# 11th ICFA International Mini-Workshop on Diagnostics for High-Intensity Hadron Machines, October 21-23, 2002

The 11th ICFA International Mini-Workshop on Diagnostics for High-Intensity Hadron Machines was held at the Spallation Neutron Source (SNS) project office in Oak Ridge TN, on Oct. 21-23, 2002. The purpose of the workshop was to summarize the state of the art in diagnostics, produce a prioritised list of diagnostic developments, and propose experiments to test new diagnostics or techniques. Twenty representatives from 13 projects/institutes attended. The workshop was divided into three sessions; 1) a summary of diagnostics at different institutes, and the accelerator physics needs, 2) general diagnostics and 3) non intercepting profile monitors. These sessions are summarized below. Presentations, an attendance list and other workshop material can be found at http://www.sns.gov/icfa .

Prior to the workshop, a table of diagnostics used at high intensity hadron facilities was compiled. Input was also solicited from facilities not able to send participants to the workshop (this table is available from the above workshop web-site). For convenience, it is divided into two parts, one for linacs and another for rings (and transfer lines).

## *Session 1: Overview of Diagnostic status and Accelerator Physics Needs*

There were three classes of talks in this session: 1) a summary of the SNS project and its diagnostics needs, 2) some accelerator physics diagnostic proposals, and 3) summaries of existing facility diagnostic needs and requirements. Some overall themes from this session were identified. First, more use should be made using information from existing diagnostics, and also reliable, believable output is an important characteristic for useful diagnostics. For high intensity machines, a good loss monitor display is an important, commonly used application. Finally, good glitch detection systems are recommended, which are triggered by a machine protection trip and dump circularly buffered data on local diagnostics, throughout the facility. This glitch system should be common for diagnostics, and other systems such as RF and magnets.

**SNS**: For the SNS, talks were given by N. Holtkamp, S. Henderson J. Galambos and A. Fedotov. A common theme is that attaining MW level beam power for a user facility requires extremely low loss levels and high reliability. Additionally there are time correlation needs of diagnostic data due to the pulsed nature of the machine. The low loss level requirements at high power levels imply not only a good loss monitor system, but also a need to understand sources of losses, approximately 20 sources of beam “halo” producing mechanisms were identified. Additionally, a need to continuously monitor the beam profile on the neutron target is important and challenging due to the harsh radiation environment.

**Accelerator Physics Proposals:** S.Y. Lee presented an idea for a quadrupole-mode transfer function diagnostic, which is especially useful for high intensity space charge dominated beams, and can also be used for noninvasive emittance measurement. V.

Danilov presented some analysis on beam invariants, aimed at identifying the minimum number of simultaneous phase space coordinate measurements that are needed to unambiguously use measured data in simulations.

**Facility Overviews:** Regarding facility overviews, the summary table described above provides lists of diagnostics used at facilities, and only highlights are presented here. E. Prebys presented an overview of the FNAL Booster diagnostics. The booster is presently loss limited, but faces a need for intensity increases of up to a factor of eight. There is a need to understand the large injection losses as well as other losses further into the acceleration. A. Feschenko presented an overview of the linac at the Institute for Nuclear Research (INR). This MW level linac is well instrumented, with careful measurement of the low energy beam, including independent bunch shape and energy measurements. J. Dooling presented an overview of the IPNS, which is a loss limited spallation neutron source. An ESEM (energy spread and monitor) system has been developed for on line measurements. Additionally bunch-by bunch measurements have been made following the beam from the linac through acceleration in the ring. P. Forck presented an overview of the GSI diagnostics, including a proposed idea for a MCP and CCD combination for a fast readout of profile measurement. Finally K. Wittenburg presented an overview of the DESY diagnostics, which included an IPM system capable of low intensity profile measurements.

Some overall desires for diagnostic development that were discussed are:

- Single linac bunch profile diagnostics – not averaged.
- Laser-based HARP (simultaneous x-y profile).
- Beam observables vs. time in linac pulse
- Diagnostics capable of handling full pulse length and rep-rate
- Halo/beam tail measurement capability to $10^{-4}$ level
- Incoherent tune (tune footprint)
- In-situ Secondary Electron Yield Monitor
- Electron Cloud Monitor (across chamber aperture)
- Beam profile on target measurement
- 6-d phase space tomography
- Higher-order instability monitor
- Laser wire for non invasive $H^-$ profile and Emittance measurements
- Good display ergonomics / easy use of measurements
- Better coupling to theory
- Non-destructive Emittance measurement over the entire linac
- Reliable diagnostics

by J. Galambos, ORNL

## *Session II General Diagnostics*

This session covered a wide range of topics that do not conveniently fit in one category. The presentations covered; 1) Intercepting devices (bunch shape monitor, harp, and halo),

2) Issues for High Intensity (electron cloud, loss monitors) and 3) Techniques (superconducting resonators and tune).

