# The Spallation Neutron Source Diagnostics: Initial Integration and Commissioning Progress Report*

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*Abstract*
The Spallation Neutron Source (SNS) Project, a collaboration of six national laboratories, is constructing an accelerator based neutron facility at ORNL. The SNS accelerator systems will deliver a 1 GeV, 1.44 MW proton beam to a liquid mercury target. The high-beam power and desired high availability of the accelerator complex have had important consequences for the design and implementation of diagnostics at the SNS. Namely, diagnostic systems have been designed with high reliability, the ability for hands-on maintenance, redundancy in critical diagnostics, and commonality of subsystems in mind. The multi-laboratory diagnostics group has successfully implemented and commissioned a number of systems at LBNL during initial commissioning of the SNS Front-End systems. This talk reports on the team's progress in diagnostics commissioning and performance for the SNS, summarizes the approach that has been used in this multi-laboratory effort, describes the lessons learned and presents the technical and organizational challenges that lie ahead.

## INTRODUCTION

Most of the beam diagnostics [1] at the Spallation Neutron Source (SNS) are similar to other accelerators: beam position monitors, beam loss monitors, wire scanners, beam current monitors, slit and collector emittance stations, Faraday Cups, etc. Each accelerator section, Figure (1) lists the suite of diagnostic systems and their channel counts[3,4]. As described below, additional systems will be provided for early commissioning of the Front End and the DTL. Systems are being designed and constructed by the multi-lab diagnostics team. The team is comprised of groups from BNL, LANL, LBNL, and ORNL. The ORNL group also coordinates the team's activities. A Diagnostics Advisory Committee provides external guidance. This committee reviews all major system designs at the conceptual and detailed design.

The low loss requirement (average loss of no more than 1 Watt/meter) has added challenges in the diagnostic design and implementation. For example, we added modified the BLM design to accommodate the machine protection system fast turn-off requirements. The other example is the diagnostics being implemented in the supper conducting LINAC (SCL). The high beam power and the superconducting rf cavity challenges have led to the development of a laser profile monitor system that replaces the wire scanner system in the superconducting linac (SCL). The challenges associated with the e-p instability and the expected beam loss in the ring also have led to improvements in the gas ionization profile monitor design. We have also taken advantage of

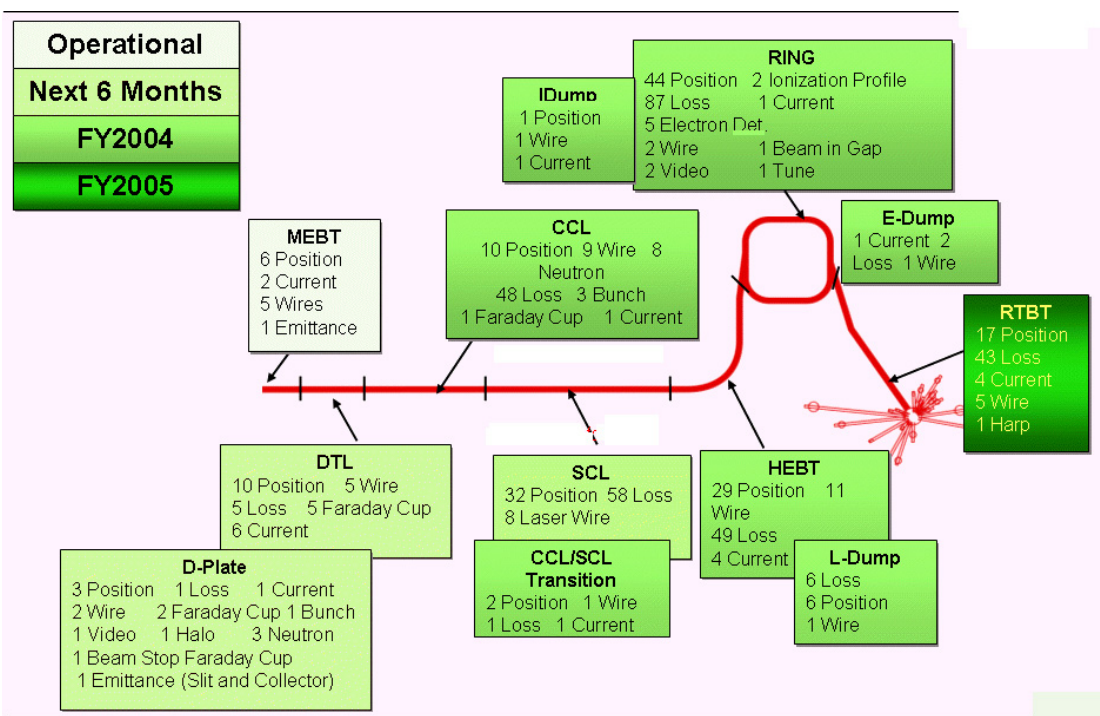


Fig. 1. Layout of the diagnostics in the SNS facility, color-coded to indicate the staged installation dates.

