Beam Instrumentation Performance and Plans

Alexander Aleksandrov

Beam Instrumentation Acting Group Leader

February 23, 2009

Outline

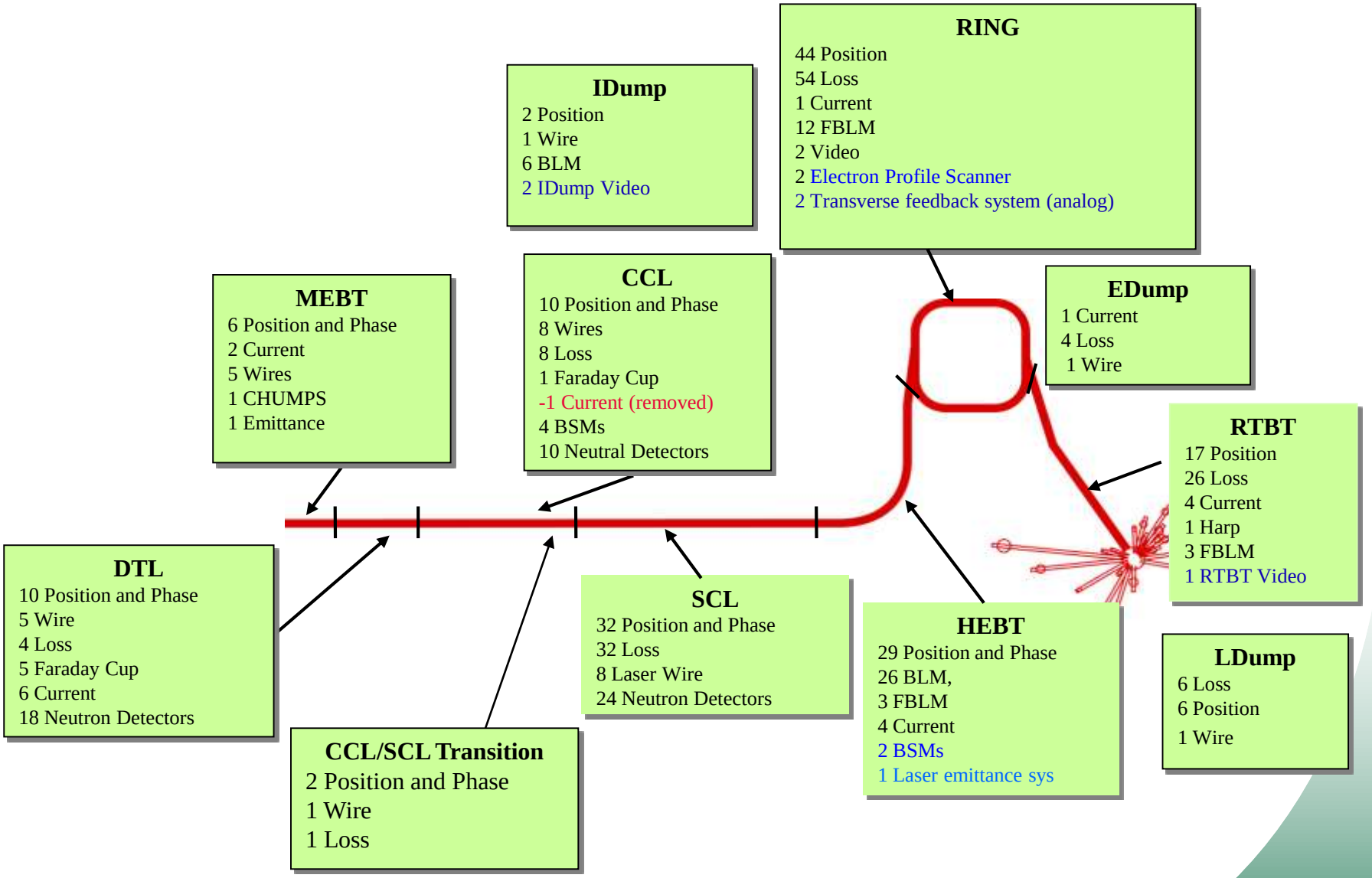
- Beam Instrumentation Group priorities
- Overview of existing and planned diagnostics systems. Performance and upgrades
- Featured diagnostics
  - SCL laser wire
  - Beam Shape Monitors
  - Ring Electron Scanner
  - Ring Transverse Feedback system

Beam Instrumentation Group priorities

- **#1. Diagnostics required for beam delivery: Beam Loss Monitors, Beam Accounting Systems for dumps and target, Machine Protection significant Systems**
  - **Cause downtime if not operational**
  - **Focus is on improving reliability, serviceability and reducing time to repair**
- **#2. Diagnostics required for machine tuning: Beam Position and Phase, Profile Measurements**
  - **Slows down setting up production run if not operational**
  - **Focus is on improving quality of delivered data and user friendliness**
- **#3a. "High end" diagnostics for machine study: emittance, halo, longitudinal measurements, experimental diagnostics**
  - **Does not affect beam downtime directly.**
  - **Focus is on improving quality of delivered data and maximizing performance**
- **#3b. Answering to urgent requests from Accelerator Physics and other groups**

Total diagnostics related downtime for FY09/09 runs = 12 hours

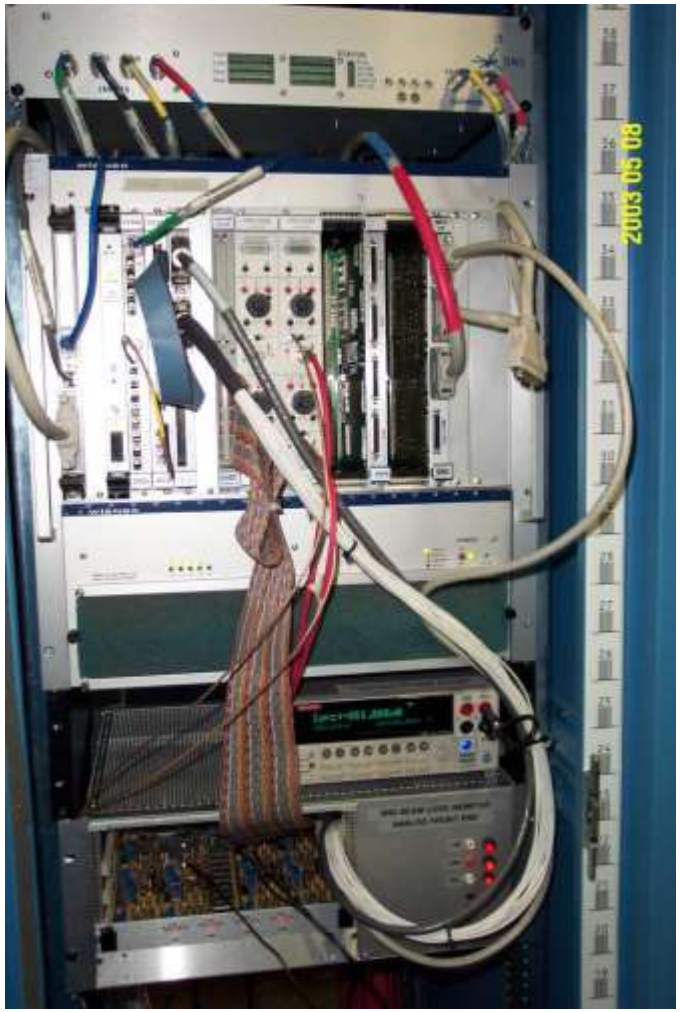
SNS Beam Instrumentation Systems are Numerous and Diverse



Beam Loss Monitors System Development

- **Front-end electronics upgrade**
  - **Independent 1chanel per board and 1 power supply per board design (vs. existing 12 channels per board per power supply design)**
  - **Hot swappable boards**
- **Dual PMT based detectors**
  - **Very efficient noise and X-ray background cancellation**
  - **Dual detector design is immune to single chanel failure**
- **Ongoing improvement of VMX software**

Next Generation BLM System



Existing

New

Data Acquisition tested at 300 Hz

Obsolescence of components is a concern

Beam Position and Phase

- **Major tool for machine tune up**
  - **Phase measurements is basis for linac tune up**
  - **Position measurements for trajectory correction, injection set up and centering beam on dumps and target**
- **Recent Developments**
  - **Automated gain adjustment in ring style BPMs**
  - **User friendly timing setting**
- **Near term plans**
  - **Add 5 new BPMs in HEBT**
  - **New timing card is under development**
  - **Increase injection dump BPM accuracy to speed up beam centering**

Transverse Beam Profile Measurements

- Conventional wire scanners in MEBT, warm linac, HEBT, beam dumps, and RTBT
  - Deliver reliable profiles with dynamic range of ~100, which is sufficient for beam core matching but not sufficient for beam halo and loss study.
  - Investigating possibilities to increase dynamic range to 10^3 – 10^4
  - Retrofitting wire scanners with more reliable actuators
- Non-perturbing laser wire in SCL
  - Delivers reasonable data on a good day
  - Has not been available for routine measurements
  - Made significant improvements to software
  - Hardware problems have been identified and all seem solvable. More details below
  - Making laser wire available for routine measurements is high priority for beam instrumentation group.
- Non-perturbing profile measurements in ring
  - Successfully tested electron beam scanner
  - Considering development of Ionization Profile Monitor

Transverse Beam Profile Measurements (cont.)

