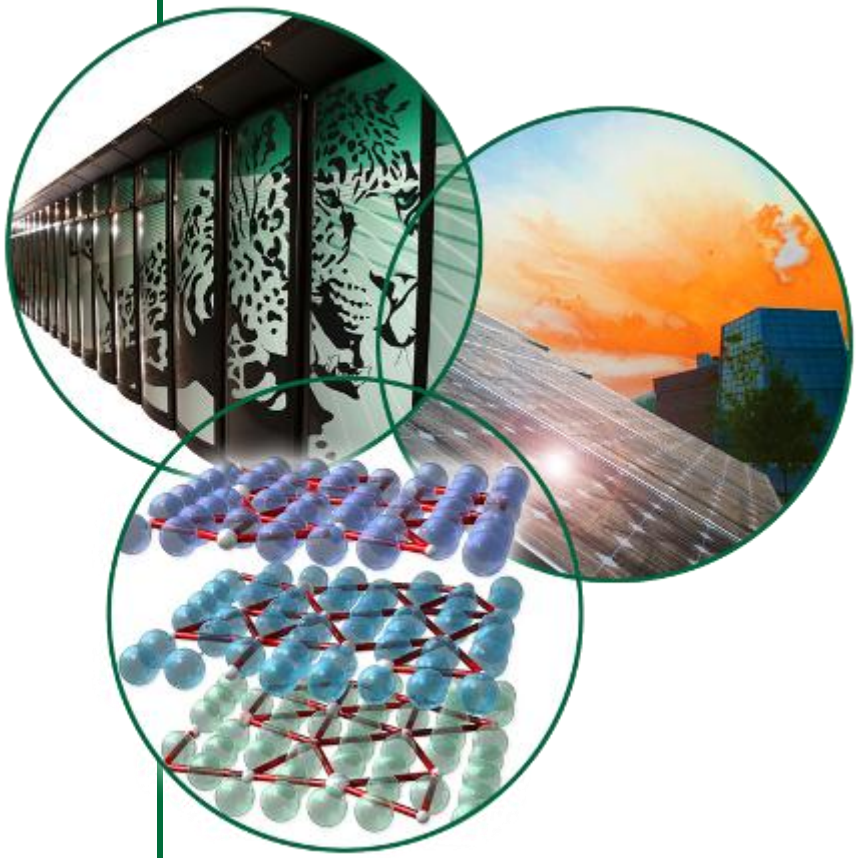
SNS Beam Diagnostics

A. Aleksandrov

Spallation Neutron Source, Oak Ridge, USA



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

The Spallation Neutron Source:

is an accelerator- driven user facility for neutron scattering research at Oak Ridge National Laboratory in USA

Design Beam Parameters

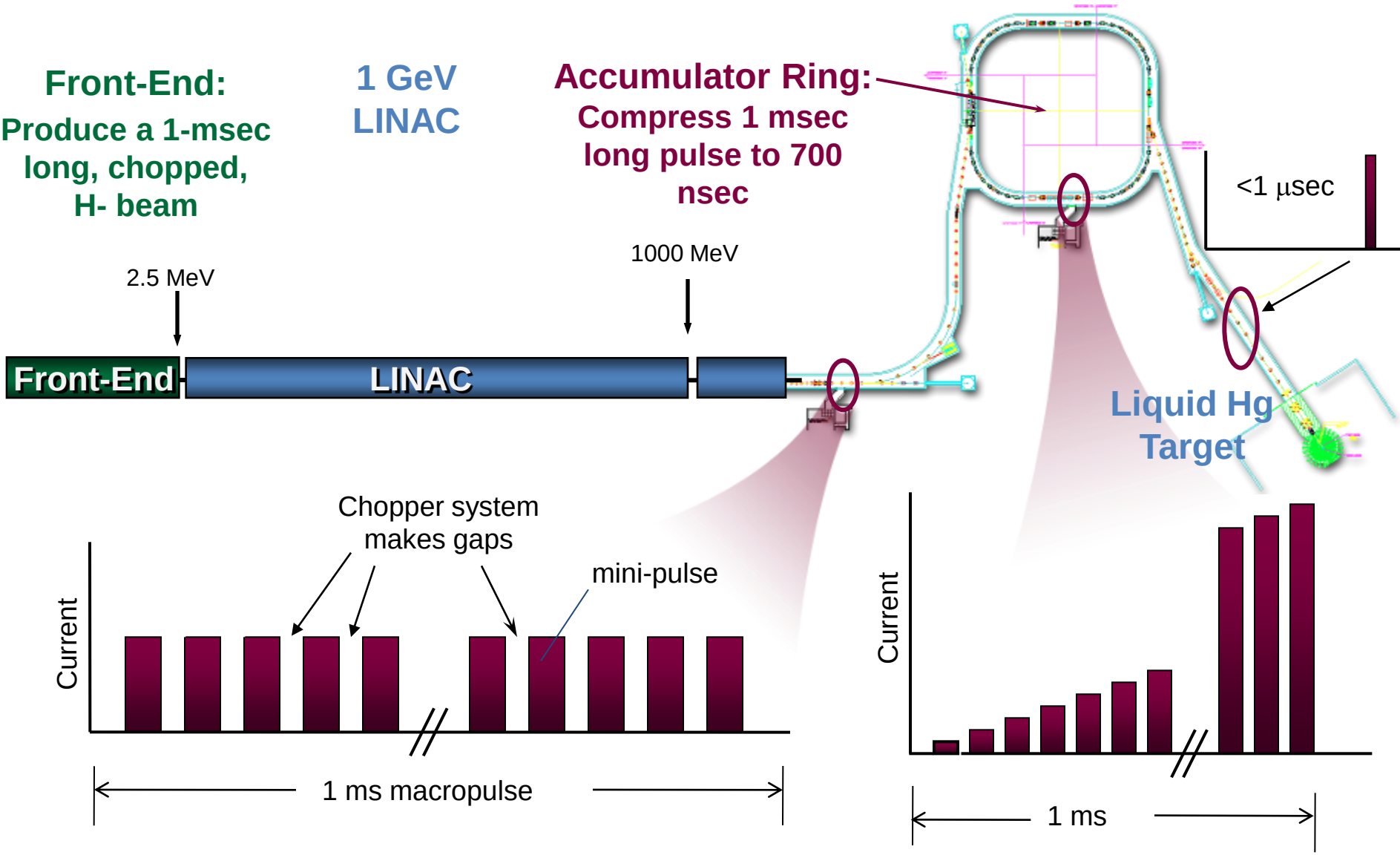
P beam on target :	1.44MW
I beam average:	1.44mA
Maximum Beam energy:	1 GeV
Duty factor:	6%
I beam peak:	40 mA
Rep. rate:	60Hz
Pulse width:	1ms

SNS Accelerator Complex

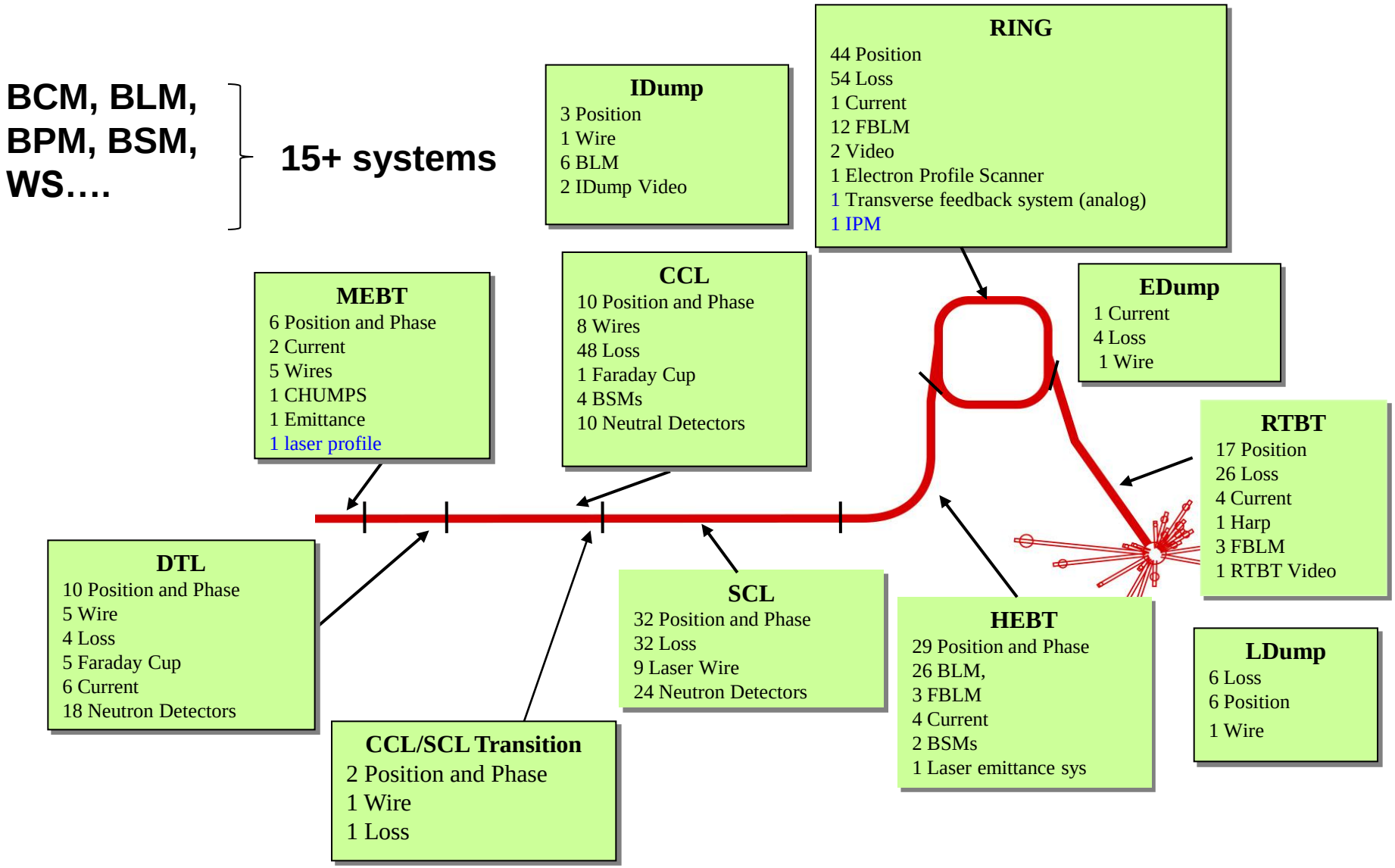
Front-End:
Produce a 1-msec long, chopped, H- beam

1 GeV LINAC

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec

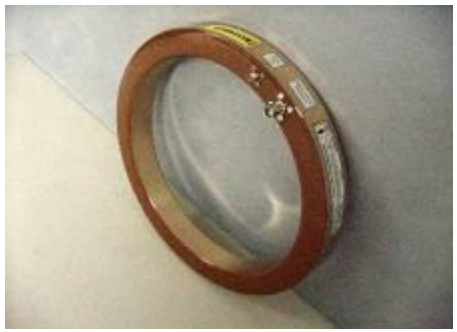


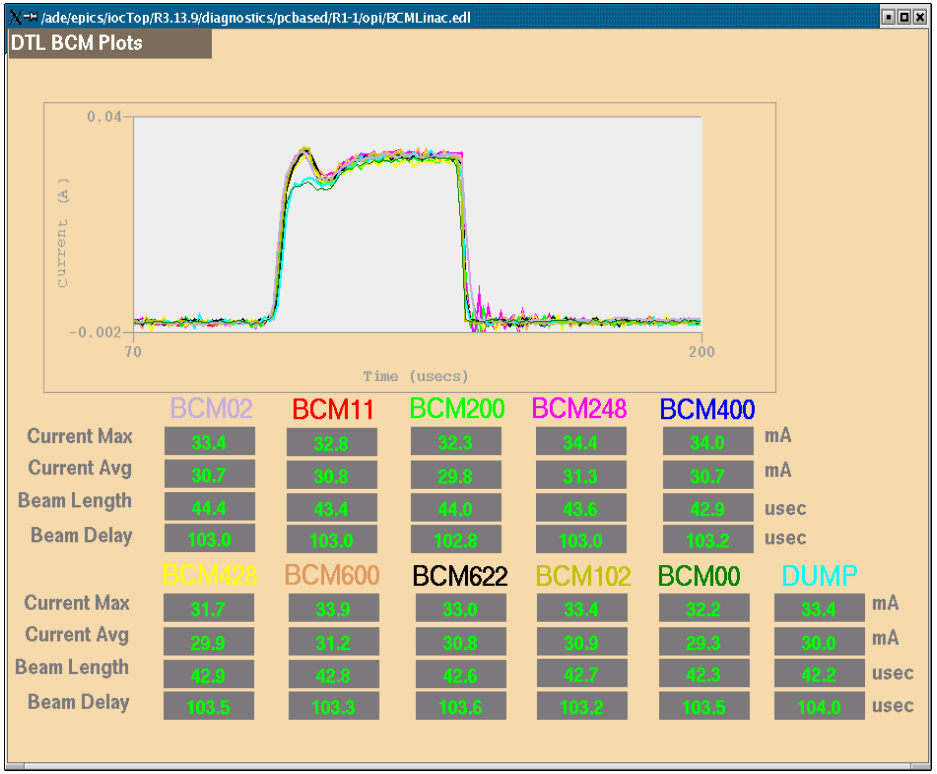
SNS Beam Instrumentation Systems Map



Beam Current Monitors

- 23 beam current transformers in total
- 4-6 are in use for operation
  - RFQ output
  - Injection dump current
  - Beam to target current
  - MEBT scrapers protection
  - ~3-5% accuracy