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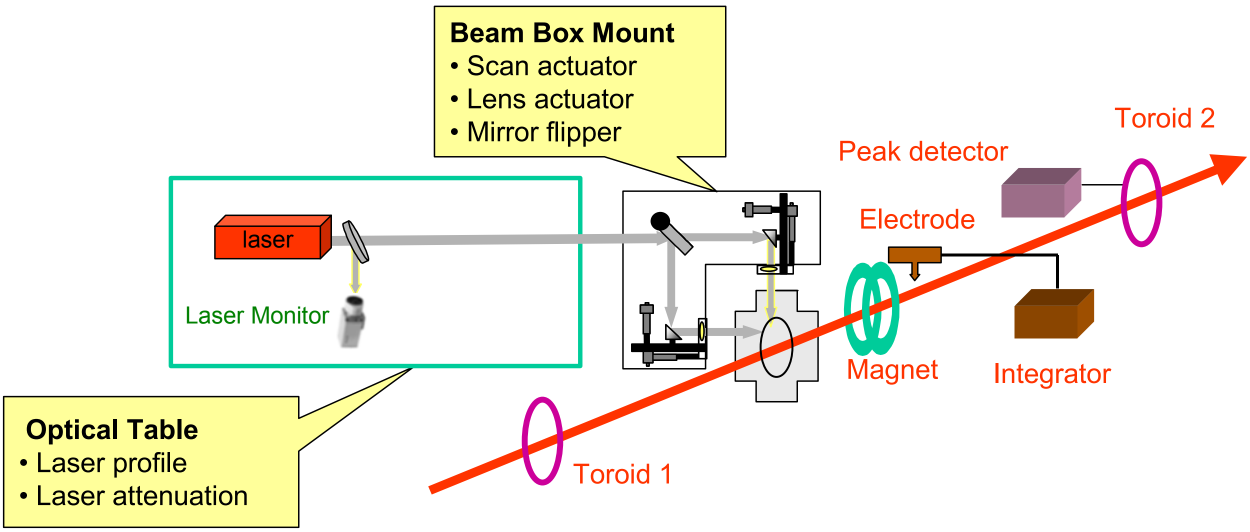


Fig. 2. Schematic layout of the SCL laser beam profile monitor.

technology developments by basing many of our diagnostics instrumentation designs on the personal computer (PC) platform. A layout of the various diagnostics systems is shown in Fig. 1.

## LASER PROFILE MONITOR SYSTEM

The profile monitor system for the SCL was originally envisioned to be a carbon wire scanner system. However, linac designers were concerned about the possibility that carbon wire ablation, or broken wire fragments, could find their way into the superconducting cavities and cause them to fail. Carbon wire scanner actuator was developed [2] at Los Alamos National Laboratory (LANL) in tandem with experiments [3,4] using a laser to measure profiles of $H^-$ beams at Brookhaven National Laboratory (BNL).

Once the laser profile monitor concept was proven by experiments at BNL 750 keV, 200 MeV LINAC, and subsequently on the SNS MEBT at Lawrence Berkeley National Laboratory, the decision was made to replace the carbon wire scanner system with the laser profile measurement system in the SCL. The advantages that the laser profile monitor system has over the wire scanner system are: 1) profiles can be measured during normal operations, as opposed to the 100 µs, 10 Hz duty factor restriction needed to prevent damage to carbon wires; and 2) there are no moving parts inside the vacuum system, thus reducing the possibility of a vacuum system failure. A disadvantage is that the laser is not as rad hard as a wire scanner actuator, but we have overcome this issue by placing the laser far away from the beam line.

The laser profile monitor concept is straightforward: a tightly focused laser beam is directed transversely through the $H^-$ beam, causing photo-neutralization. It only take about .755eV to detach the electron. The released electrons are either swept away by magnetic fields normally present in the linac lattice, or directed by a special dipole magnet to an electron collector that may or may not be part of the laser profile monitor system. The beam profile is measured by scanning the laser beam across the $H^-$ beam and measuring the resultant deficit in the $H^-$ beam current and/or, if the released electrons are collected, by measuring their current. A simple schematic of the concept is shown in Fig. 2.