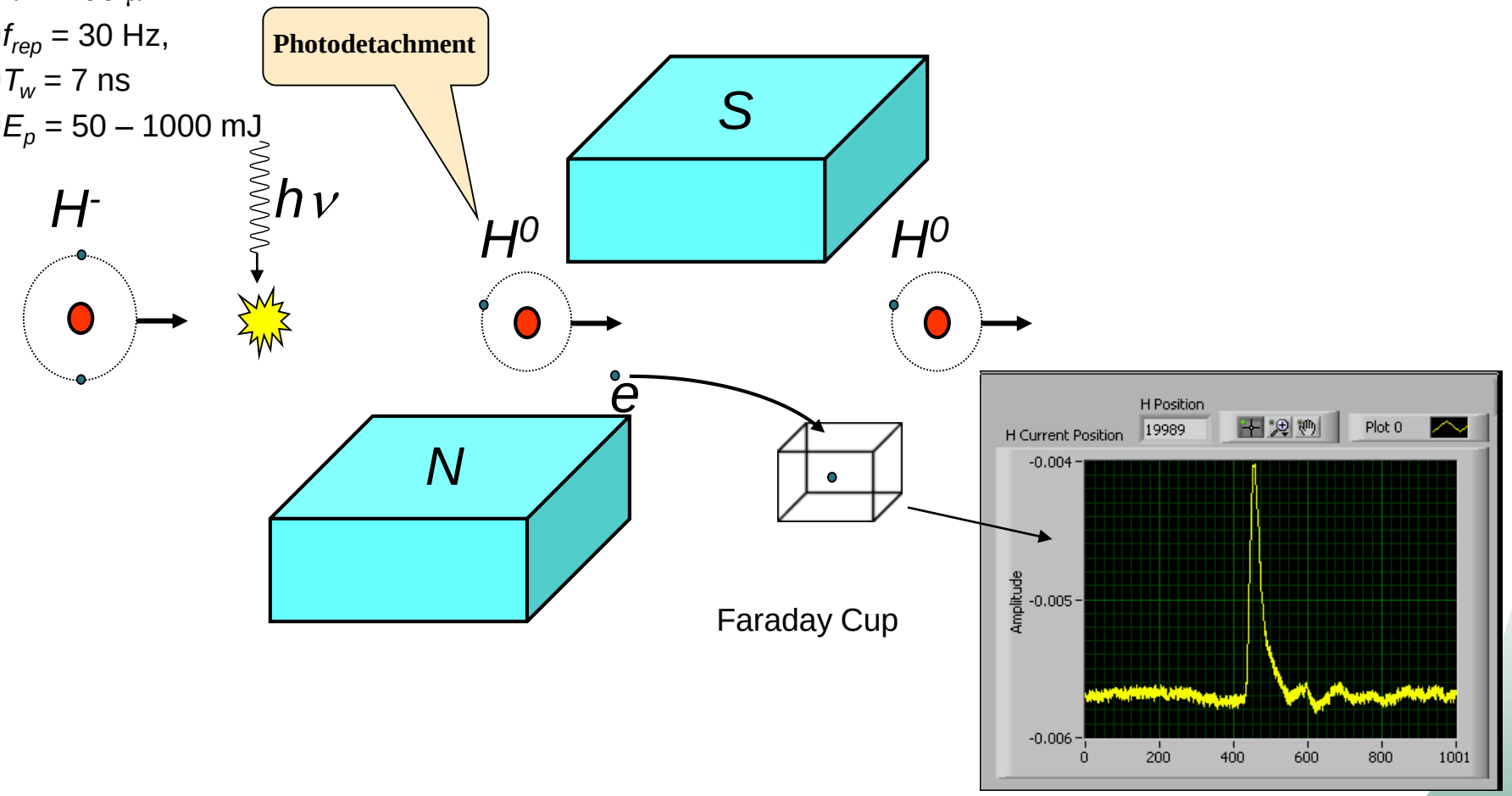
- **Emittance measurements**
  - **Significant improvements of MEBT slit/harp emittance scanner**
  - **Finished design of non-perturbing laser based emittance station in HEBT**
- **Halo measurements**
  - **There is no dedicated halo measuring device**
  - **Developed current measuring system for HEBT scrapers capable of measuring down to 10^{-5} level. This system can be used for transverse halo evaluation or can become a basis for a dedicated halo monitor.**
- **View screens in injection line and RTBT**
  - **Are used for visual qualitative observations**
  - **Better software needs to be developed to facilitate quantitative measurements**
  - **Radiation damage to injection foil video system is an issue**

Longitudinal Beam Profile Measurements

- **Beam Shape Monitors**
  - **Have had 3 BSM in CCL1 since day one**
  - **Added and fully commissioned 1 BSM at CCL4**
  - **Added 2 BSMs in HEBT. Will finish commissioning in March**
  - **Plan to install 1 more BSM in HEBT after arc for laser stripping experiment**
  - **Very reliable devices with very large dynamic range (10^3 – 10^4)**
- **Mode-locked laser based longitudinal profile measuring system in the MEBT**
  - **Used to verify longitudinal beam parameters during commissioning**
  - **Decommissioned later due to lack of resources**
  - **Have desire to resurrect this diagnostics with increased dynamic range. Do not have firm plans yet.**

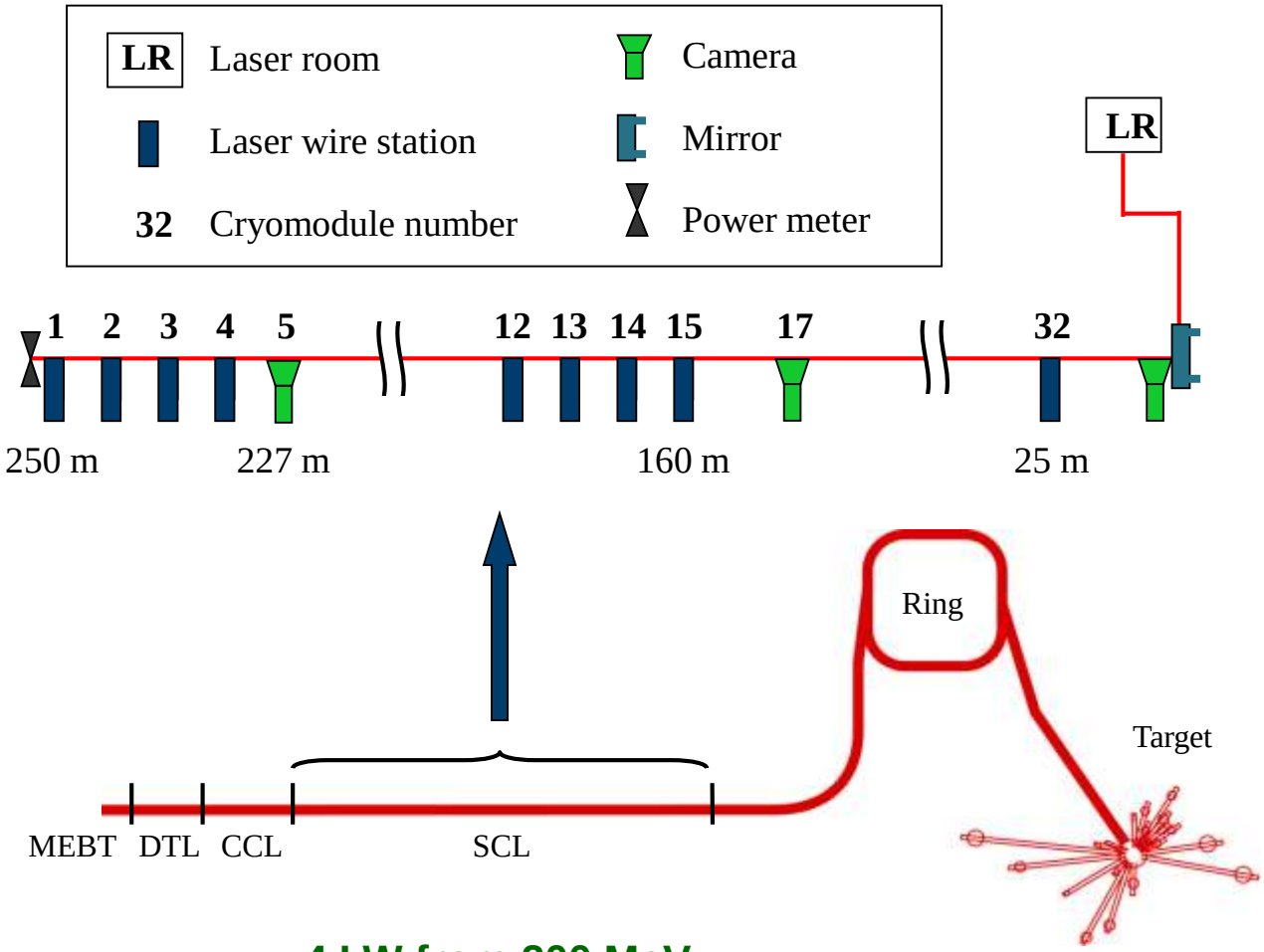
Principle of Laser Wire

- Q-switched Nd:YAG laser
- λ = 1.06 μm
- f_{rep} = 30 Hz,
- T_w = 7 ns
- E_p = 50 – 1000 mJ