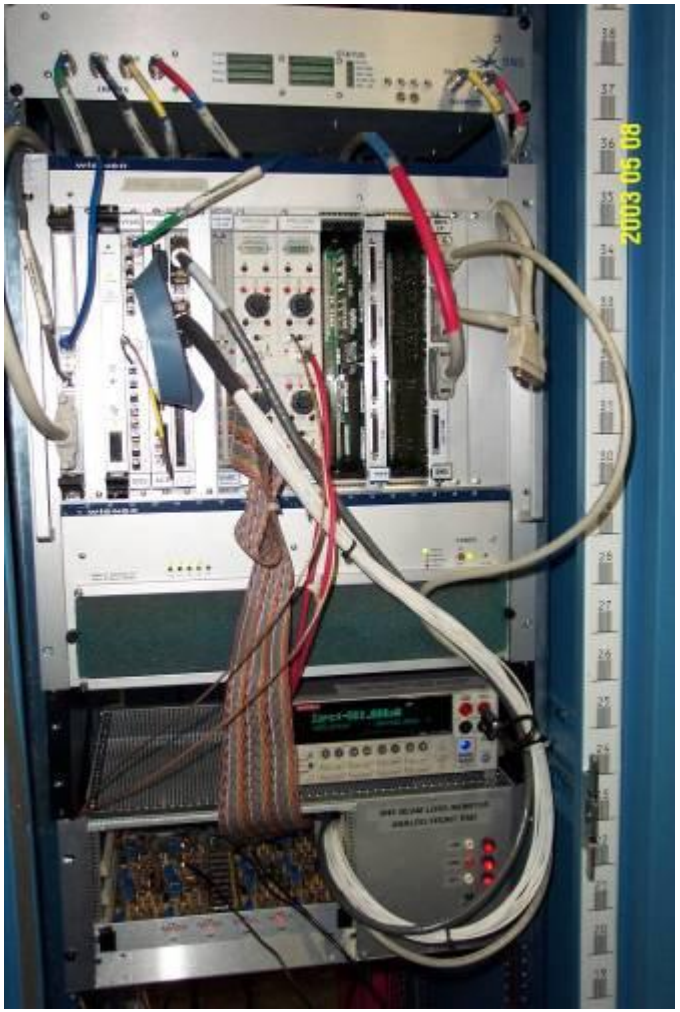


Beam pulse propagation from RFQ output to linac dump

Beam Loss Monitoring System (BLM)

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

Beam Loss Monitoring System



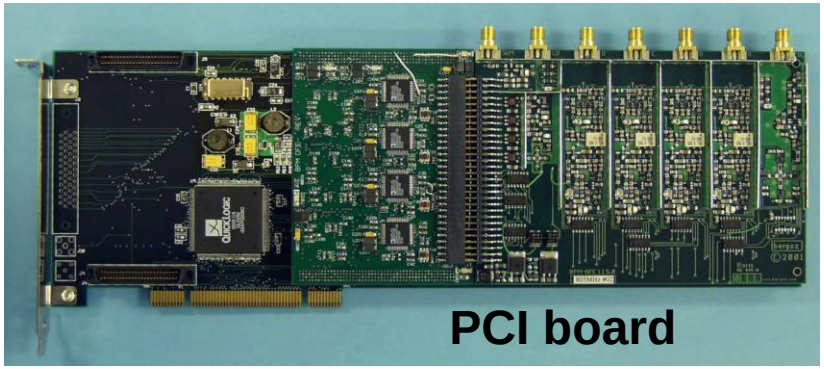
BLM performance and issues

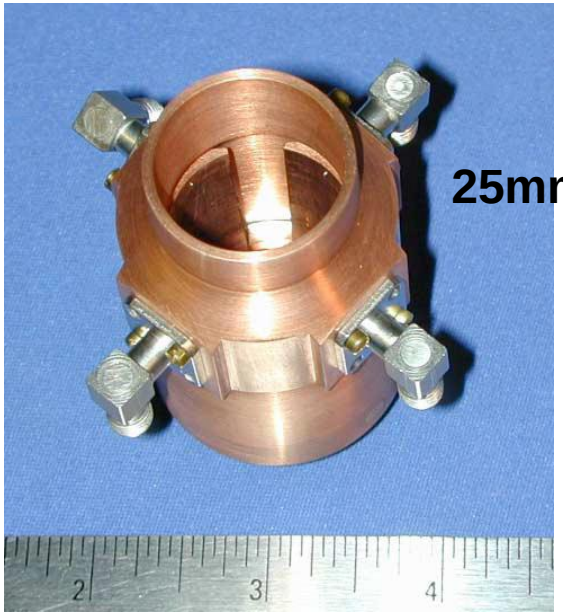
- Very reliable system overall
  - Less than 10 hours of downtime per year
- Significant background from X-ray near RF cavities
  - Implemented background subtraction using no-beam pulse every 10s. (59.9Hz beam repetition rate)
  - Major limiting factor for S/N improvement
- Blind spots in some areas
  - Increase number of detectors.
- Poor loss localization with neutron detectors
  - Sufficient for machine protection
  - Less useful for machine study

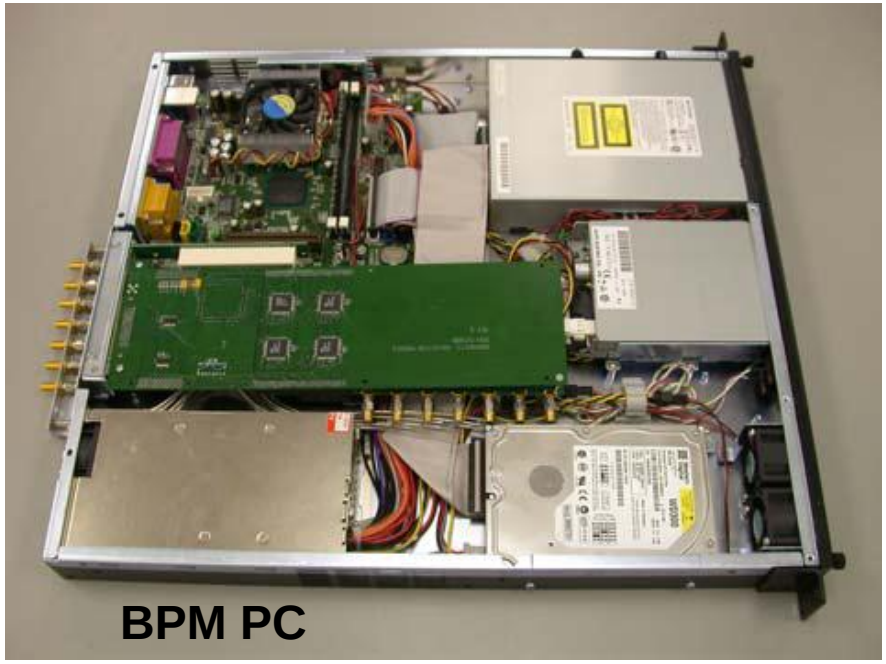
Beam Position and Phase Monitors (BPM)

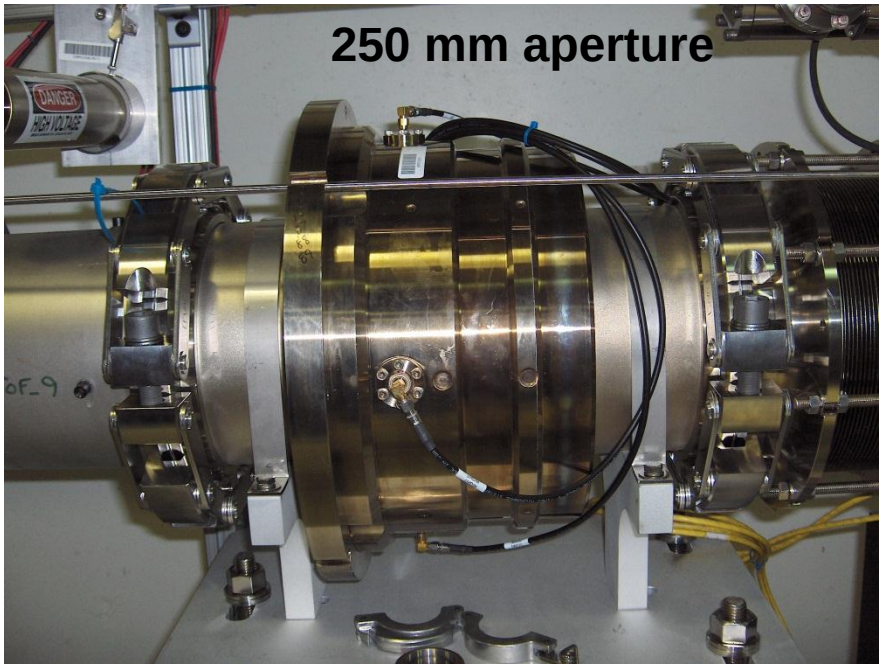
- Major tool for machine tune up
  - Phase measurements is main tool for linac tune up
  - Position measurements for trajectory correction, injection set up and centering beam on dumps and target
- 160 4-electrode strip-line pick-ups
  - 96 “linac type” operate at 402.5MHz and 805MHz
  - 64 “ring type” 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)

BPM hardware



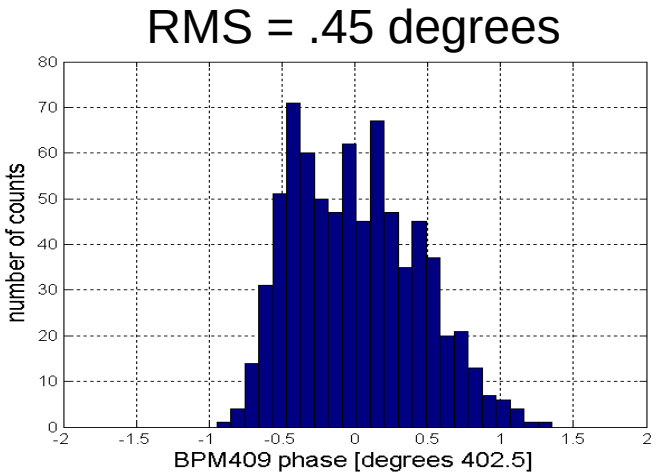






BPM performance and issues

- Good phase and position resolution
  - Better than .5 deg (805Mhz) for phase;
  - Better than 1% of aperture for position

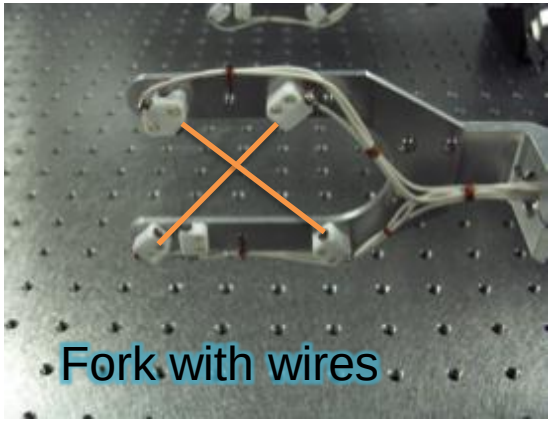


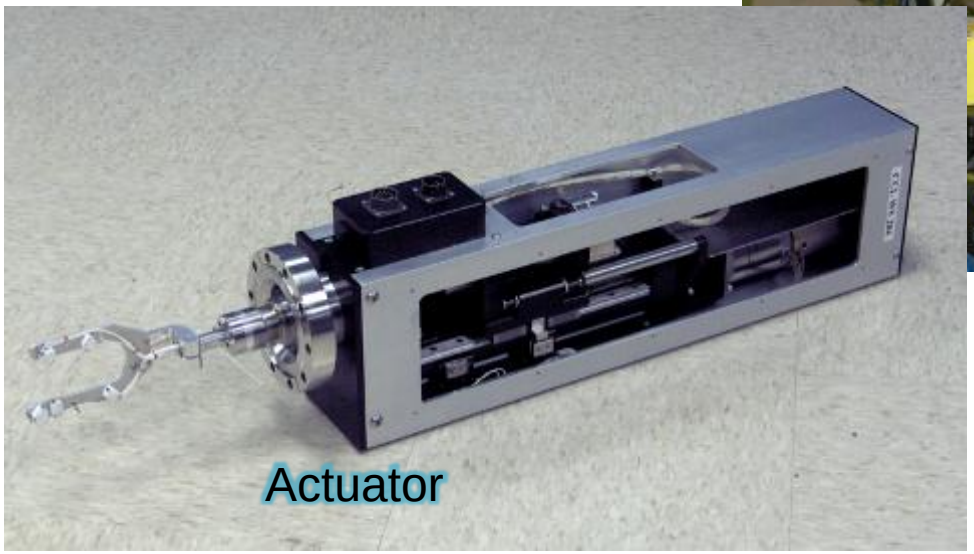
- Issues with reliability and maintenance
  - Computers hang up
  - Motherboard to PCI card compatibility

Intercepting Transverse Beam Profile Measurements

- 41 stepping wire scanners in warm linac, transport lines, and beam dumps
  - 32um carbon wire from 2.5MeV to 7.5Mev
  - 100um Tungsten at higher energies
  - 50us, 1Hz limit on beam pulse, 10us time resolution
  - 2 wires on each actuator (horizontal & vertical)
- 1 multi-wire harp in RTBT
  - 64 Tungsten wires, 100um size
  - Dual plane, independent
  - Non-retractable