The advantage of collecting electrons vs. measuring the deficit in beam current are: 1) the signal to noise ratio is better because of the large numbers of released electrons; and 2) the simplicity of the electron collector, since the electron energy is well defined and the electrons are well collimated. The disadvantages are: 1) an external magnetic field is required, 2) an in-vacuum electron collector is required, and 3) the electron collector signal may suffer from interference caused by beam loss. At the SNS linac we will use both methods. Every laser station will have an electron collector, and there will be beam current measurements at the entrance and exit of the superconducting linac.

However, concerns about long-term radiation damage have led us to install a single laser in a room above the SNS linac, and to transport the laser beam to the profile monitor stations using a system of mirrors.

The laser chosen for the SNS system is the Continuum Powerlite Precision II, 600 mJ, 10 nsec, 1064 nm, 30 Hz ND-YAG laser. The laser beam is transported down through a hole in the ceiling of the beam tunnel at the downstream end of the linac, and then along the length of the linac to the various beam profile measurement stations. Each of the 32 warm inter-segment regions will contain a beam box with fused-silica view ports and an electron collector. However, to contain costs, only the first four inter-segment regions in the medium-beta portion of the SCL and the first four inter-segment regions in the high-beta portion of the SCL will be instrumented with the actuators, the electron deflection magnet, and the electronics needed to make a profile measurement. With this setup, a laser station can be moved or added in an 8-hour shift.

Proof of principle tests were conducted at BNL and on the SNS MEBT at LBNL. The most recent and most complete tests were conducted last January on the SNS MEBT at ORNL [5]. Shown in Figure 3 is an example of this latest test, where the SCL prototype system was installed at the end of the MEBT using the final-design beam box, dipole magnet, lenses and mirror actuators.

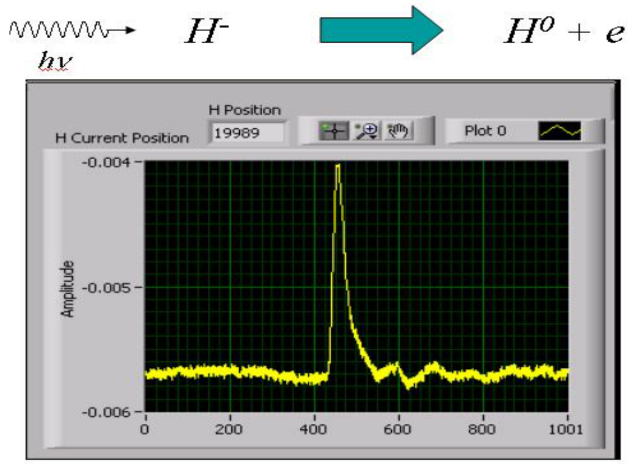


Figure 4. Photo-neutralization via laser beam observed on (BCM) beam current monitor.

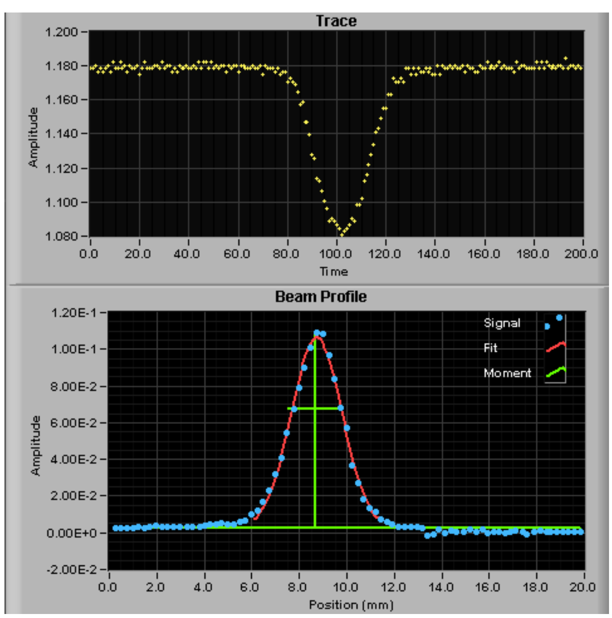


Figure 3. Horizontal beam profile in the SNS MEBT, measured January 2003. Top: an example of the electron collector signal. Bottom: the results of the measurement, with a Gaussian fit plotted out to 2.5 σ.