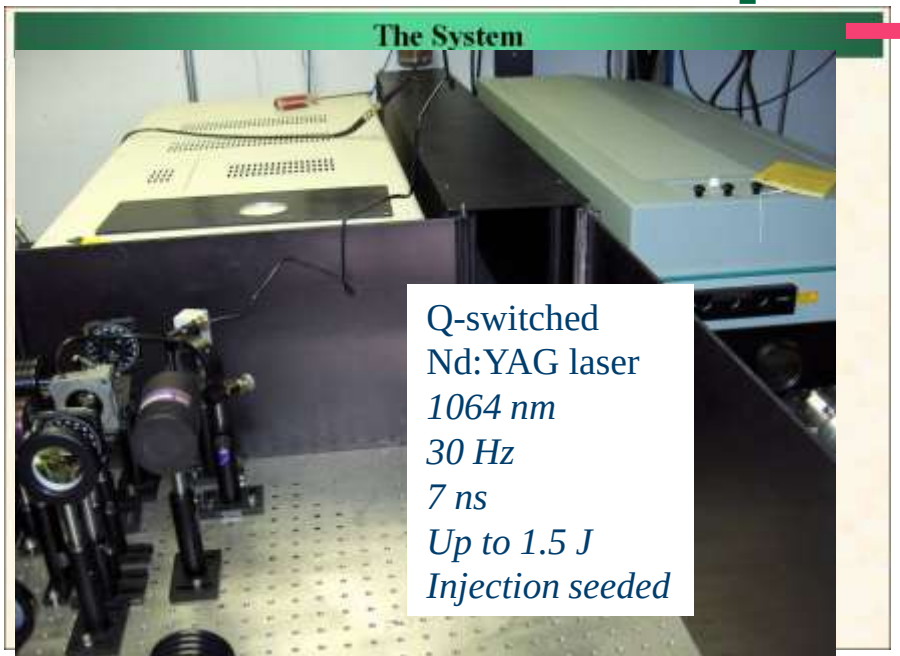
- Detected electron number is proportional to the ion density

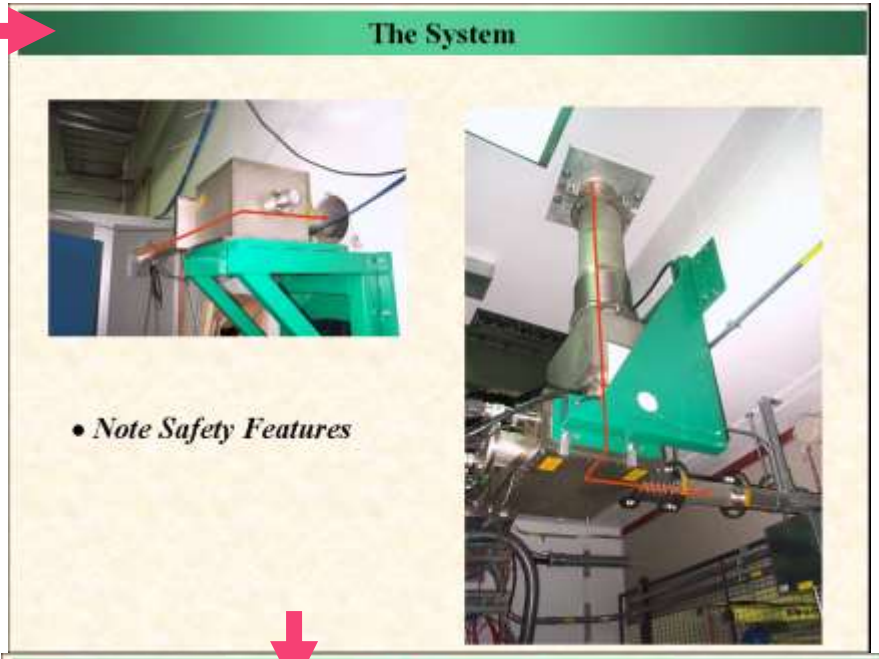
Layout of the SCL Laser Wire System

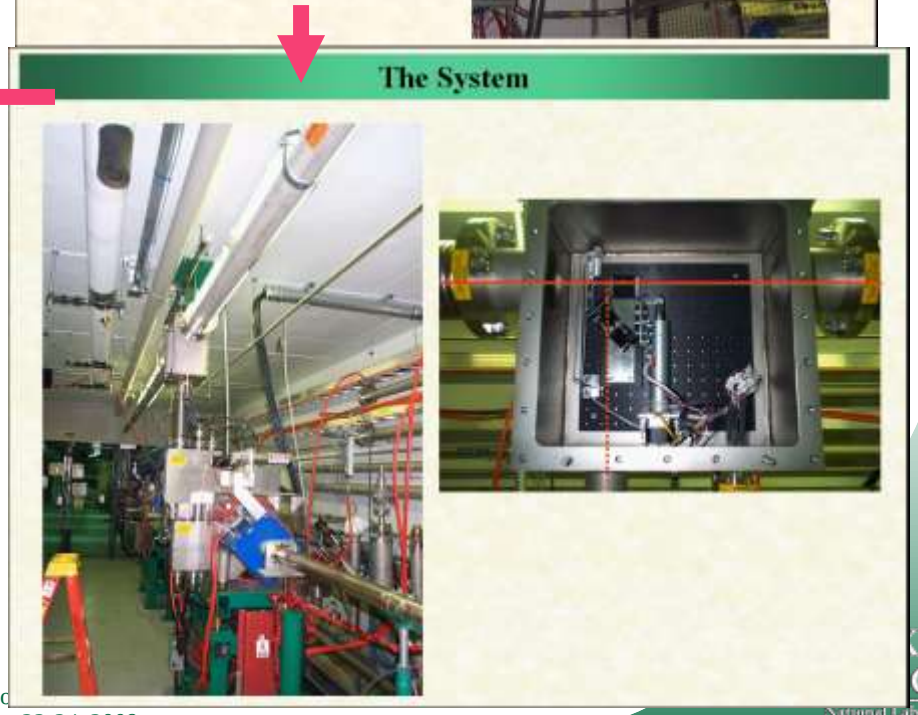


- **4 LW from 200 MeV**
- **4 LW from 450 MeV**
- **1 LW at 1 GeV**

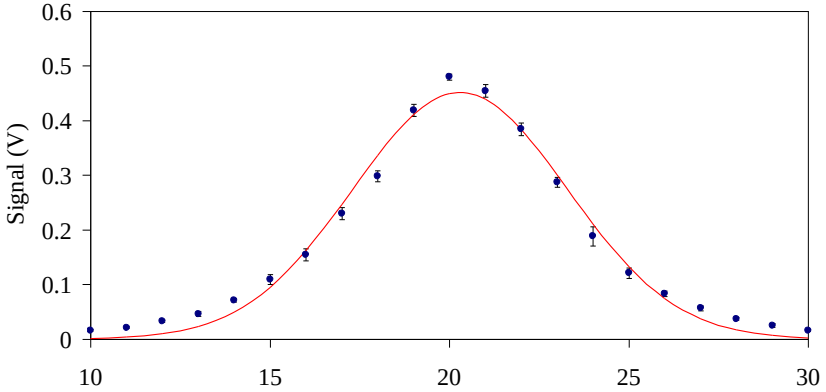
SCL Laser Transport Line

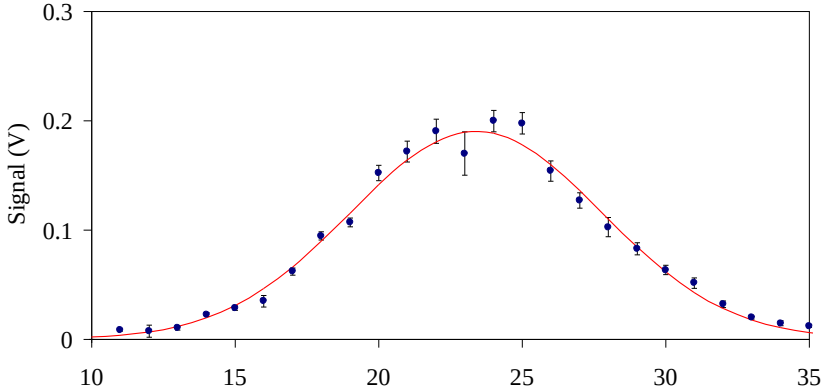




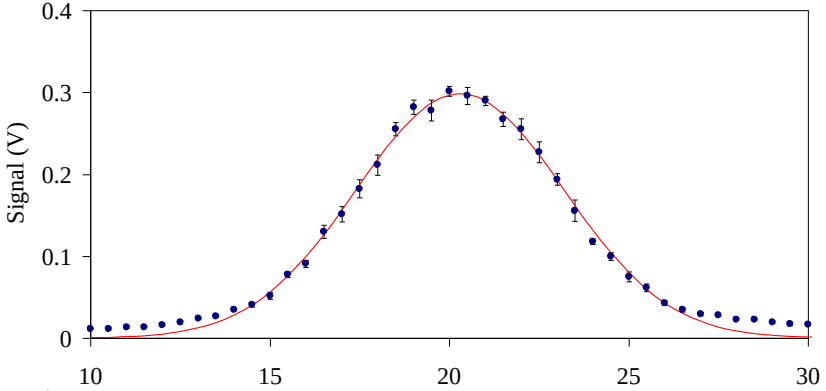


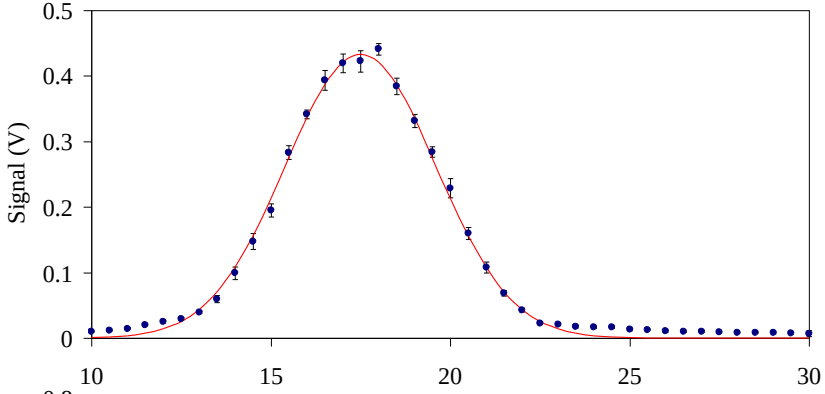
Beam Profile Measurements (Yun Liu and Cary Long)