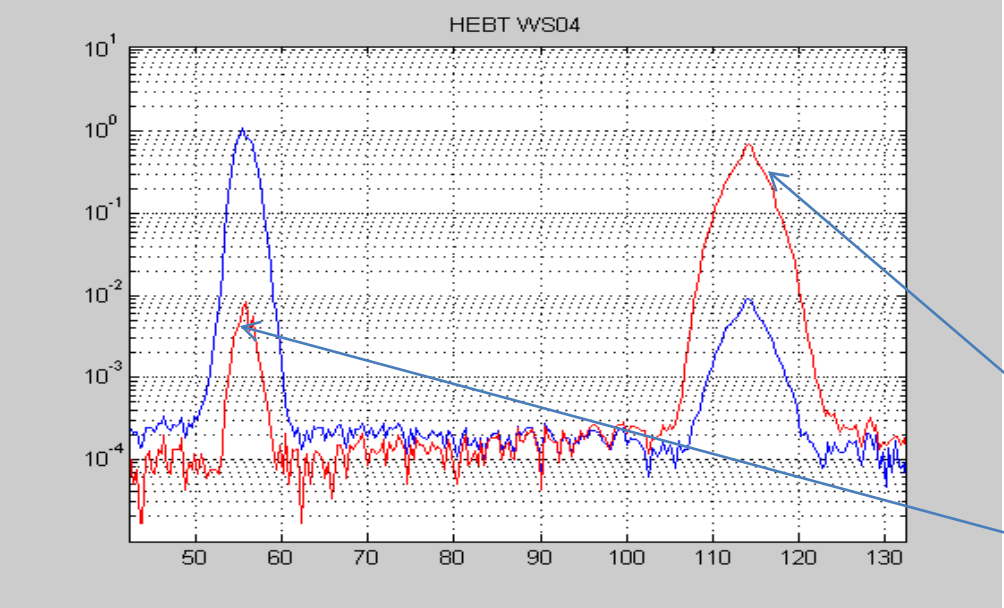
Wire Scanner Profile Monitor





Wire scanner performance

- Good resolution and dynamic range
  - ~5% accuracy of rms size (Gauss fit)
  - Dynamic range of 10^3-10^4 (~ 4 σ from beam center)

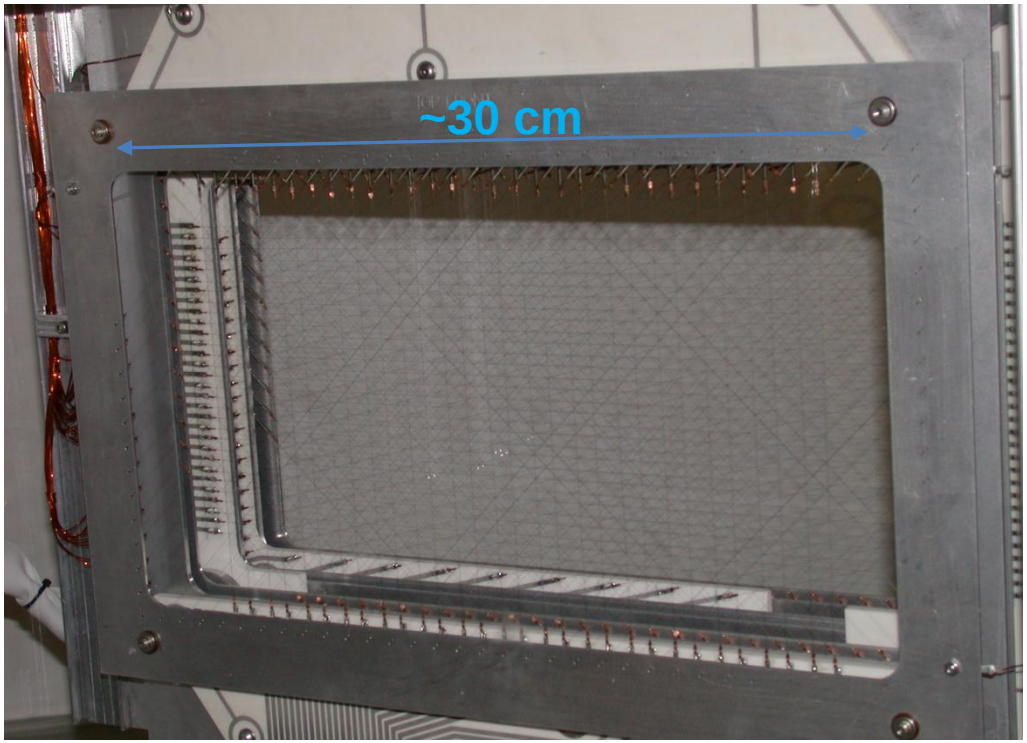


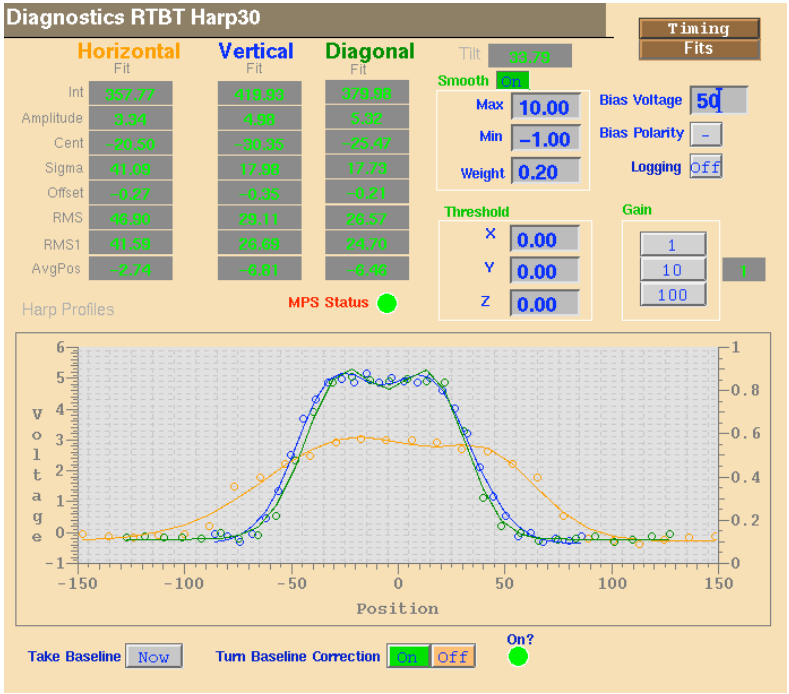
Measuring H- has advantages
large signal
And disadvantages
coupling between wires
due to scattered electrons

Main signal

Coupled signal

RTBT harp

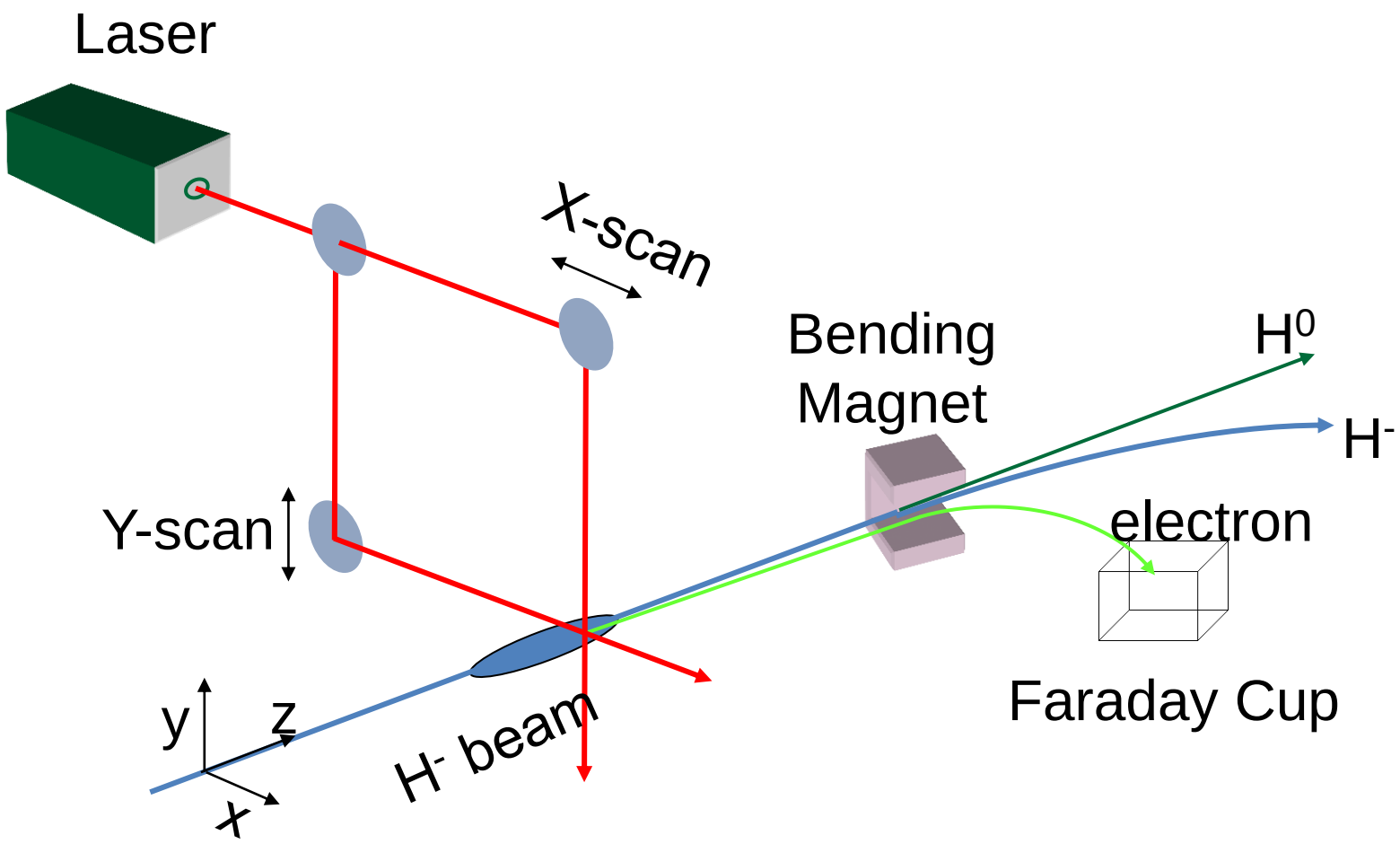

~30 cm


Diagnostics RTBT Harp30
Timing
Fits
Horizontal
Fit
Vertical
Fit
Diagonal
Fit
Tilt
Int
Amplitude
Cent
Sigma
Offset
RMS
RMS1
AvgPos
Smooth
Max
10.00
Min
−1.00
Weight
0.20
Bias Voltage
50
Bias Polarity
Logging
Off
Threshold
X
0.00
Y
0.00
Z
0.00
Gain
1
10
100
Harp Profiles
MPS Status
Voltage
Position
Take Baseline
Now
Turn Baseline Correction
On
Off
On?

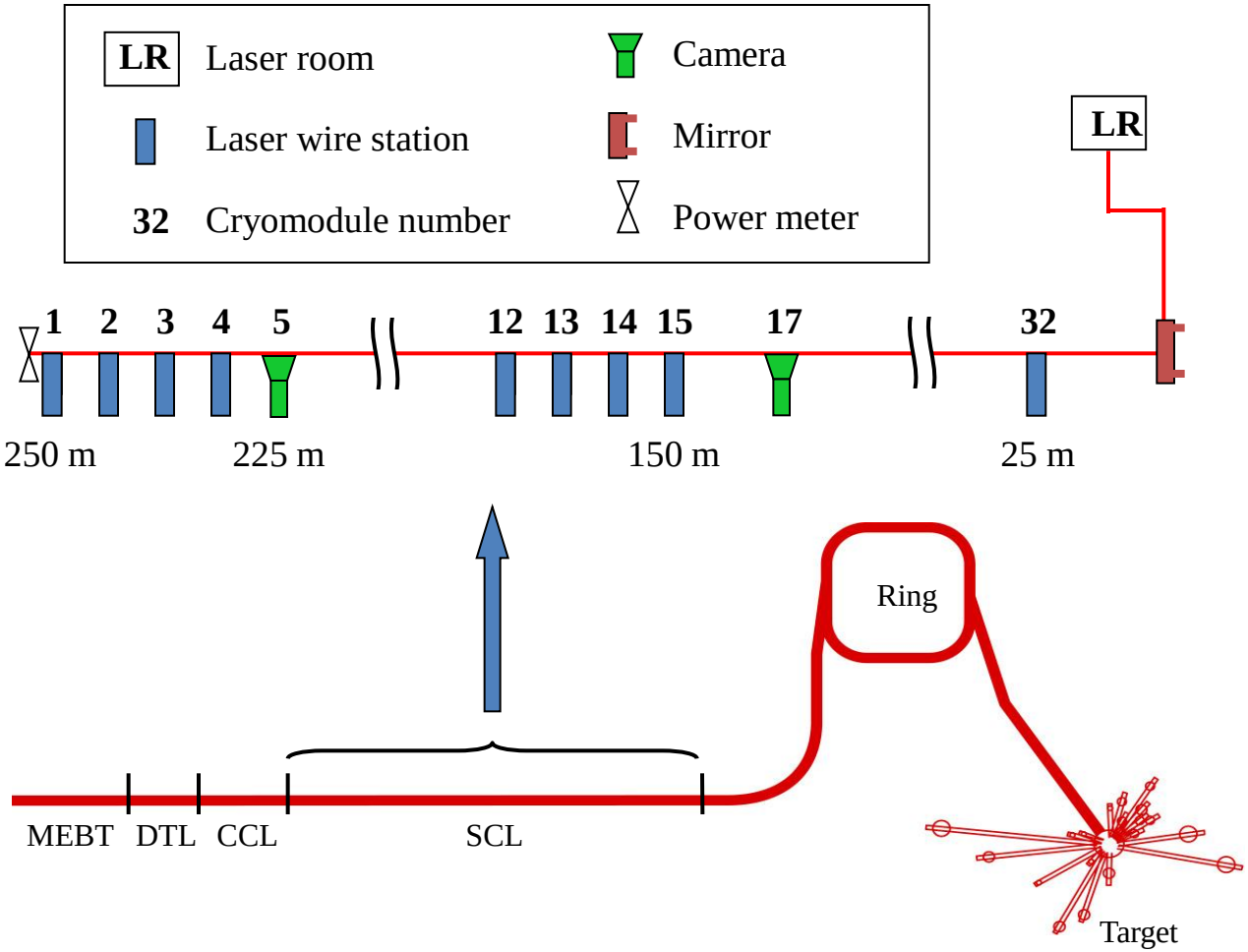
Non - Intercepting Transverse Beam Profile Measurements