## BEAM LOSS MONITORS

SNS will use 295 argon-filled ion chambers as the primary detectors for monitoring beam losses. Argon has the advantage of fast electron transit time compared to slower air filled detectors [6] The initial choice was an ion chamber designed for the Tevatron, but concerns about saturation at high dose rate and long ion transit time (~ 700 μsec at 2 kV bias) led to the development of a new ion chamber designed to overcome these limitations [7]. It utilizes a larger inner diameter electrode to significantly decrease the ion transit time and raise the collection efficiency for a 1% local loss.

The new design tested at BNL has proven to be superior to the original Tevatron BLM system. The smaller gap required careful high voltage design. Guard electrodes were used to divert leakage from the HV electrode to ground and define the active region. Voltage gradients have been reduced by rounding the electrode ends. Figure 5 shows the new design. Two prototypes tested at BNL.

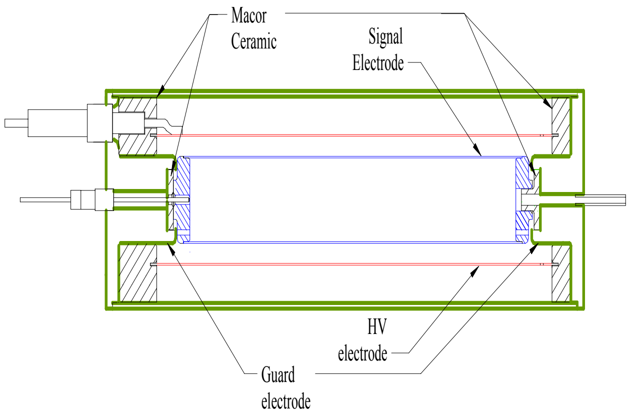


Figure 5. The new SNS ion chamber design.

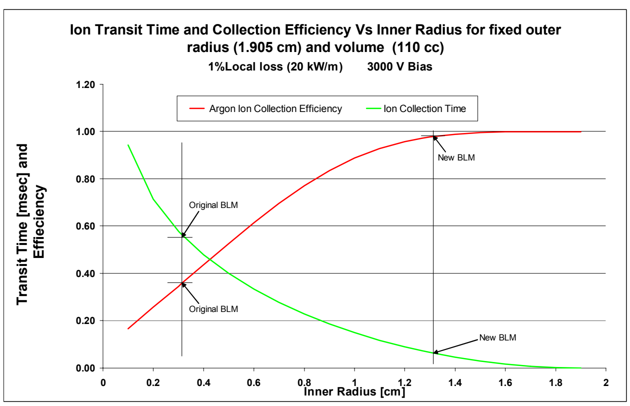


Figure 6. The collection efficiency and ion transit time are shown in Figure 1 as a function of inner cylinder radius

The first was filled with Nitrogen at 1 ATM. A second prototype with ahigher voltage feedthrough and improved ceramic and guard rings was able to hold 4.5 kV with 1 ATM Argon. Detailed description is presented in these proceedings [8].

## IONIZATION PROFILE MONITOR

The SNS ionization profile monitor (IPM) being developed by the BNL team, to be installed in two (one horizontal, one vertical) locations in the ring. These are based on an improved version of the IPMs installed [9] in the RHIC ring. In fact, some of the improvements have already been tested on the RHIC IPMs.

The SNS (and RHIC) IPMs are based on electron collection in parallel electric and magnetic fields. The electrons are amplified by a micro-channel plate and collected on a 64-channel gold-plated printed circuit board. The simplified schematic is shown in Figure (7).

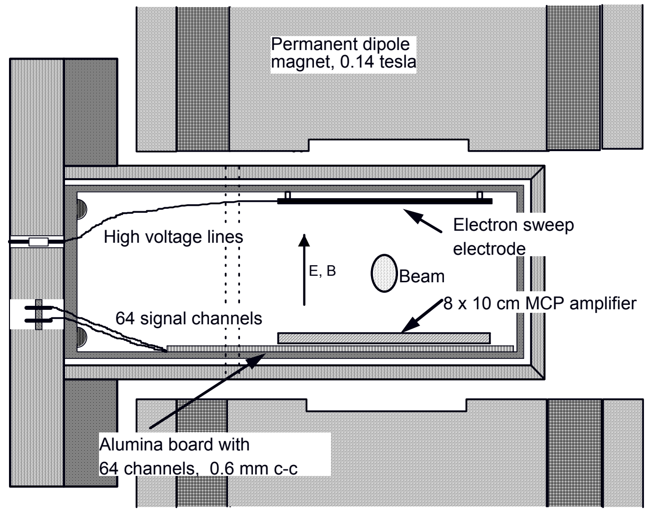


Figure 7. The original design of the SNS and RHIC IPM.