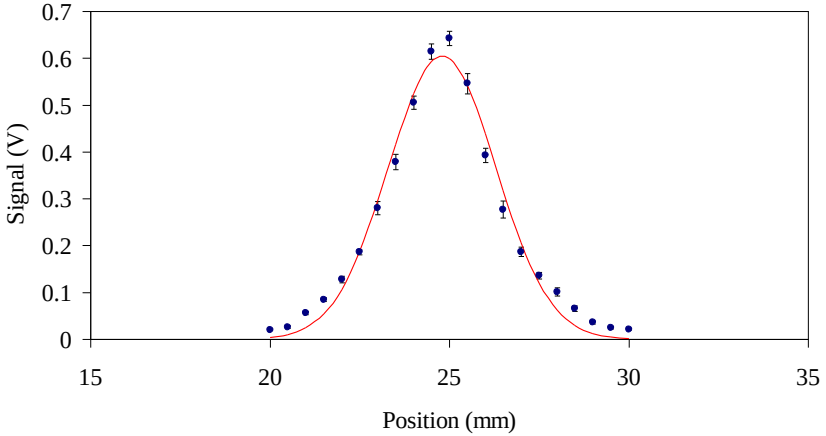


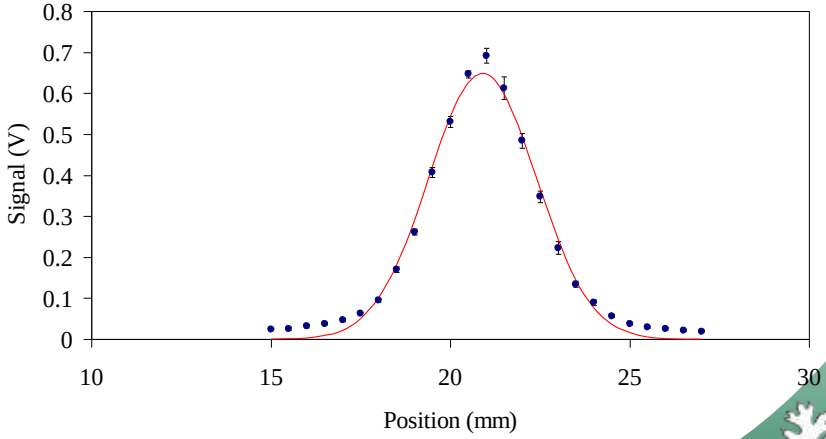
LW1





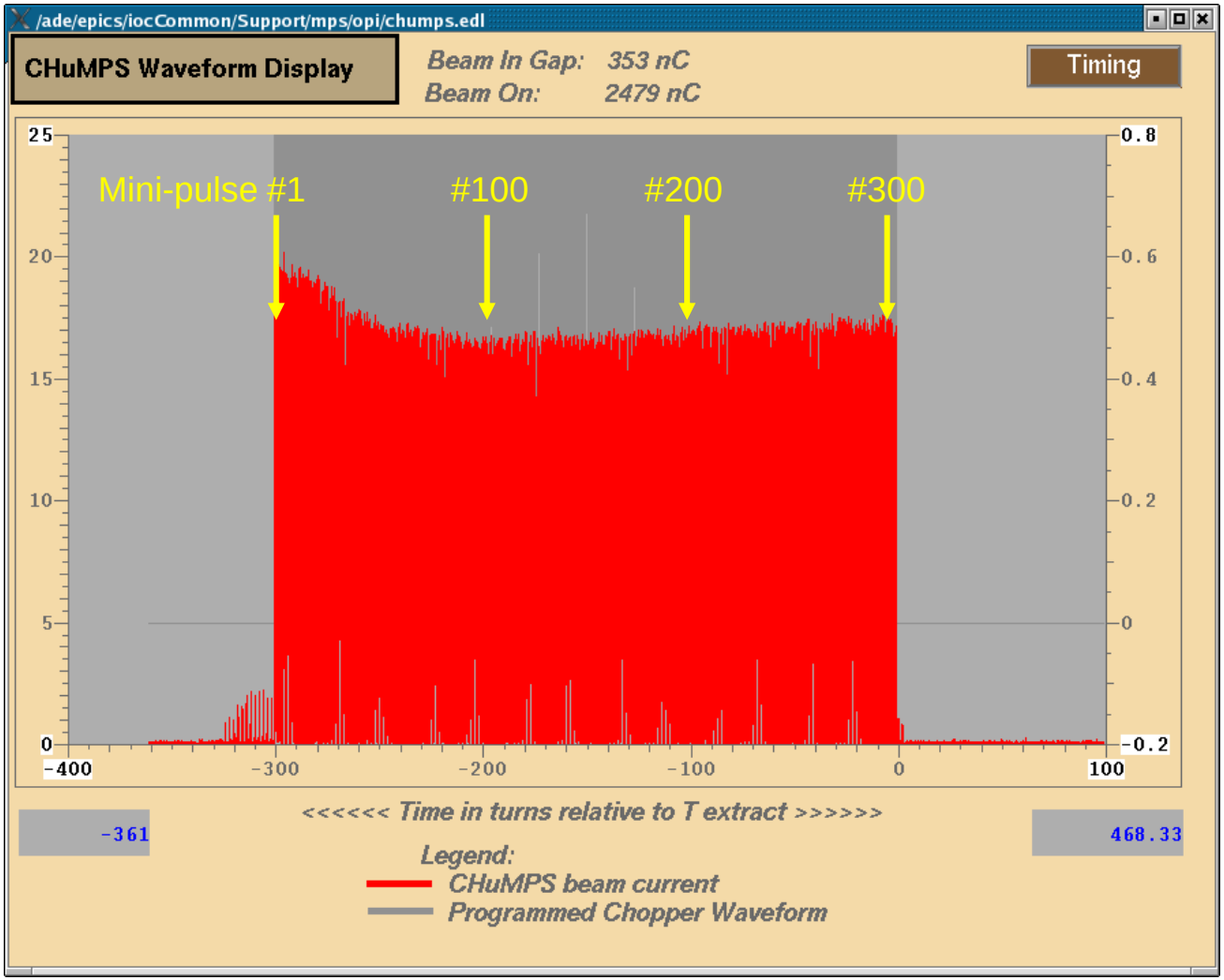
LW5



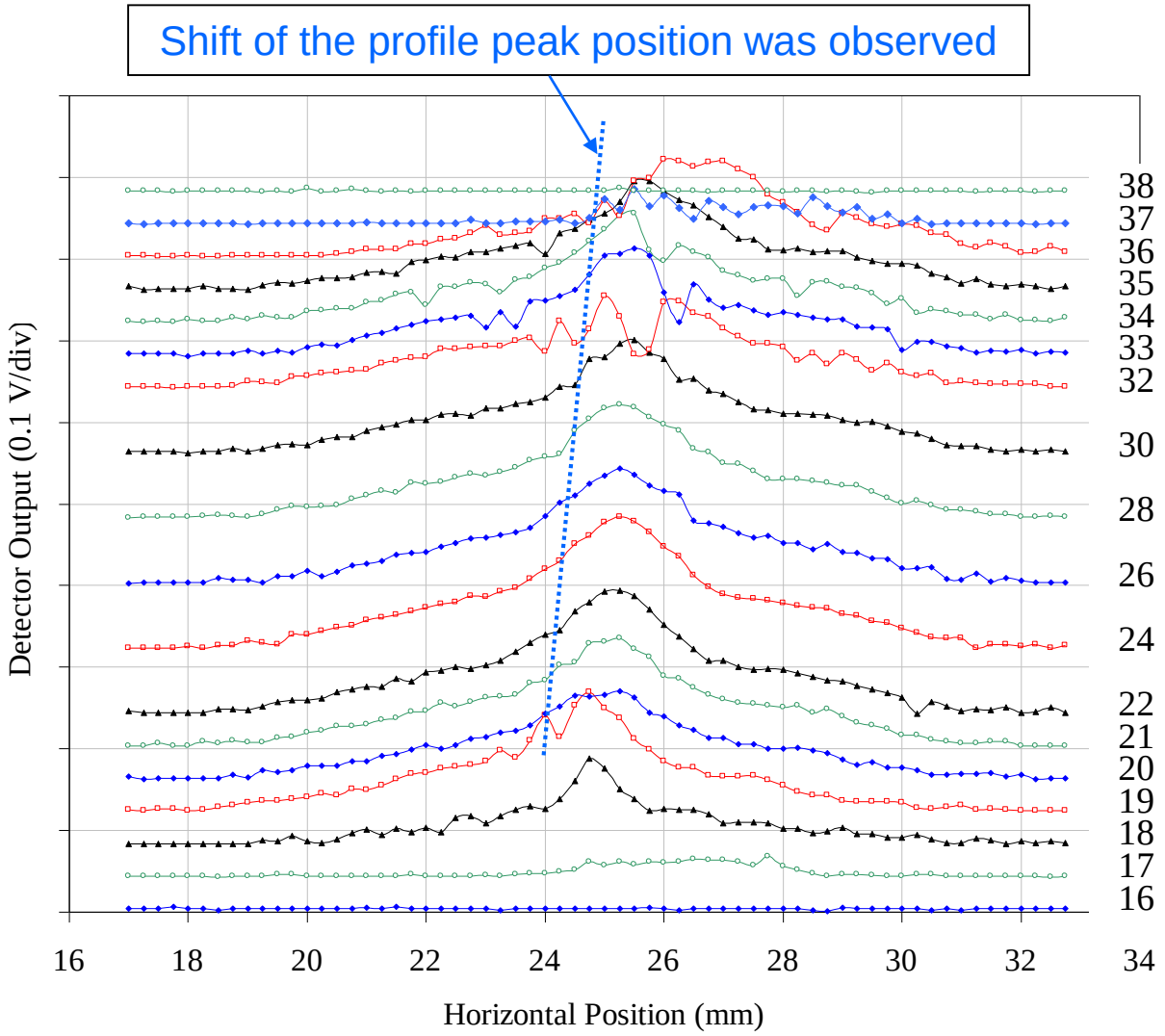


LW9

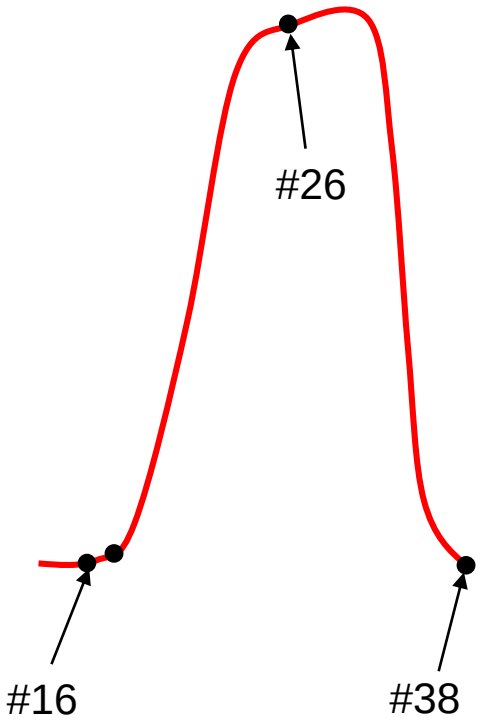
Longitudinal Scan of Beam Train with Laser Wire



Longitudinal Beam Scan within First Mini-pulse



Experiment on the 1st mini-pulse

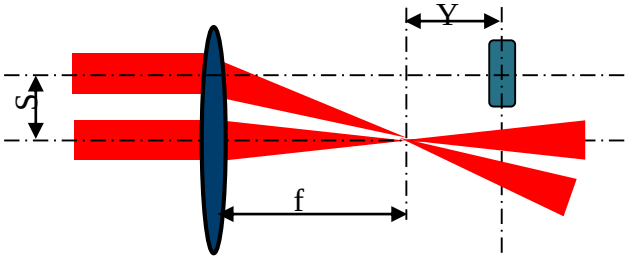


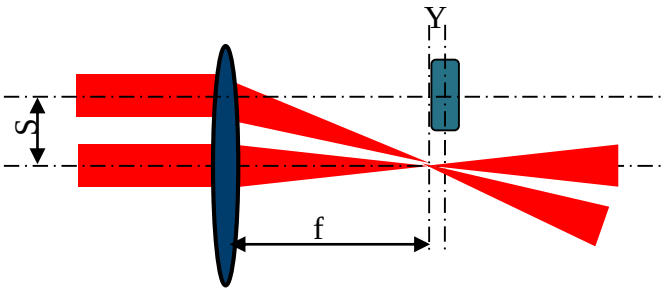
Laser-beam interaction location (unit: sub-rev turn, ~30 ns)

Laser wire problems

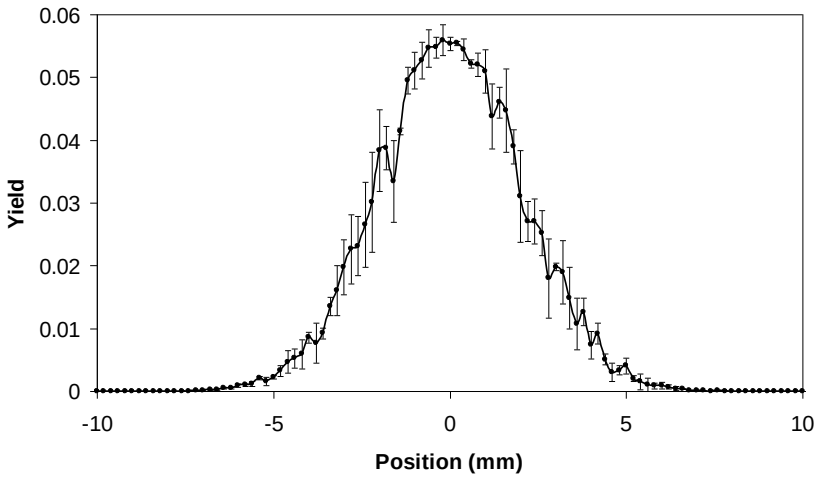
- **Laser beam stability**
  - **Intrinsic pointing stability of the laser**