- Laser Wire
  - 9 stations in SCL and 1 in HEBT
  - 20ns time resolution
  - Dynamic range of ~100
  - Simultaneous measurements at 9 locations
  - Dual plane, one at a time
- 1 electron beam scanner in Accumulator Ring
  - 20 ns time resolution
  - Dual plane, independent
- 1 Ionization Profile Monitor in Accumulator Ring
  - Under development
  - 20 ns time resolution
  - Dual plane, independent

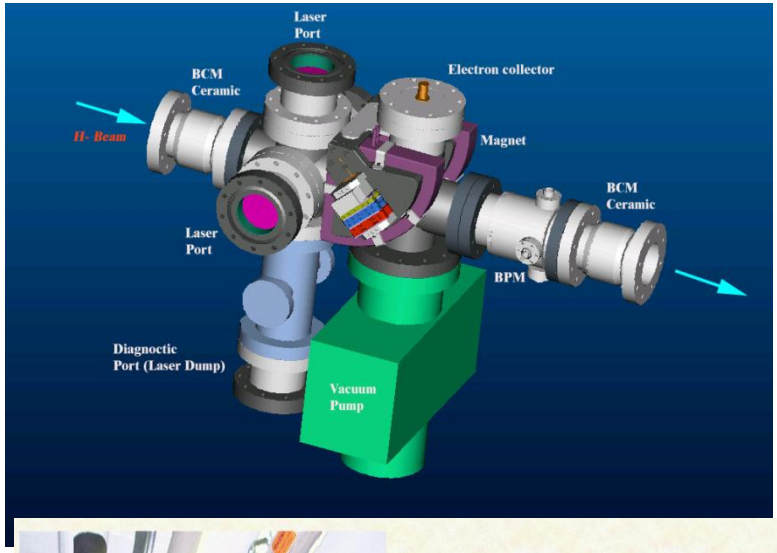
Principle of operation of SNS "laser wire"