The detector components were inserted inside the beam-line. This restricted the aperture and made Detector components vulnerable to stray beam. The modifications to the RHIC IPM were necessary due to rf coupling to the beam, susceptibility to beam loss, and possible interference from the e-p beam instability. Beam loss in the vicinity of the IPM can cause the primary beam and secondary particle showers to pass through the micro-channel plate and the collector board, thus causing large background signals. Also, as demonstrated in the LANL Proton Storage Ring, the e-p instability can create huge amounts of electrons that could be collected by the IPM and possibly swamp the beam profile signal.

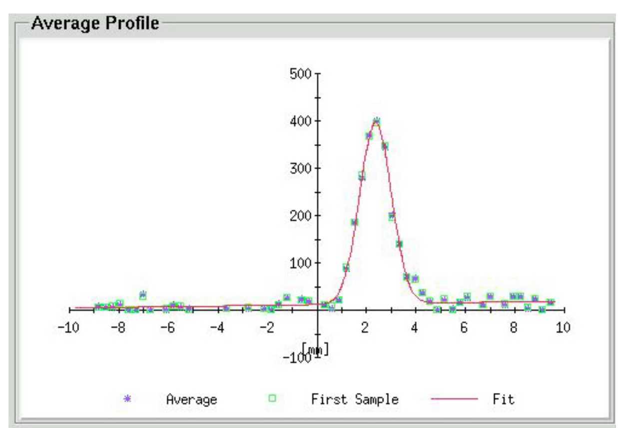


Figure 8. The modified SNS/RHIC ionization profile monitor measurement has lower background from e-p instabilities.

## NETWORK ATTACHED DEVICES

At the SNS we have chosen to base many of our diagnostics on the rack-mounted personal computer (PC) platform, rather than the more typical VXI, VME, or

CAMAC platforms. The basic idea behind a Network Attached Device (NAD) is to implement an instrument as a single networked device with its own resources [1]. Our reasons include 1) lower costs; 2) an industry standard processor (PC) and internal bus (PCI); 3) each instrument can be a node on the network, thus reducing common failure points like a VME crate; and 4) the availability of a wide variety of low-cost, commercial off the shelf PCI cards. We also chose embedded Windows 2000 or Windows XP for the operating system, and LabVIEW for the signal acquisition and signal processing software. To round out the standard software suite [6], each PC runs Input-Output Controller (IOC) core software to make it appear to be an IOC to the EPICS control system. Bench tests on a prototype network attached device demonstrated a 100 element (with 4 bytes /element) waveform update rate of 1000 Hz from LabVIEW to EPICS.

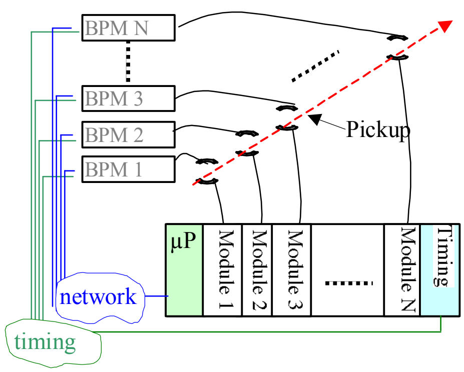


Figure 9. Concept of NAD vs. traditional VWE/VXI system.

With the prototype BPM, BCM, and wire scanner systems on the SNS MEBT at LBNL in February 2002 were based on the NAD model. .All these systems were brought on line in less than one week, and performed well during this initial commissioning period.

## TEMPORARY DIAGNOSTICS

Figure 10. An assortment of diagnostics are prepared for the DTL tank one commissioning.

## SUMMARY

An array of instrumentations have been designed to meet the challenges offered by the SNS project. These include the laser profile monitor for $H^-$ beams, ultra fast Faraday cup proved to be useful to measure pico-second bunch length, the improvements to the RHIC ionization profile monitor, and the network attached devices based on the PC platform.

To date the SNS facility has been commissioned up through the end of the MEBT at 2.5 MeV using prototype BPM, BCM, wire scanner, and slit and collector emittance systems. All of these systems have performed well. The laser profile monitor concept was successfully tested on the MEBT, as well as LBNL and BNL.

The next phase of diagnostics installation is now in progress to prepare for DTL commissioning later this summer, followed by CCL commissioning in 2004. The SNS is expected to be fully commissioned by early 2006.

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