  - **Higher modes of the laser perturb operation of feedback system**
  - **Vibration of optical elements**
- **Steering of H- beam by collection magnet cause losses (small but non-negligible at high power)**
  - **Apply pre-calculated compensation kick by SCL dipole correctors. Has to be adjusted every time when SCL settings change. Time consuming**

Proper laser focusing reduces effect of vibration (Yun Liu)

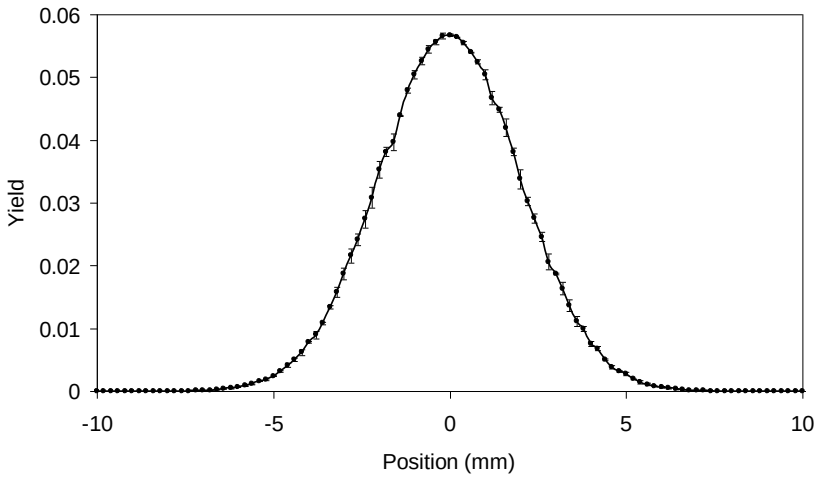




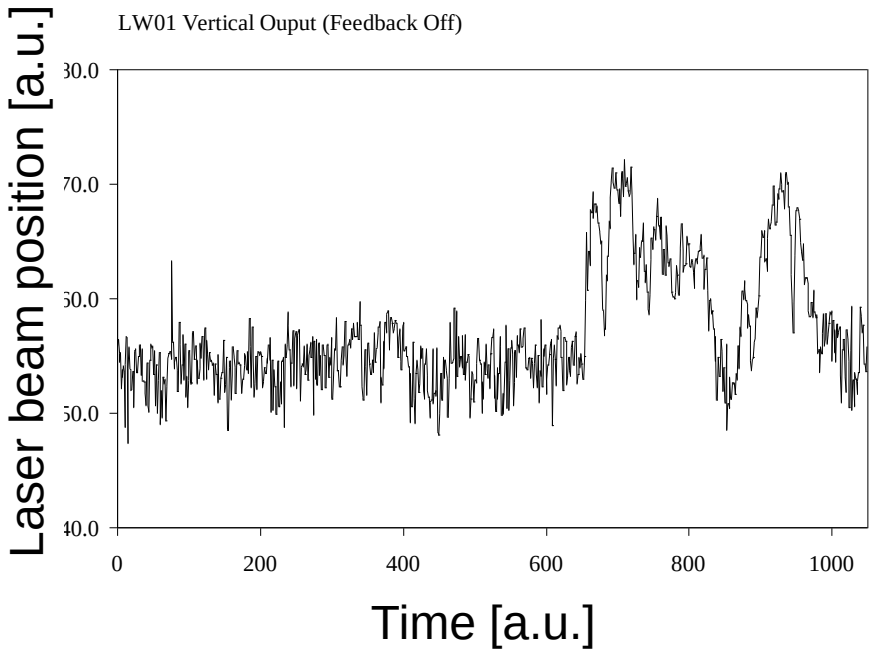
Yd=10 mm, S=-10 - 10 mm



Yd=2 mm, S=-10 - 10 mm



Laser beam stability



- Mechanical/thermal drift
- Spectra-Physics laser beam pointing stability: ±50 urad (± 10 mm at 200 m away)