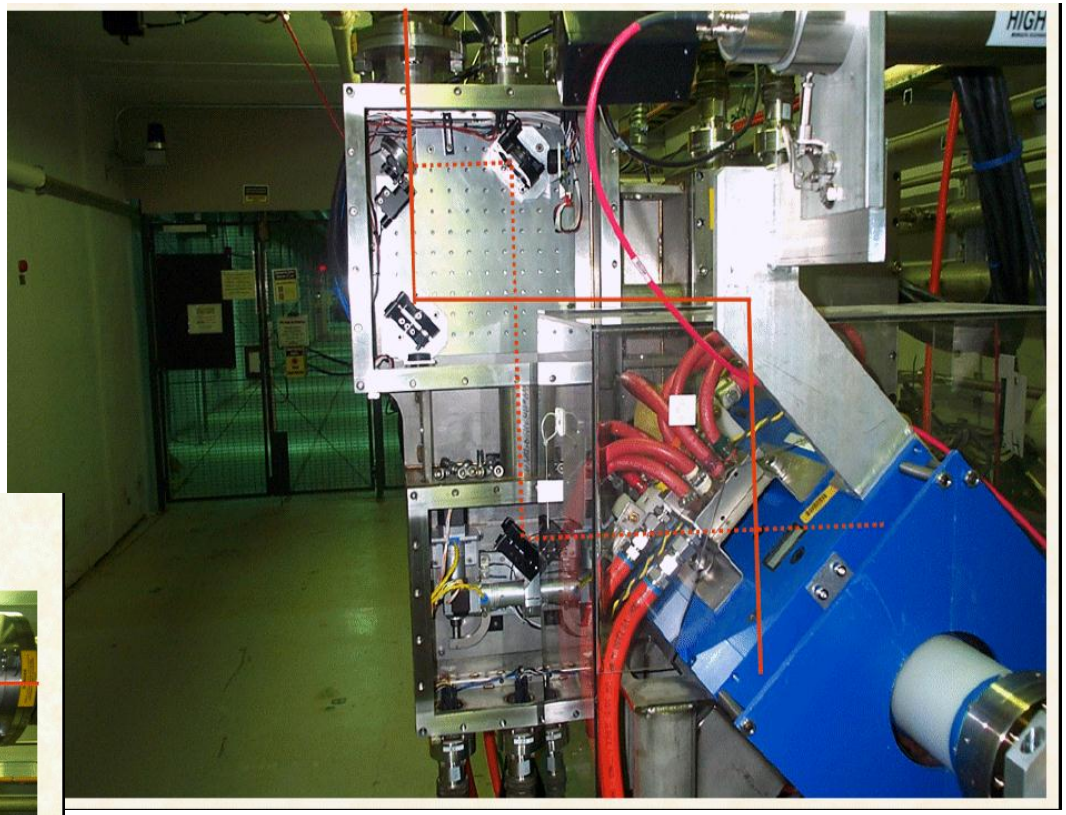


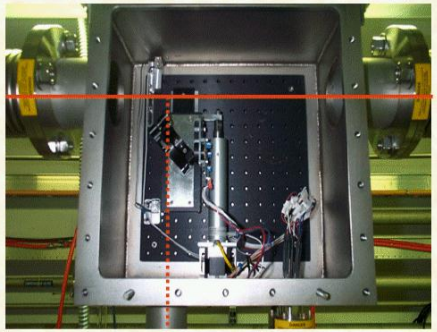
Layout of the SNS laser wire system



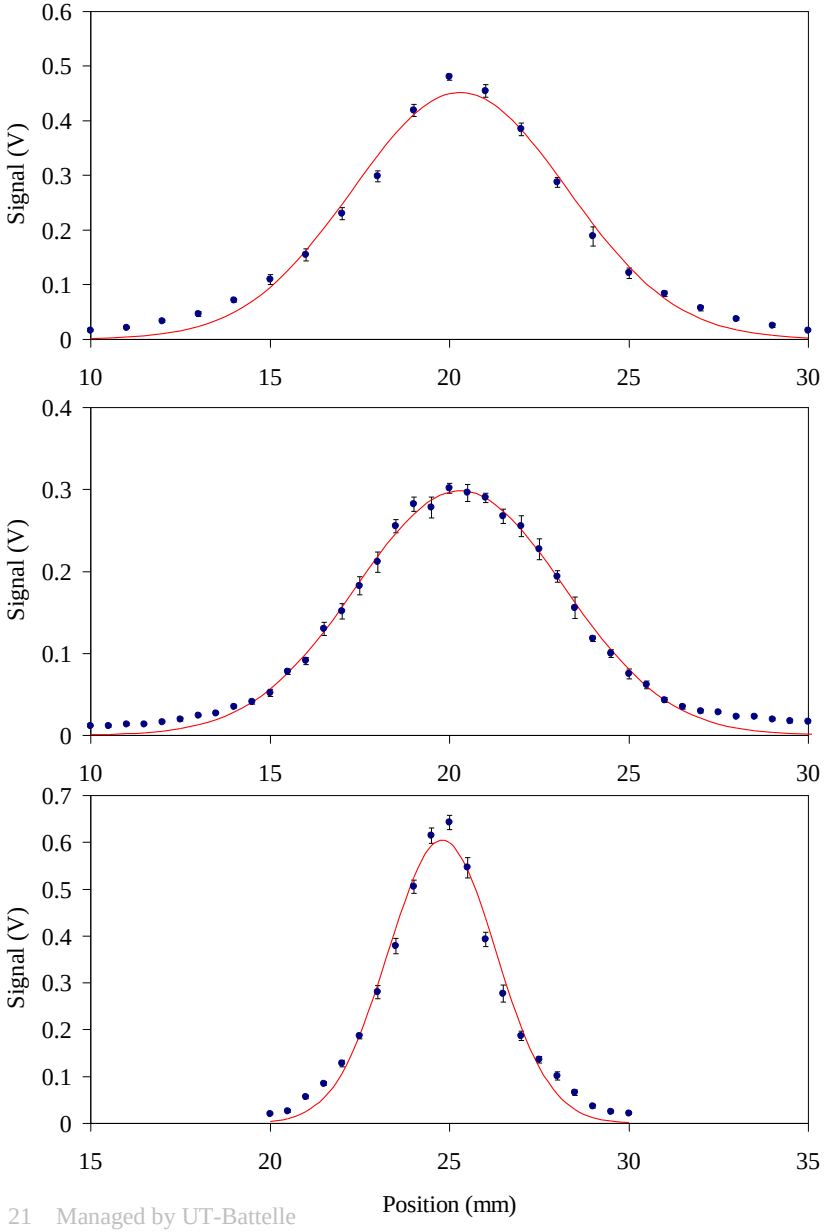
Laser wire hardware

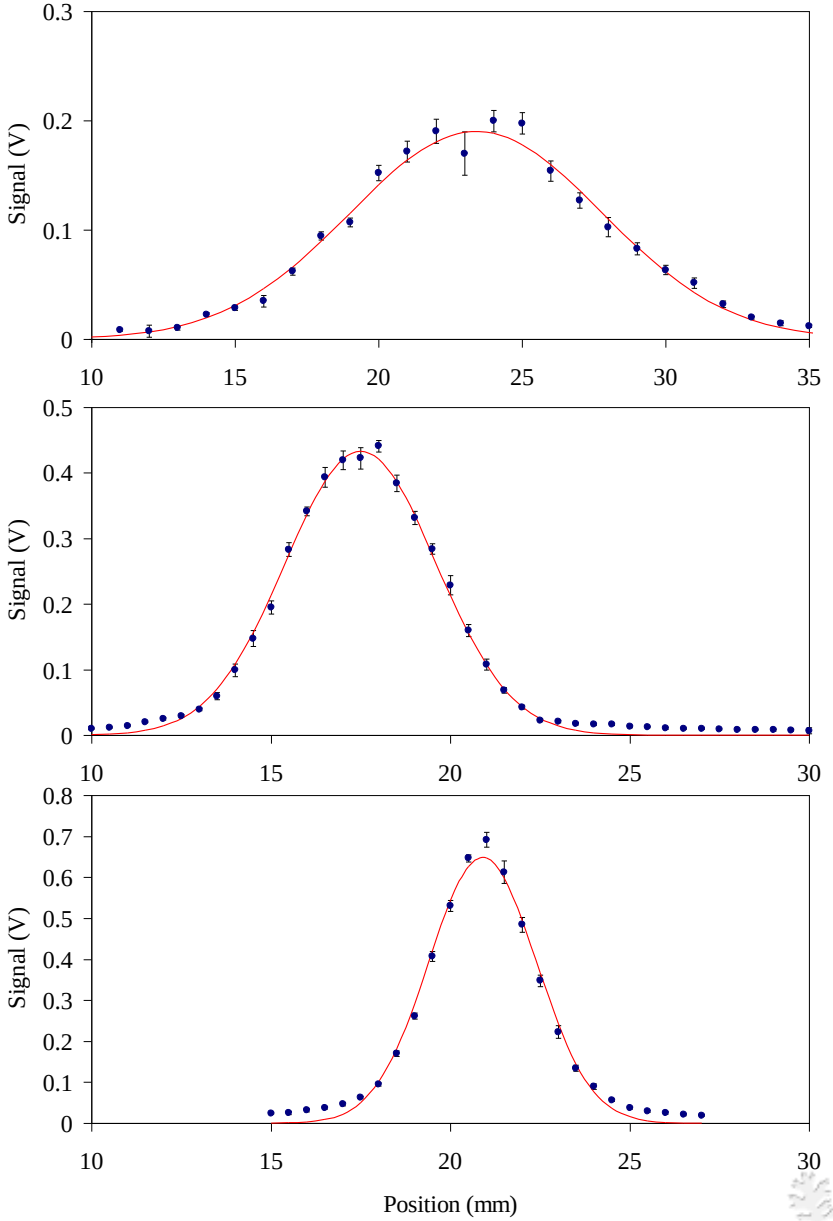






Typical laser wire measurements



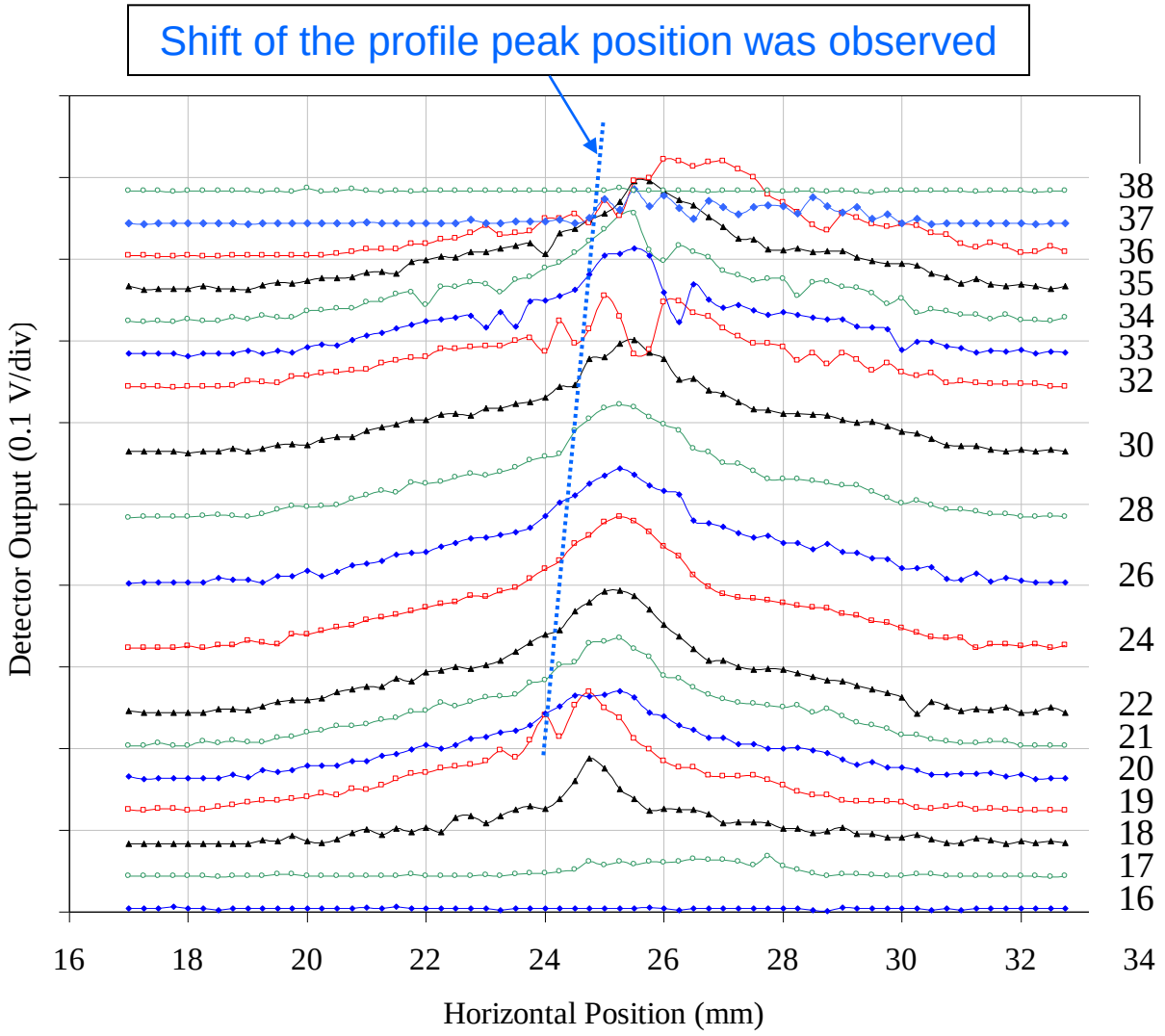


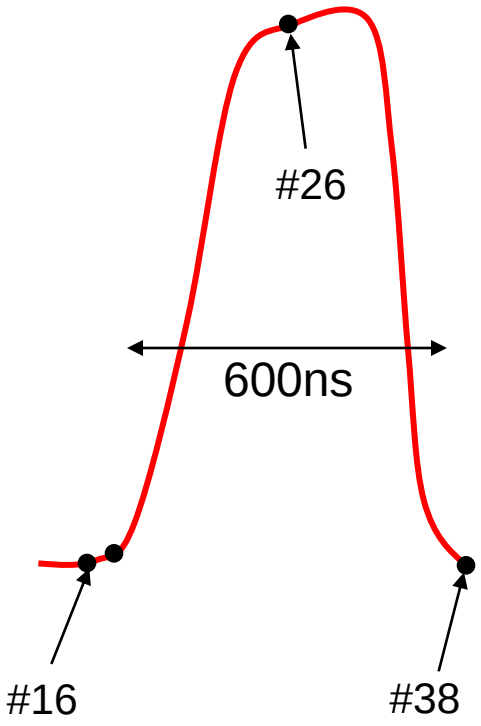
LW1

LW5

LW9

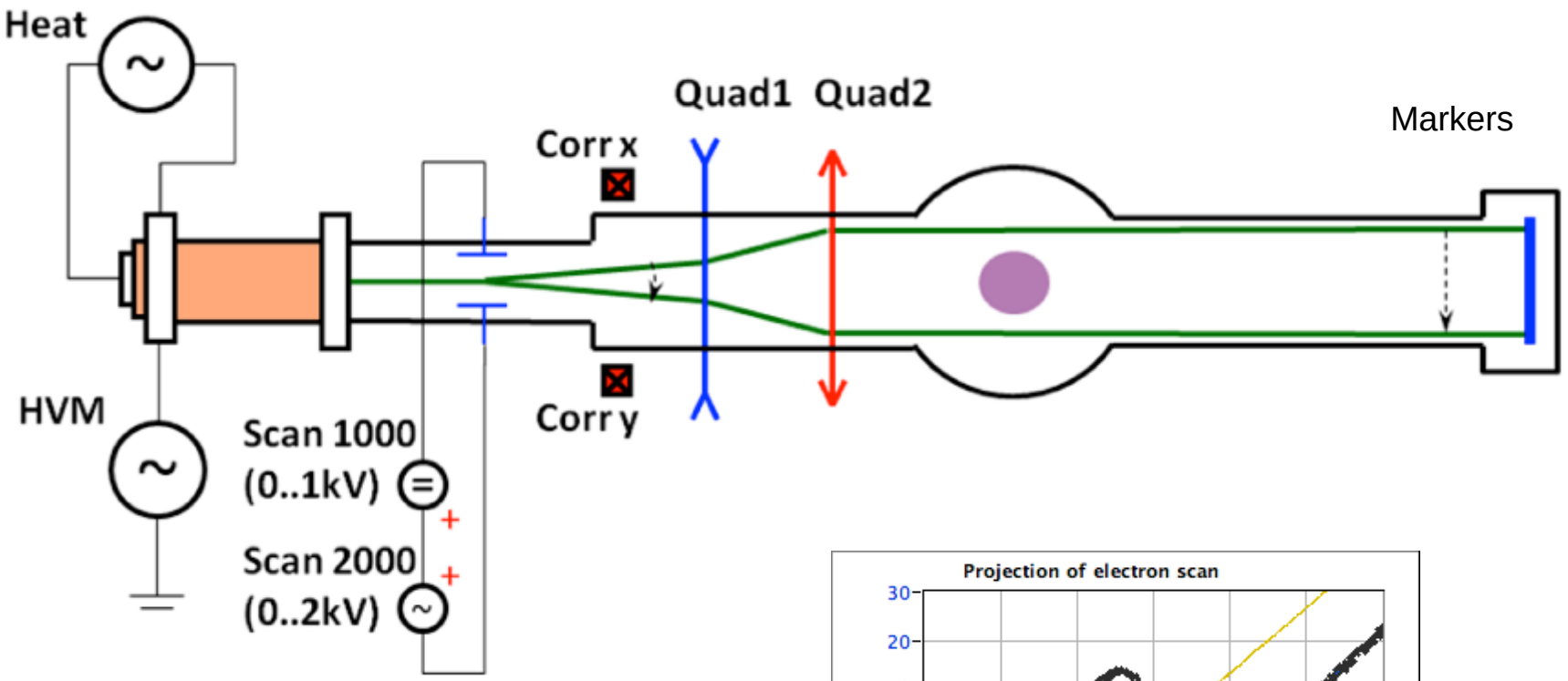
Profile measurements within a mini-pulse

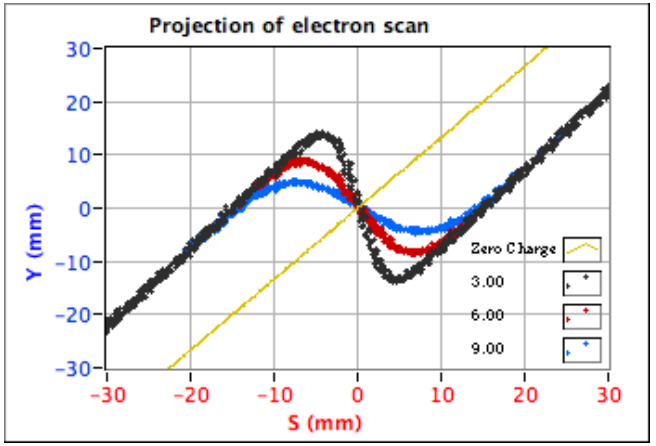




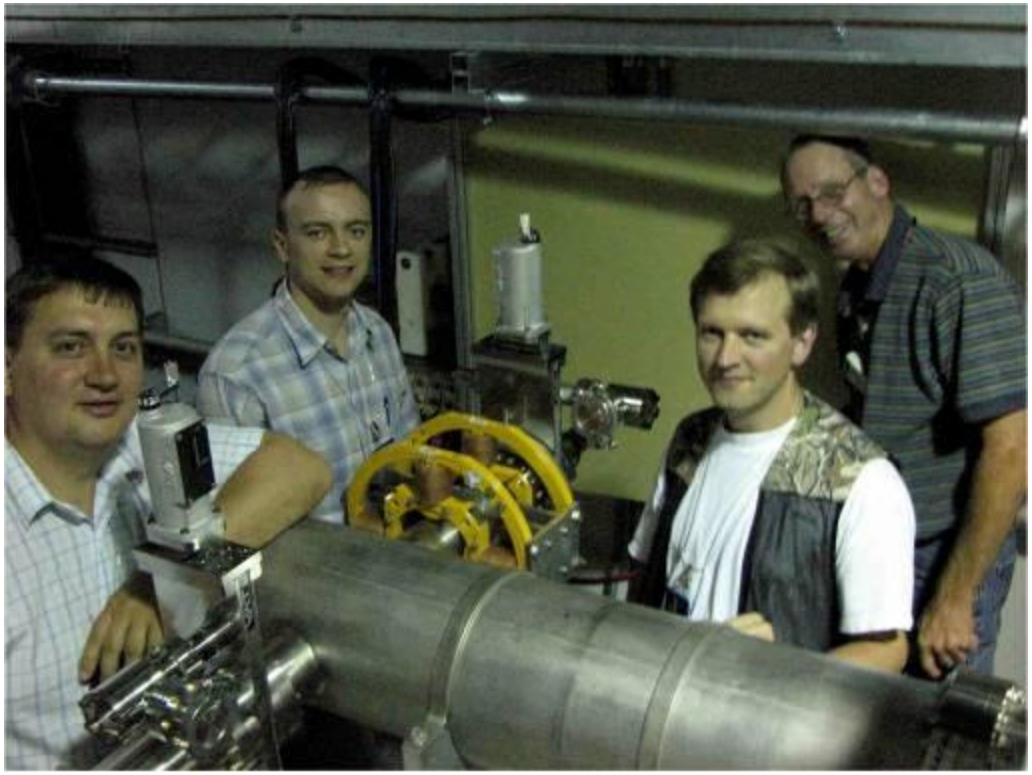
Laser-beam interaction location (~30 ns steps)

