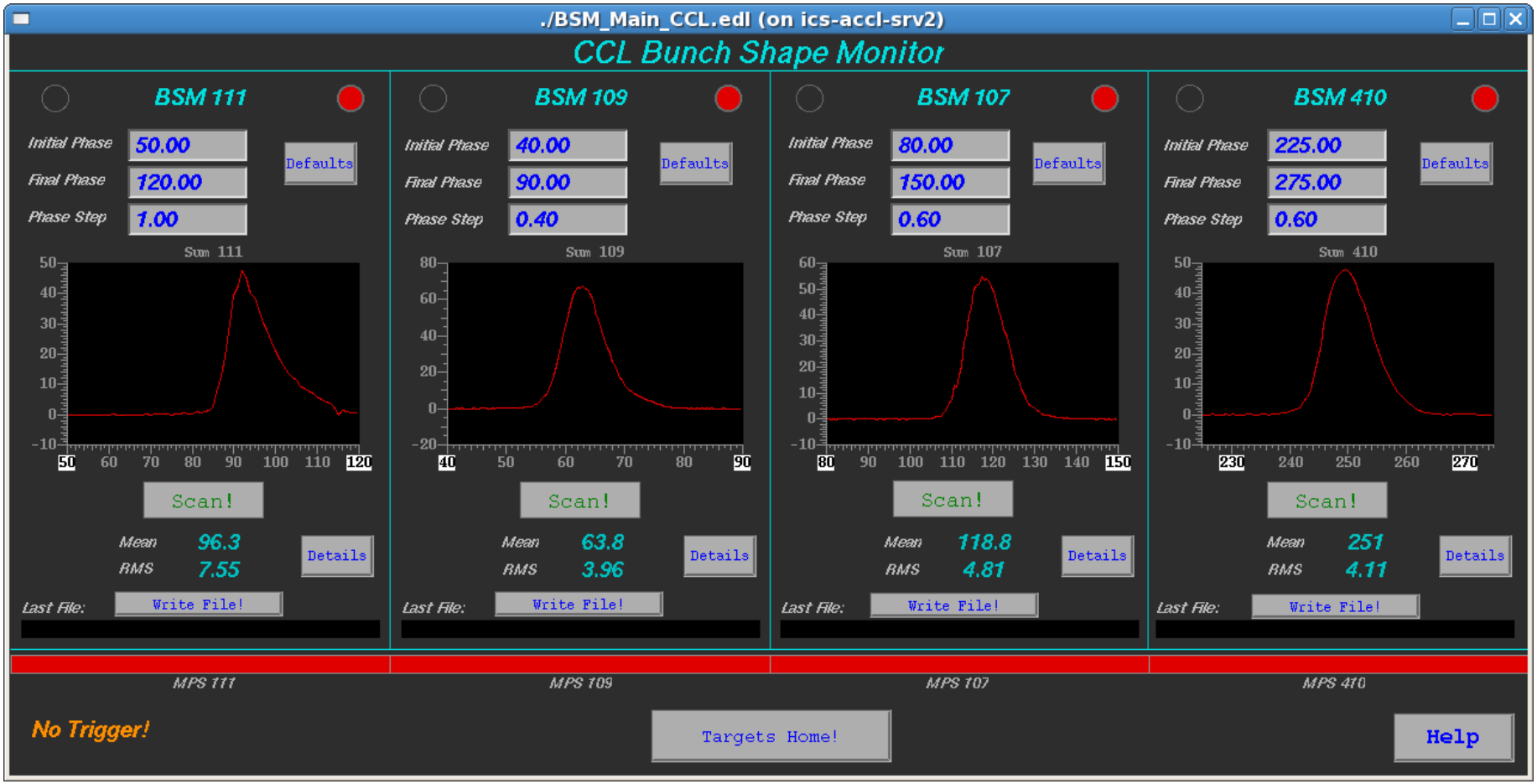


Typical longitudinal bunch profile



Measured longitudinal bunch size vs. model

New BSM EPICS GUI



- **Fully independent parallel scans**
- **Extensive set of troubleshooting and tuning tools**

Courtesy of R. Dickson

A near-term wish list

- MEBT vertical scrapers
  - Not funded in FY12
- Ring Ionization Profile Monitor (IPM)
  - Design 90% complete
  - Not funded in FY12
- Ring electron scanner aperture increase
  - Not funded in FY12
- Laser stripping experiment set-up
  - Not funded in FY12
- Laser based BSM
  - Not funded in FY12
- New Ring pinger electrode
  - Not funded in FY12
- RFQ test stand diagnostics
  - Not funded in FY12

Summary

- Existing Beam Instrumentation is capable to support machine tuning and production runs
- Downtime associated with beam diagnostics is low
- Moving steadily toward increasing dynamic range of measurements and implementing more non-perturbing diagnostics to support beam study
- Working on improving GUIs and speeding up data collection
- Approaching state-of-the-art for many systems
  - working closely together with AP team to ensure trustworthiness of data