- Measurements are immune to small position variation with proper focusing
- Measurements suffer when vibrations cause partial laser beam walk off of the mirror. Equivalent to laser power variation at interaction point

Laser Transport Line Diagnostics

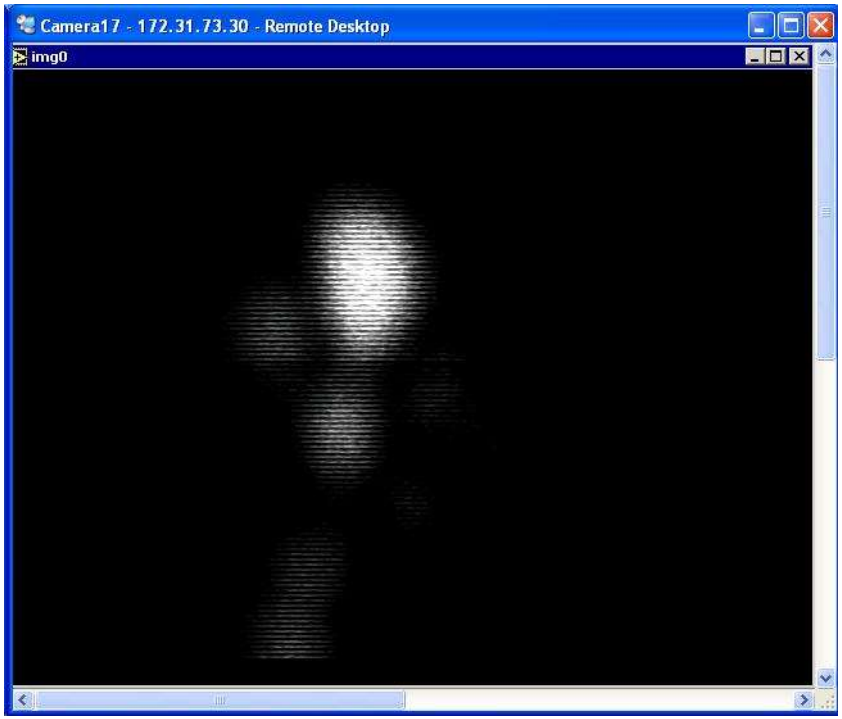


Image of Cam 17

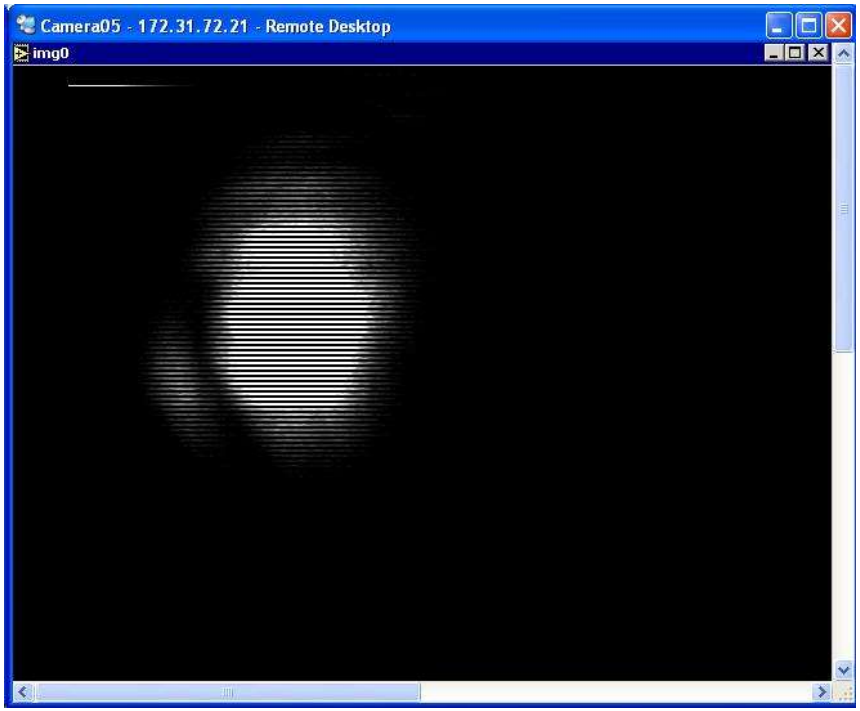


Image of Cam 5

Mitigation actions

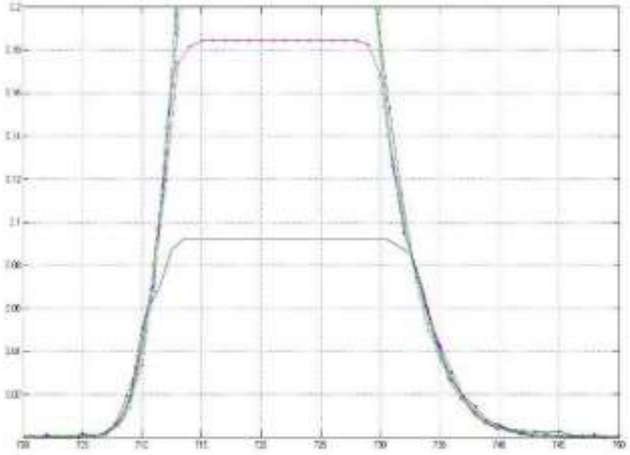
- **Laser beam stability**
  - **Recent vibration measurements throughout the laser transport line revealed single most unstable mirror. Will design a good support. (install during July or January shutdown)**
  - **Will resurrect laser pulse measurements in each pick off box. Normalization to delivered pulse power eliminates dependence on power jitter. (install during July shutdown)**
  - **Will consider adding low power guide laser for increasing positioning feedback bandwidth, which is limited to 30Hz now. (depending on success of first two)**
  - **Improve laser pointing stability and reduce higher modes generation (is in progress)**
- **H- beam steering compensation**
  - **Designed a simple compensating magnet. (install during July shutdown)**

Beam Shape Monitors (BSM) for longitudinal bunch profile measurements. (A. Feshenko)

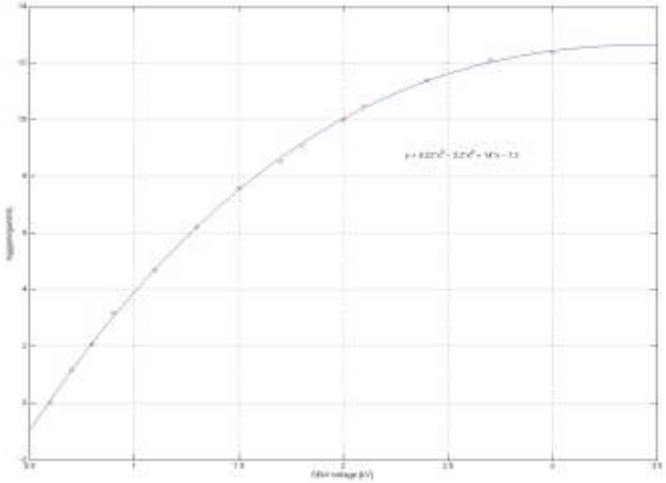
- Designed and manufactured in collaboration with INR (Moscow)
- Have had 3 BSMs in CCL1 (BSM407,409,411)
- Installed 1 BSM close to CCL exit (BSM410)
- Installed 2 BSMs in HEBT (BSM01, 19)
- Plan to install 1 BSM at laser stripping experiment location
- Allow to measure longitudinal profile with large dynamic range
- Allow to measure longitudinal emittance using multiple BSMs or by varying RF field

Large dynamic range measurements using BSMs

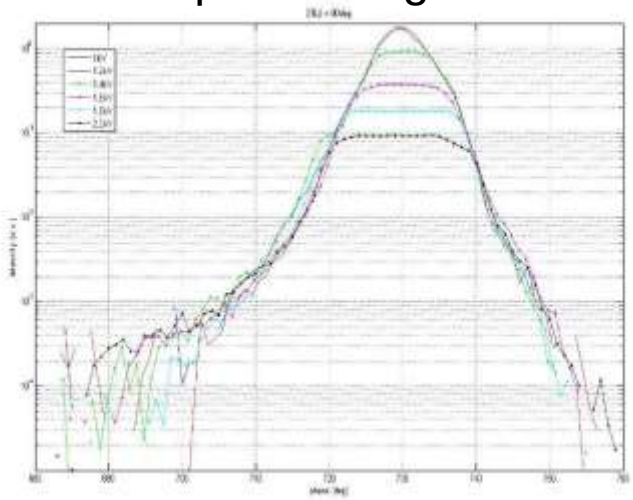
Measure profiles with different SEM gain