Electron scanner principle of operation



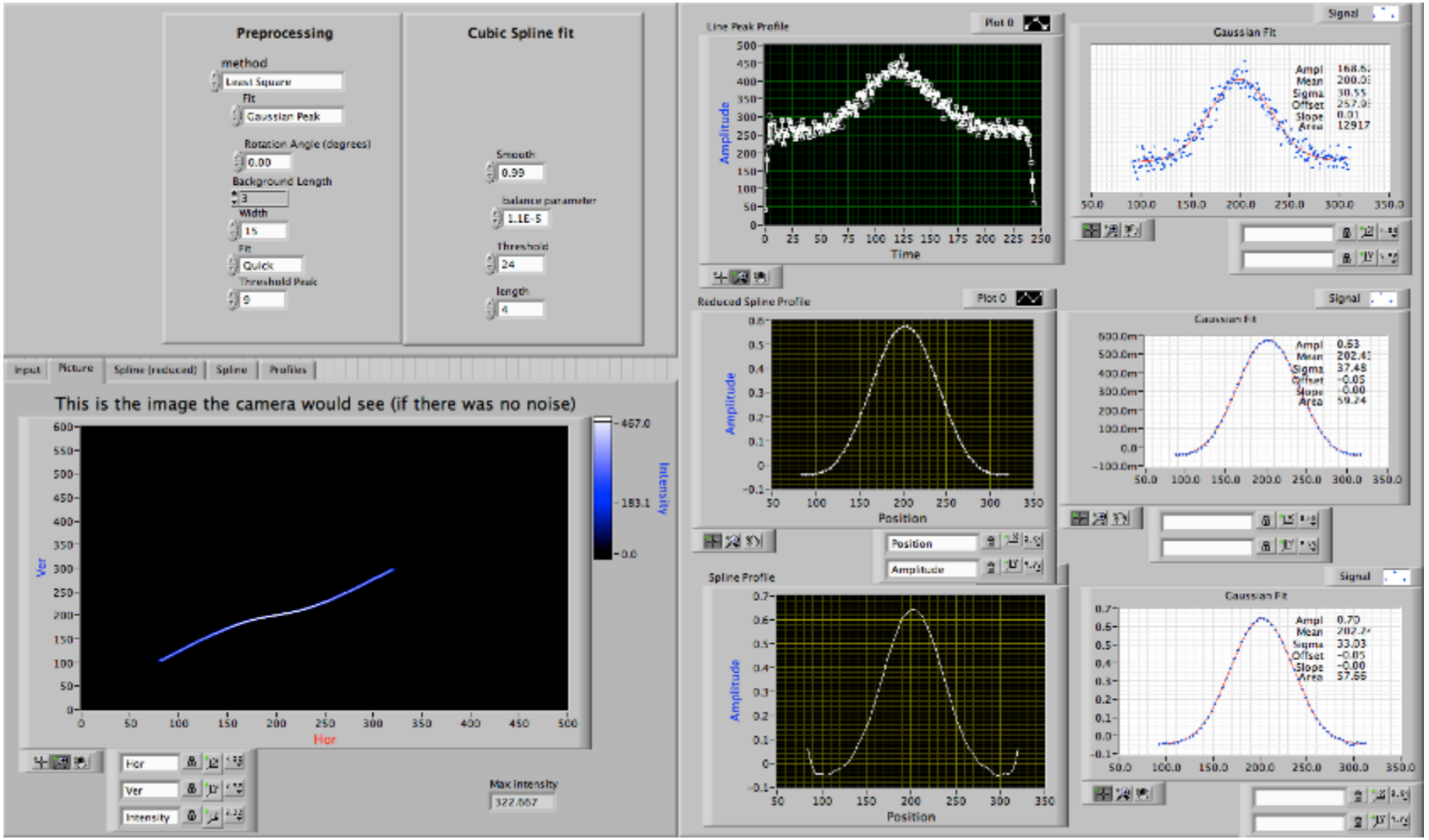


Electron scanner hardware for SNS proton accumulator ring



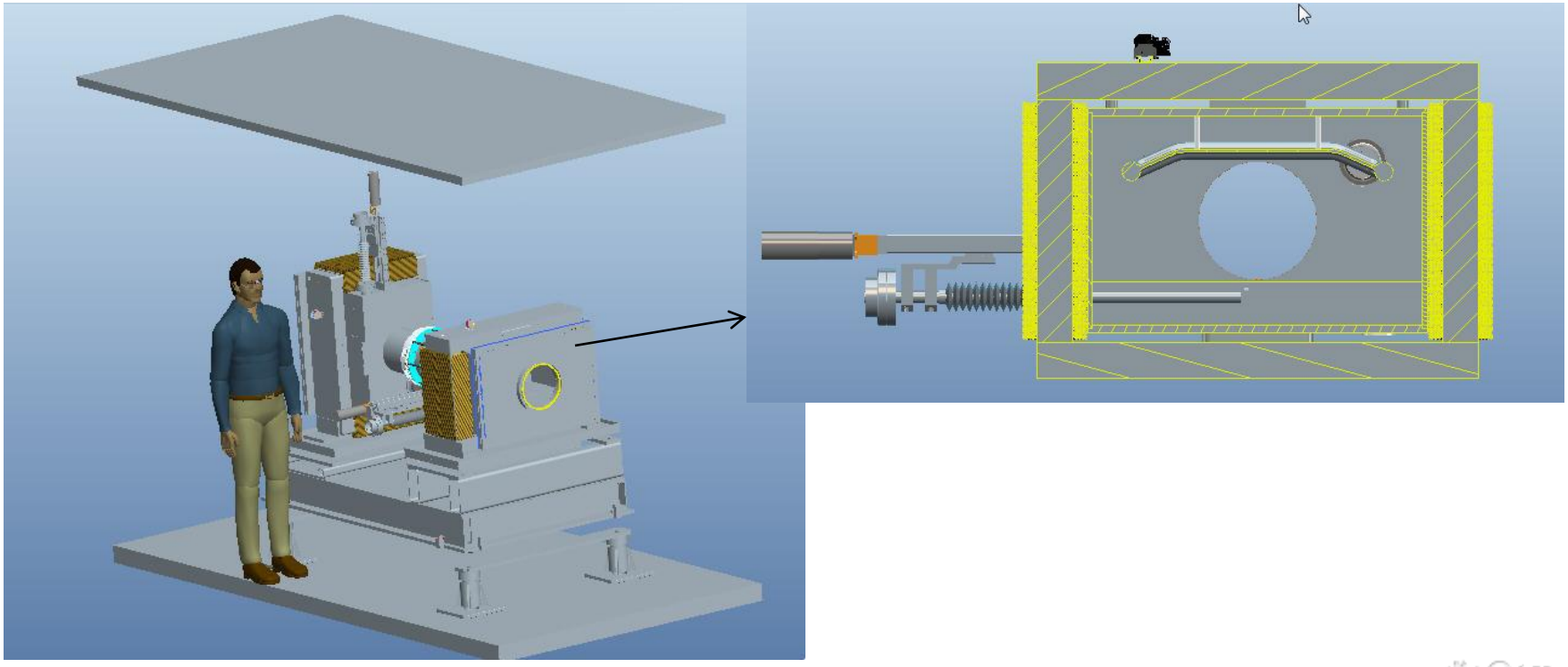
Designed and built by Budker Institute of Nuclear Physics in Novosibirsk

Software: Image Analysis



IPM for accumulator ring

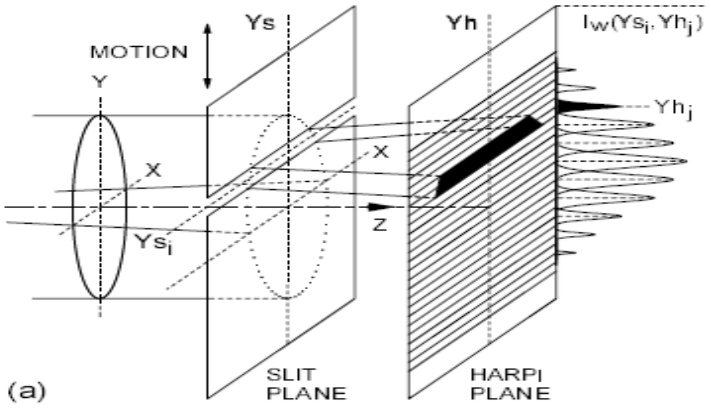
- **SNS specific problems**
  - Large beam pipe aperture of 30cm
  - High voltage of 120kV is required to overcome space charge
  - Time resolution of ~20ns requirements

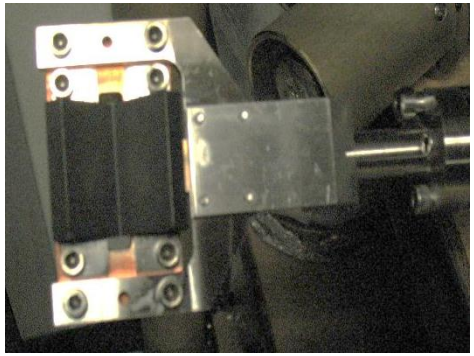


Transverse Emittance Measurements

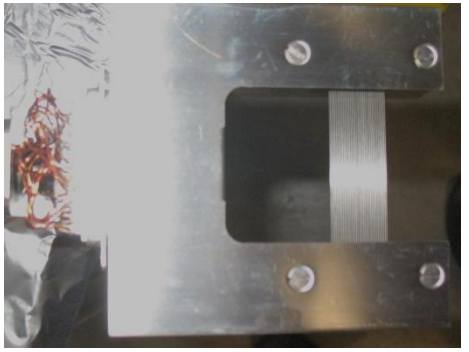
- Insertable slit-and-harp device in the MEBT
  - 100um slit, 16 signal wires harp
  - 50us, 1Hz limit on beam pulse,
  - 5us time resolution
  - One plane at a time (horizontal or vertical)
- Laser slit-and-collector device in the HEBT
  - Non-perturbing
  - 20ns time resolution
  - One plane at a time (horizontal or vertical)

MEBT emittance scanner

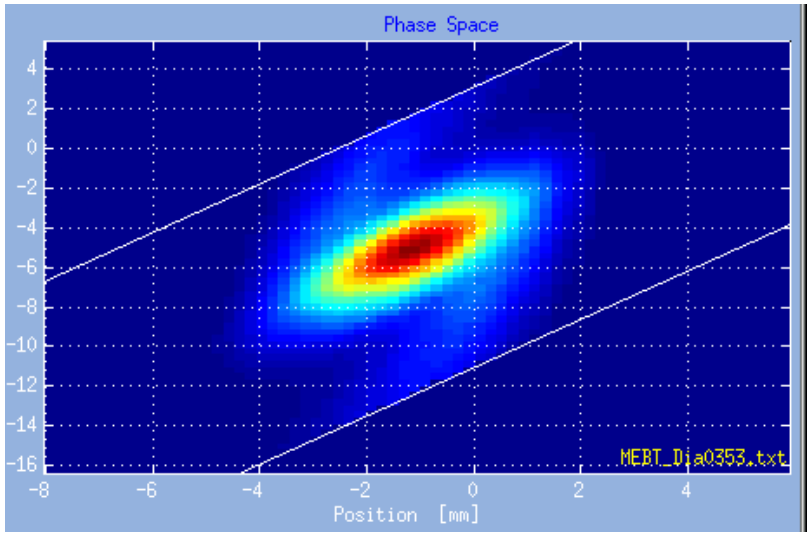




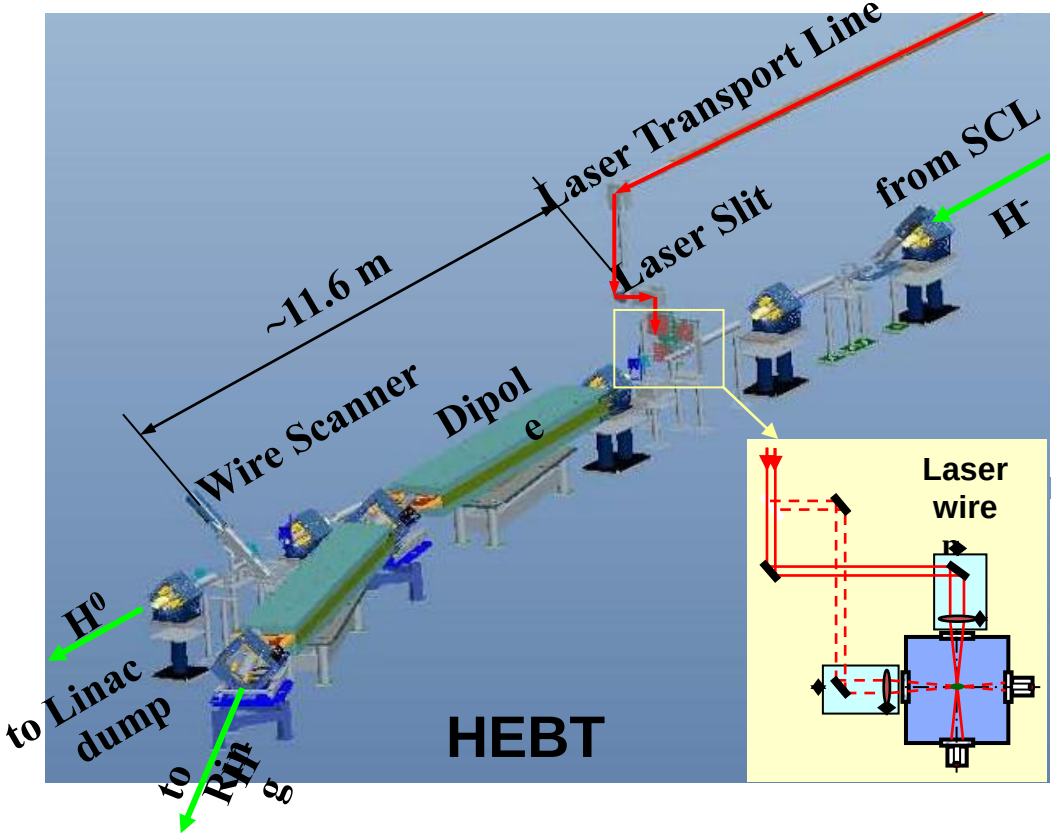
slit

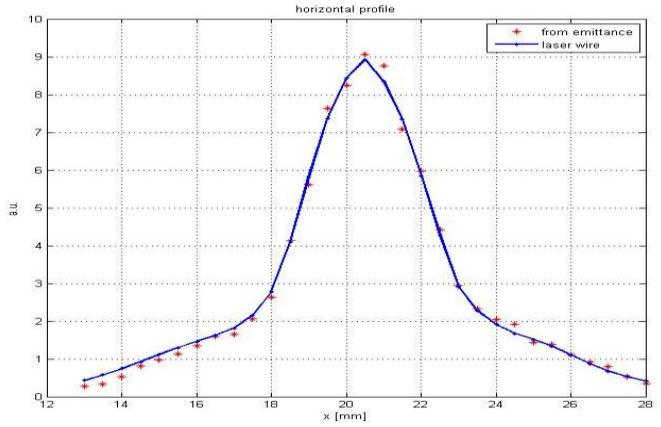


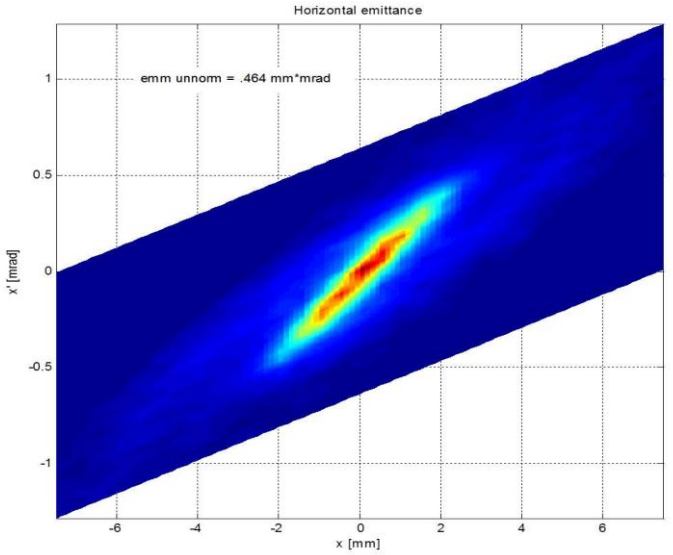
harp



HEBT laser emittance scanner



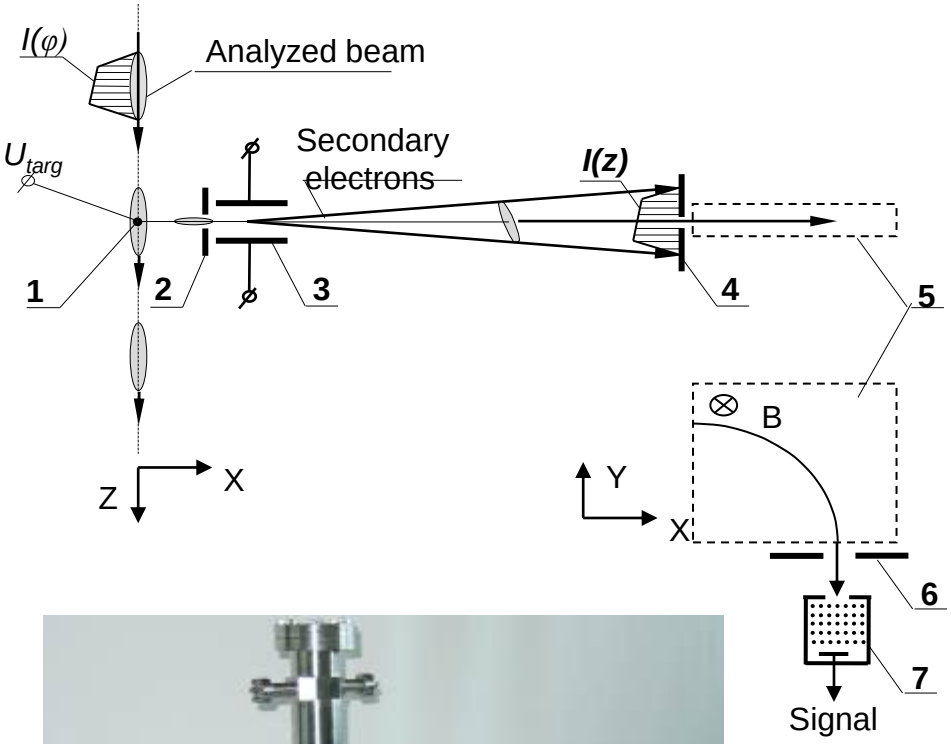




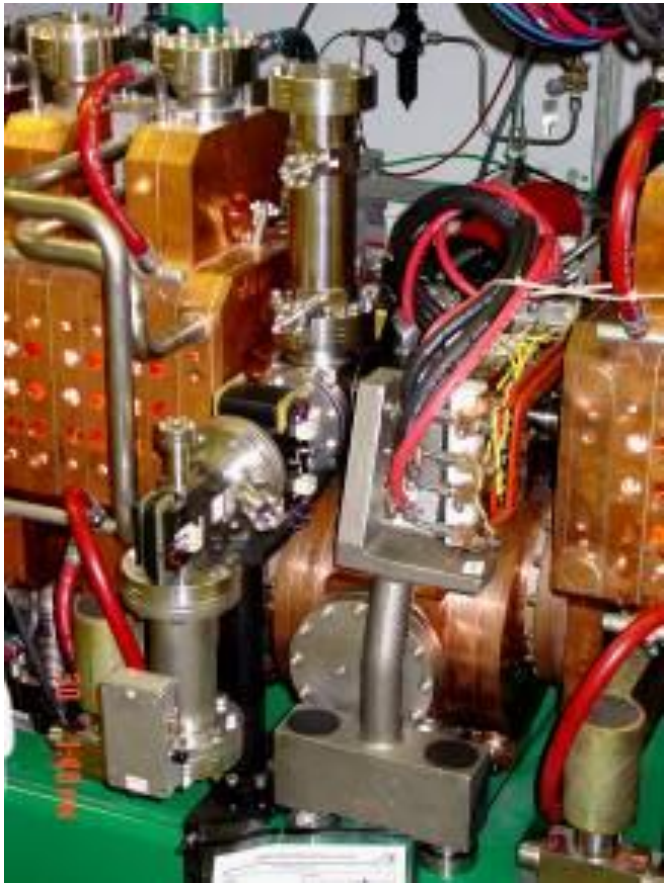
Longitudinal Beam Profile Measurements

- 6 Beam Shape Monitors (aka Feschenko monitors)
  - 4 BSMs in CCL + 2 BSMs in HEBT
  - 50us, 1Hz limit on beam pulse duty factor
  - Not single bunch capable
    - 10us time resolution (macro)
    - ~2ps time resolution (micro)
- Mode-locked laser longitudinal profile scanner in MEBT
  - Non perturbing
  - Not single bunch capable
    - 10us time resolution (macro)
    - ~10ps time resolution (micro)
  - In the process of redesign

Beam Shape Monitors

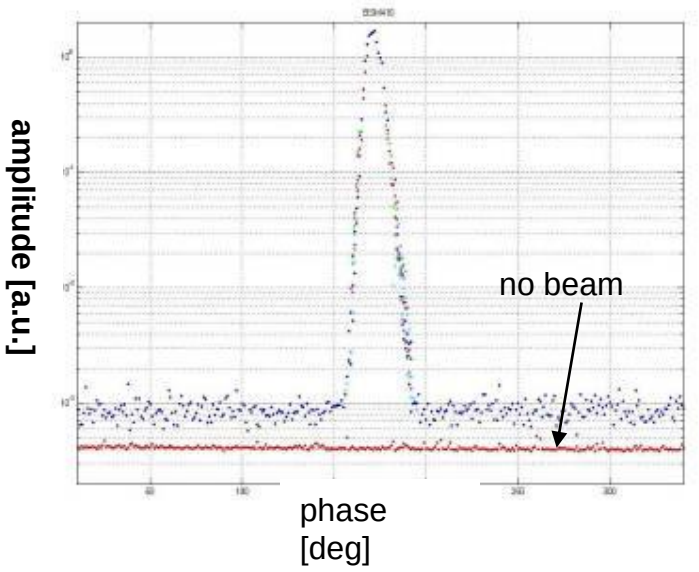


CCL BSM

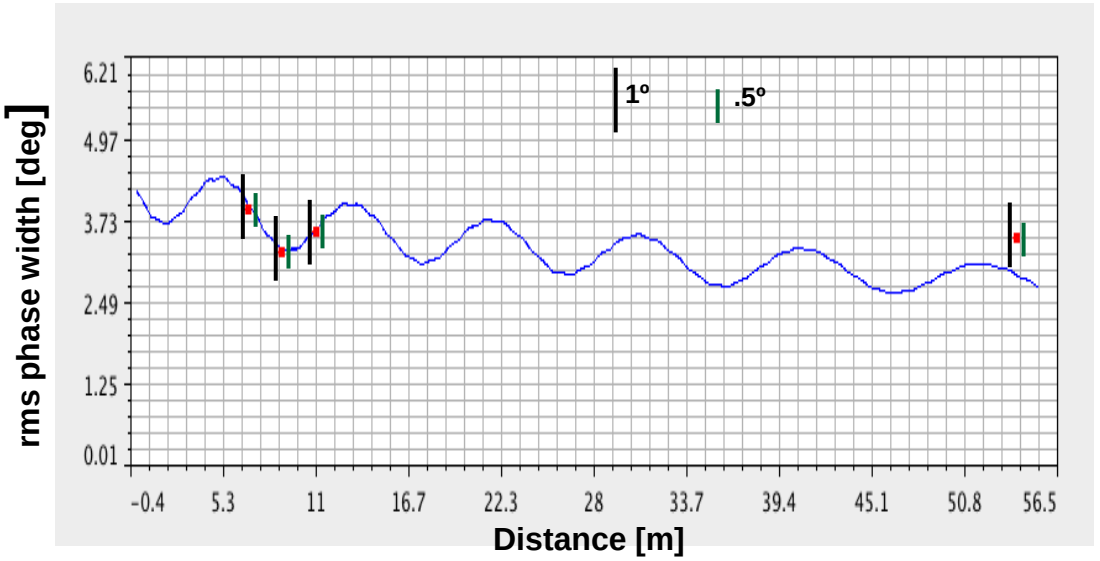


BSM performance

- Phase resolution of ~0.5º @805MHz
- Dynamic range of 10^3 - 10^4
- Sensitive to stray magnetic fields



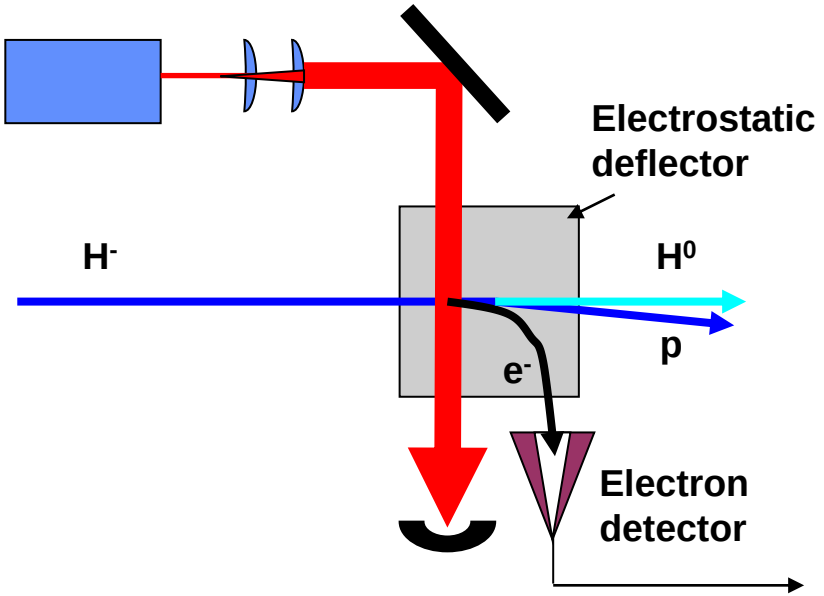
Typical longitudinal bunch profile

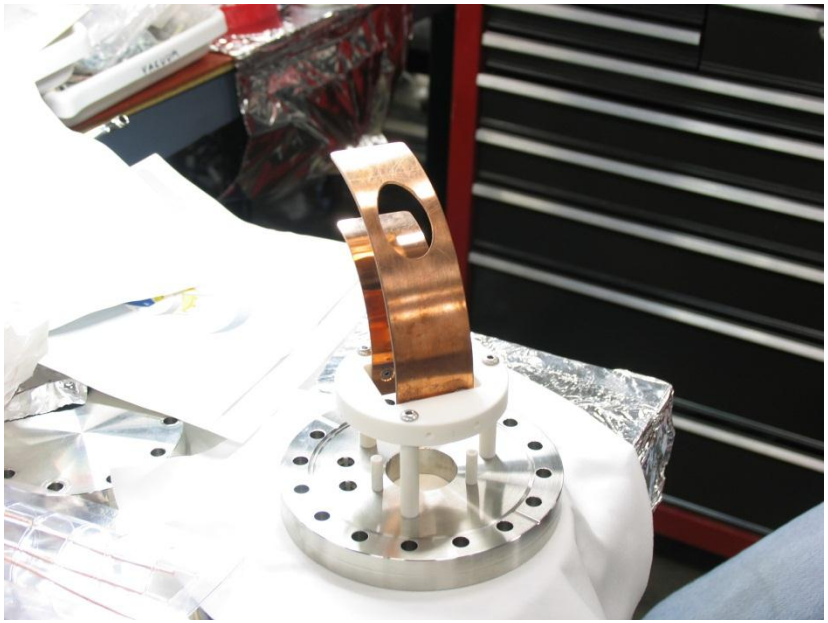


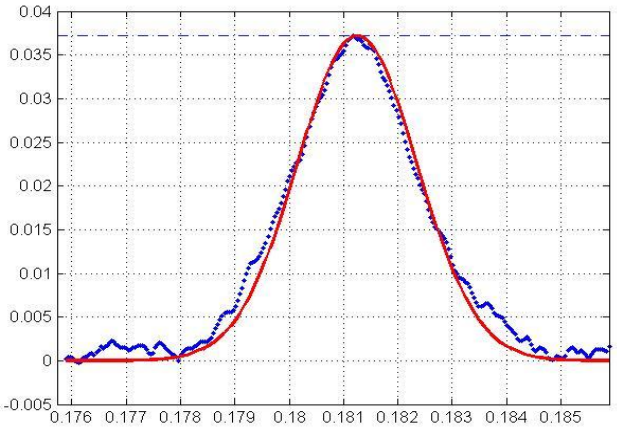
Measured longitudinal bunch size vs. model

Longitudinal Laser Profile Monitor

Mode - locked laser synchronized with 5th sub - harmonic of LINAC RF (~80 MHZ)