Measure calibration curve for SEM gain

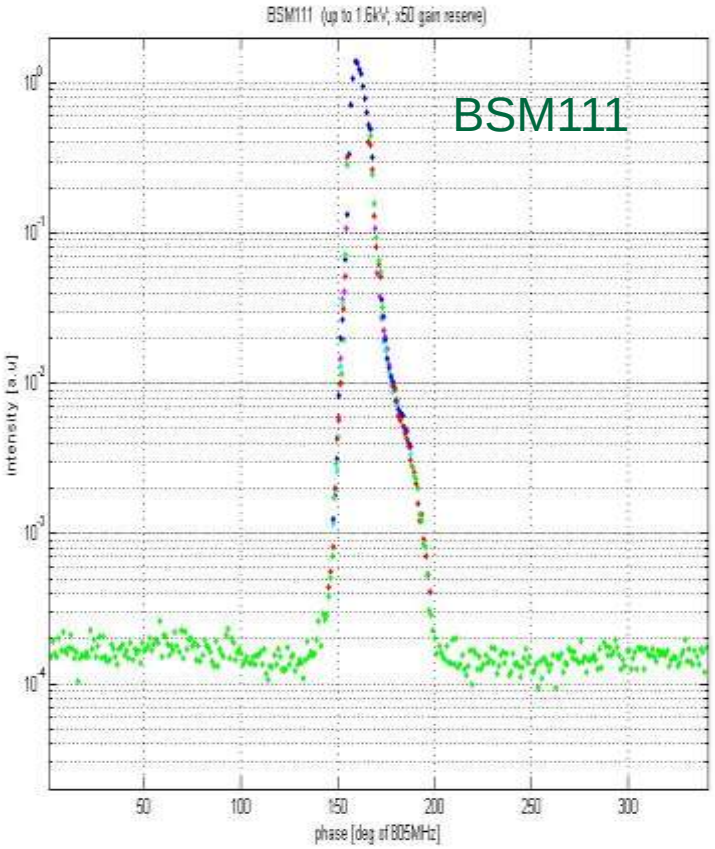


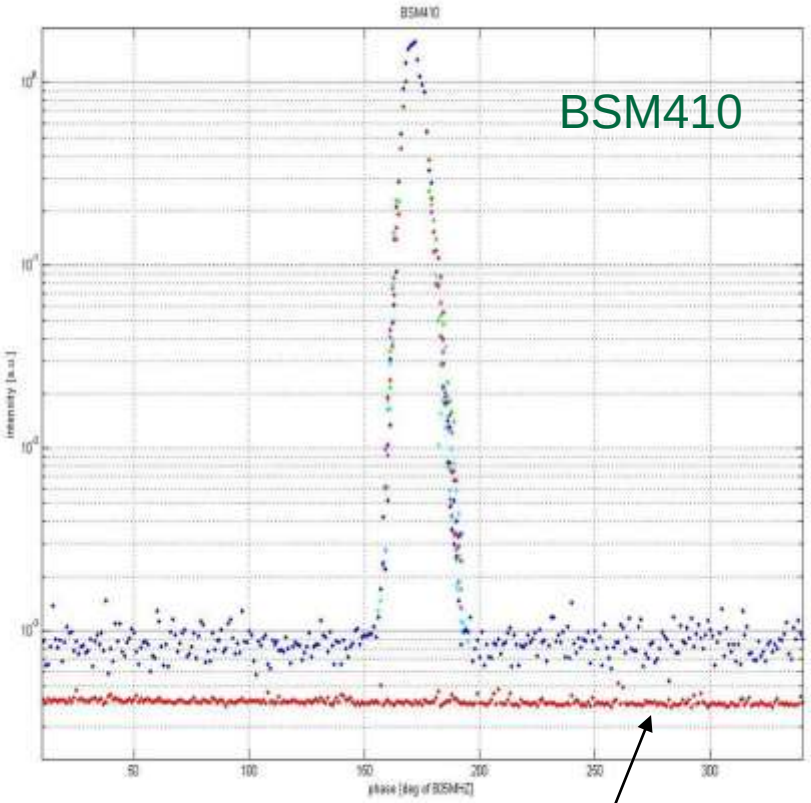
Stitch profiles together



- Done by hand. Very time consuming
- Need to develop software for gain calibration and automated stitching

Longitudinal profiles at CCL entrance and exit



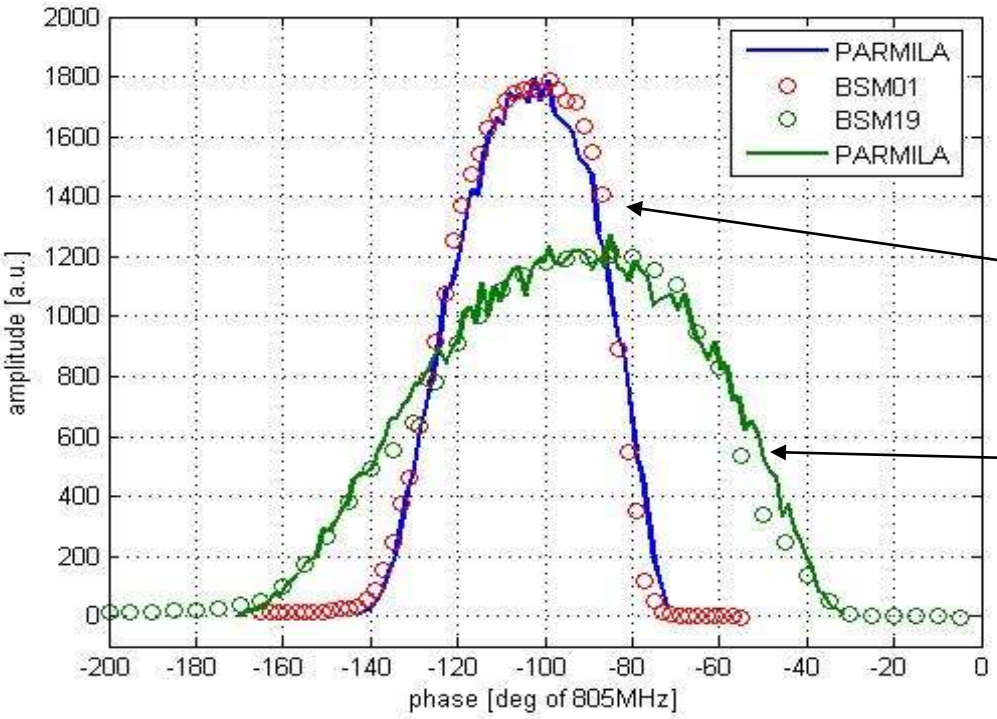


Did not reach full gain.

Still ~x50 in reserve

No beam

Longitudinal profiles in HEBT



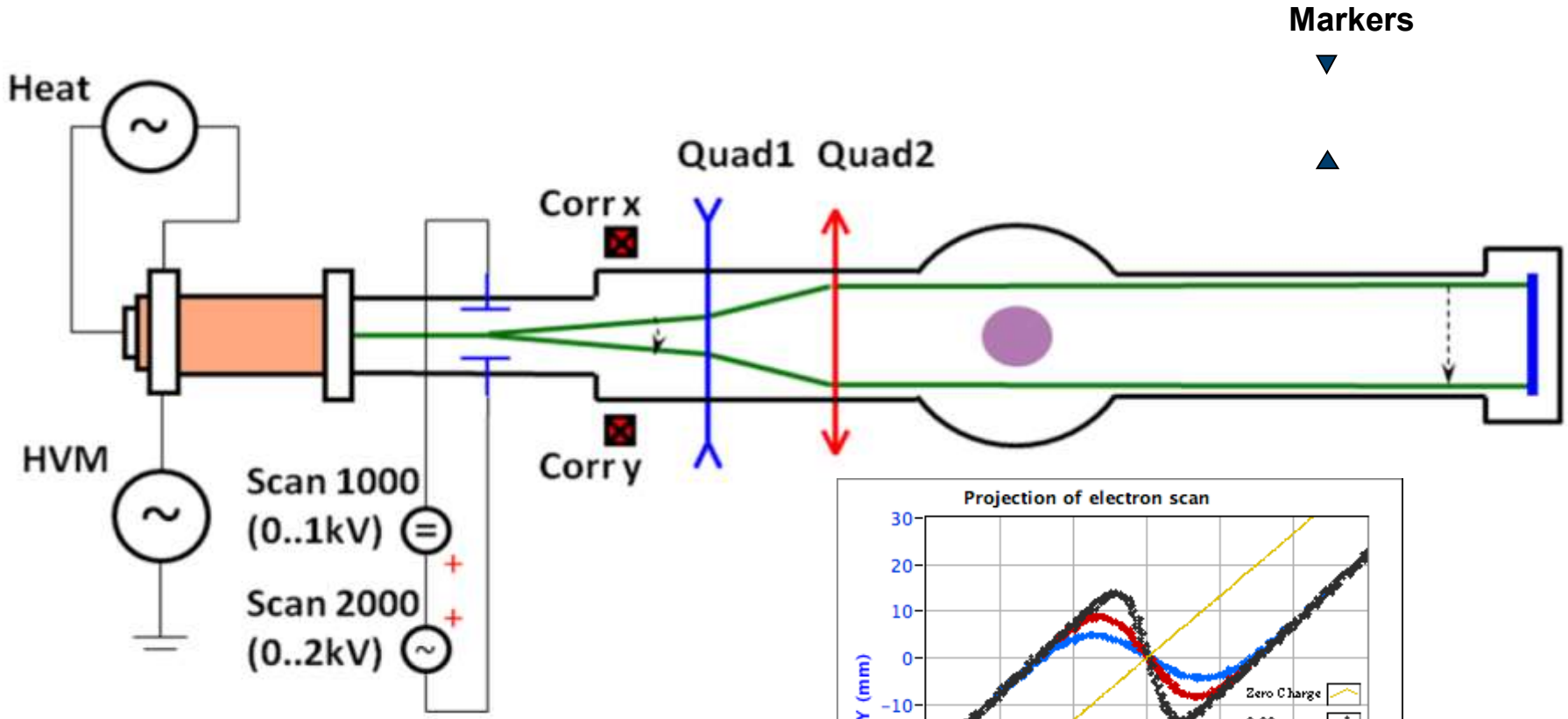
Beginning of HEBT

After arc

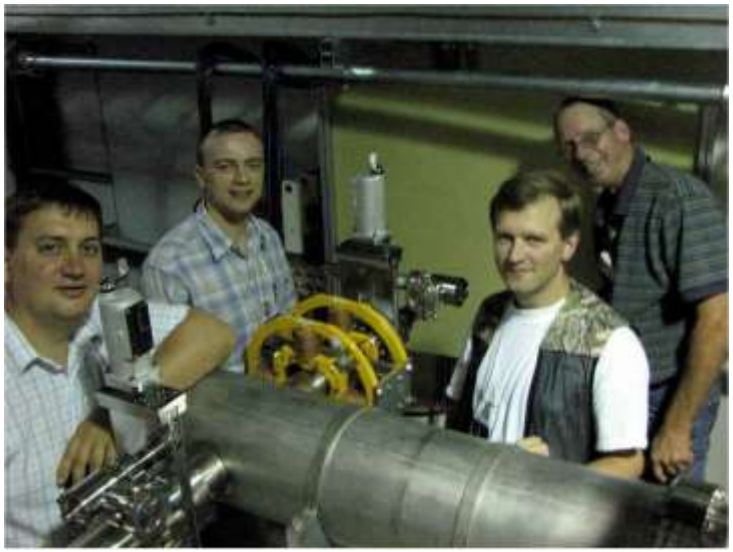
- **Not fully commisioned yet**
  - **Vacuum issues**
  - **Software**
- **Comparison with PARMILA simulation implies longitudinal emittance x3 times the nominal**

Electron Scanner for non-perturbing ring transverse profile measurements.

Designed and manufactured in collaboration with Budker Institute of Nuclear Physics (Novosibirsk)



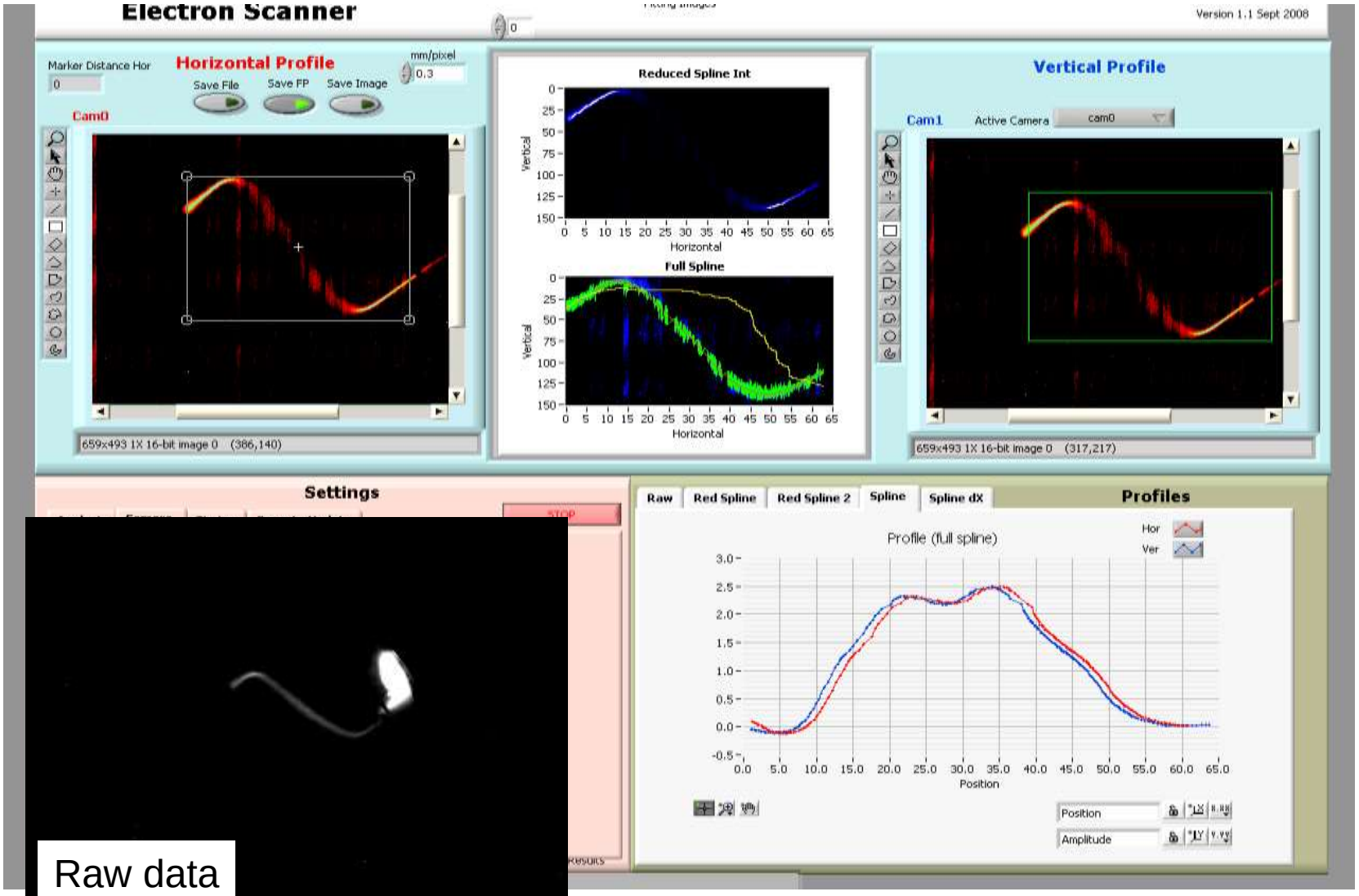
Hardware: Tunnel



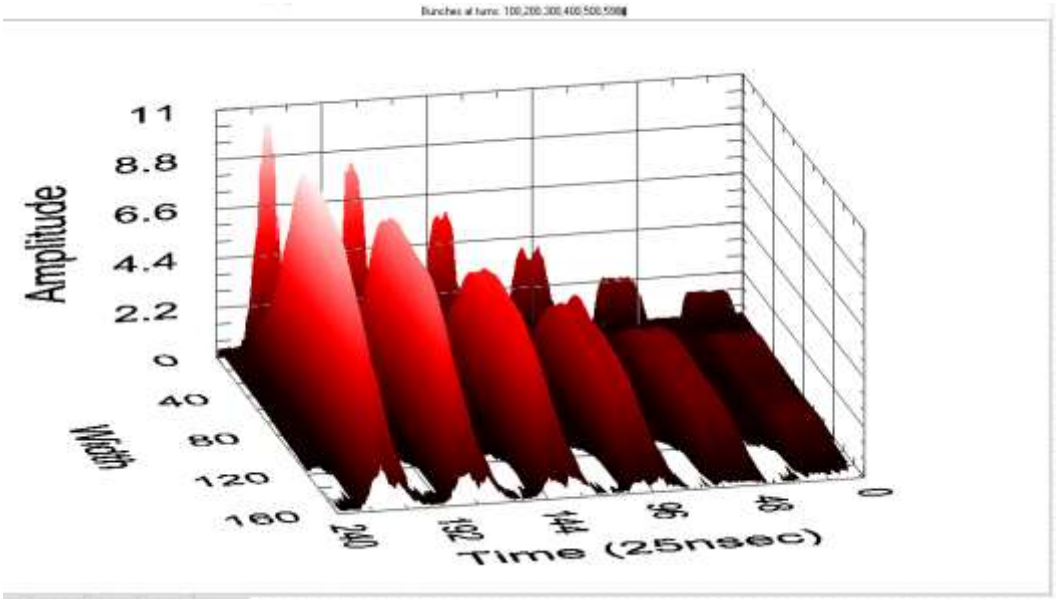
Many thanks to those involved (paperwork, planning, vacuum, safety)

Figure 5. Electron scanner Ring Tunnel pictures.

Software for data processing (W. Blokland)



Capable of measuring 20ns slices within 1 turn



- Good demonstration of capabilities
- Hardware requires many improvements
  - High voltage transformer
  - Scanning modulator
  - Scan aperture
- Can be use in expert mode only
- Is worth resources investment to continue development

Analog ring transverse feedback system (Craig Deibele)

- Broad band 800W amplifier. 1-300 MHz BW
- Analog processor is ready for beam test
- Digital processor is being developed

Conclusions

- **Existing Beam Instrumentation is capable to support machine tuning and production runs**
- **Downtime associated with beam diagnostics is low**
- **To support machine study plan to move steadily toward increasing dynamic range of measurements and implementing more non-perturbing diagnostics**
- **To bring SCL laser wire to routine operational status is high priority for this year**