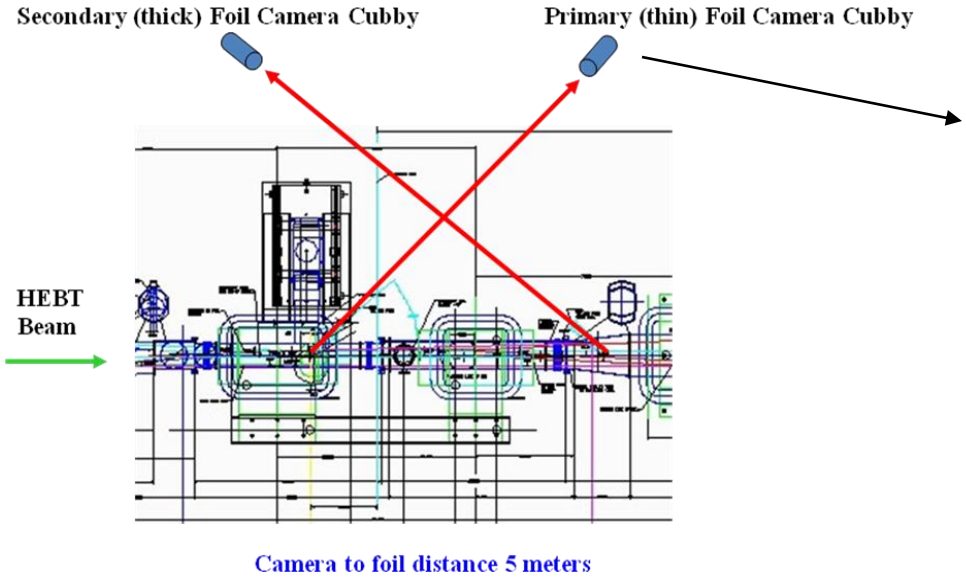


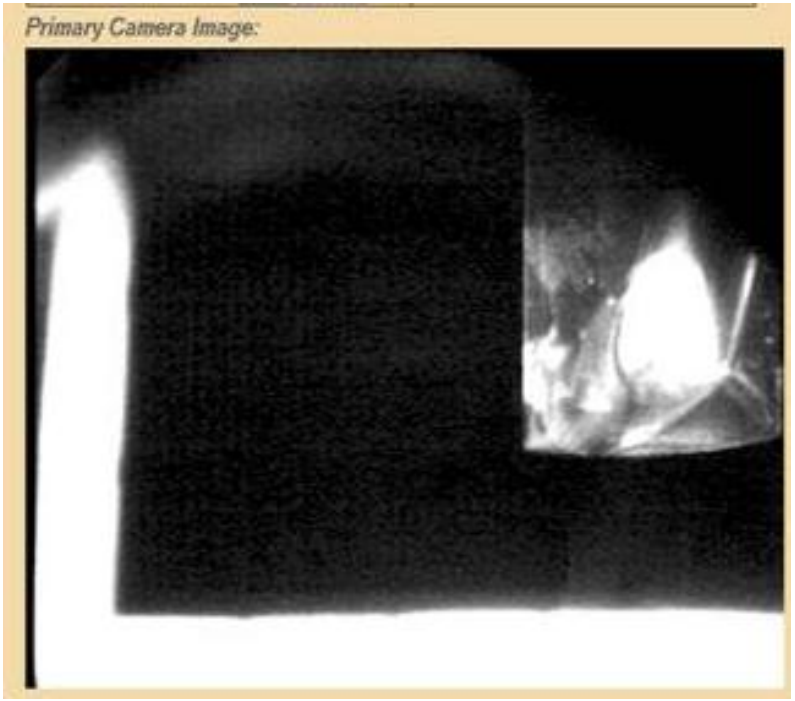




Direct beam imaging

- Phosphor screens in injection and extraction lines
  - 50us, 1Hz limit on beam pulse
  - CCD cameras
- Hot spot on injection foil
  - Analog radiation hard video camera in tunnel
  - Optical line and digital cameras outside





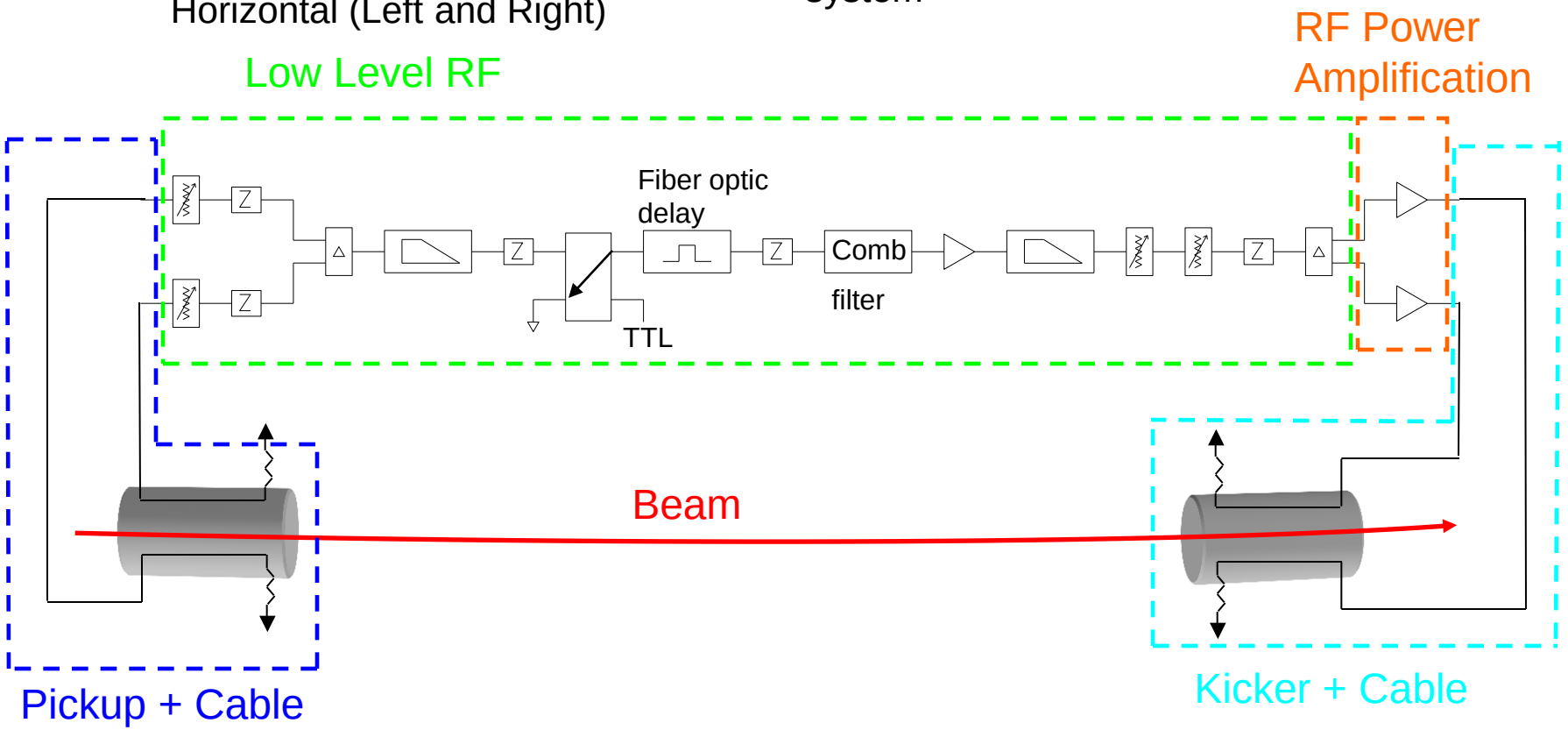
SNS Ring Feedback/Beam Transfer Function Measurement System

Consists of 2 independent systems

- Vertical (Up and Down)
- Horizontal (Left and Right)

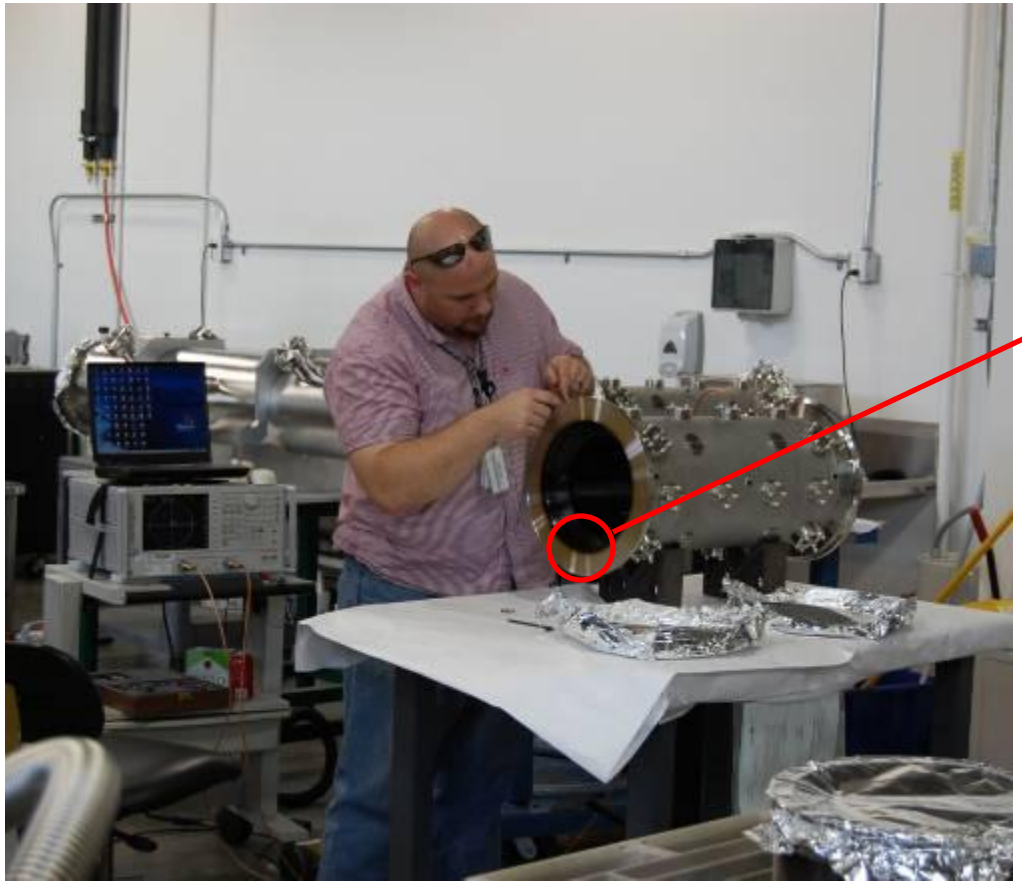
200 Watts of power per channel

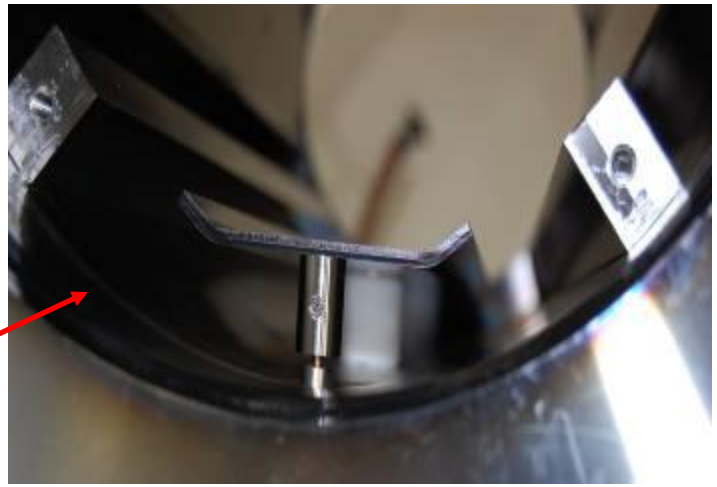
Capable of 800 Watts total for system

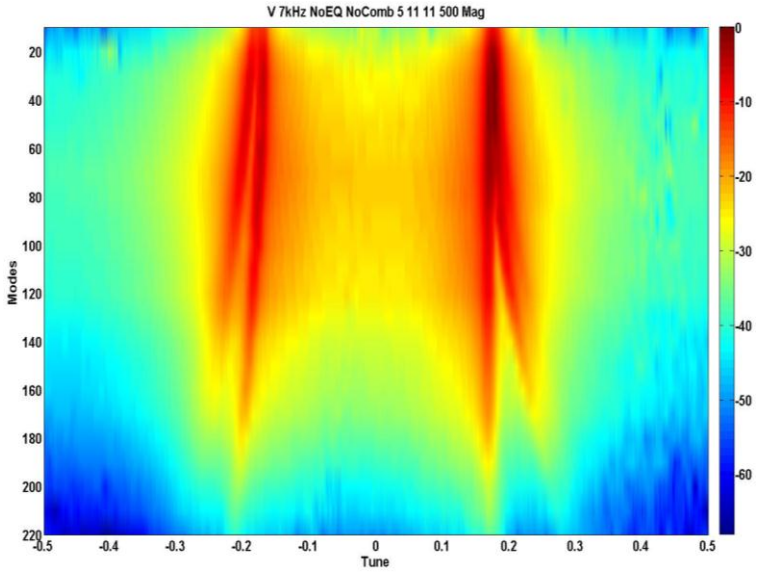


Feedback system electronics

Pick-up and kicker hardware







Other diagnostics systems

- Beam stops
- Faraday cups
- Scrapers
- Apertures
- Nano Current Detectors (10^4 dynamic range, 20ns rise time)

Development priorities

- Reliability
- User friendliness
  - GUI
  - Data analysis
- Performance
  - Dynamic range
  - Time resolution
- Speed of measurements
- Novel techniques & methods

Thank you for attention

Beam Instrumentation Networking