**Intercepting Devices**

The usual issues were raised regarding the insertion of material into high intensity beams, namely lifetime, reliability, and survivability of the target (wire or foil) and that a special study mode is usually required (shorter, lower intensity), interrupting operations.

Regarding Bunch Shape Monitors, impressive bunch length resolution is observed due to continuous improvements over the years, the longitudinal halo measurement can be complicated by higher harmonic of RF in BSM, wire heating is an issue - tungsten generally used instead of carbon and measurements of longer pulses can be made by retracting the wire from core, but bunches may appear shorter.

Harps and multiwire system presentations showed that harps near target see 10 to 100 MR per year. Kapton is successfully used in the LANCE devices near the target but wire lifetime is an issue for the SNS target harp. Actuators are very bulky and complex, but without them, wires are continuously exposed to the high intensity beam.

Halo measurements at LEDA were presented and are the most extensive to date. They utilized a combined wire and foil on a single actuator device to produce excellent dynamic range. The community should encourage follow-on studies that build on this good work. Profile measurements at HERA have demonstrated high resolution measurement of tails. Calibrations with respect to the beam core are challenging and work to develop theory remains. Many proposals are being evaluated for halo measurement in SNS ring, and will be discussed at the ICFA Halo03 workshop in May 2003, Montauk, NY.

**Issues for High Intensity**

For high intensity rings, dedicated electron collectors are strongly recommended, but some results have been achieved with standard diagnostics. For new installations, distribution of detectors needs some consideration. Questions remain about the required number and placement of electron detectors, i.e, required azimuthal and axial distributions, and locations relative to magnets. An ionisation profile monitor with variable electric and magnetic fields may be a useful device for electron cloud studies. Electron detectors have not been generally used as a tuning device, but are rather used to verify predictions, correlate with other diagnostics/vacuum data. Sufficient bandwidth to see intra-bunch effects is important.

LHC loss monitors use nitrogen used instead of argon. The high dose behaviour may be an issue for LHC and SNS. As in most machines, loss monitors provide the primary diagnostics input to the machine protection system. Availability and reliability must be carefully addressed.

**Technique**

Coherent tune measurement in high intensity rings can use frequency estimation vs. spectrograph. At LANSCE, $10^{-3}$ resolution in 25 turns is attained at PSR. For SNS, multiple techniques for measurement of incoherent tune are being studied including Schottky, BTF, and Quadrupole moment variation. One issue is applicability of the Schottky method on a short/ repetitive pulsed ring like SNS.

Use of superconducting resonators as a diagnostic was discussed, driven by the lack of space for other diagnostics. Up to 20 MeV/au, the RIA driver linac requires 1 deg phase accuracy. Tuning techniques should be compared to those planned for the SNS superconducting linac.

By T. Shea, ORNL

## *Session III: Non intercepting profile monitors*

Solid wire scanners are probably the most trustworthy devices for measuring beam profiles. Unfortunately the wire can be destroyed in high current (and high brilliance) machines by the beam itself. Another problem arises at SNS at scanner positions close to the superconducting cavities: A broken piece of wire might contaminate the surface of the cavity and may lead to quenches. Therefore alternatives were discussed during this session. Mainly three different types of non intercepting profile monitors were presented: 1) Beam Induced Gas Scintillation (BIGS), 2) Residual Gas Ionization Profile Monitors (IPM), 3) Laser Wire Scanners.

**BIGS:** Presentations by M. Plum, J. Dietrich, P. Forck

In the beginning of the workshop, the question arose of using the BIGS as a profile monitor just in front of the target. It has been shown by J. Dietrich, that this effect will create enough light to measure beam profiles even at good vacuum conditions and low beam current ($2\cdot10^{10}$ p , $10^{-8}$ mbar, 45 – 835 MeV/c). Accurate gas scintillation cross section measurements for $N_2$ and Xe gas at high proton energies (1.4 to 40 GeV/c) were presented by M. Plum. The cross section obtained for $N_2$ is 6.7 times smaller than that expected from dE/dx scaling of previous measurements with 200 keV protons and in addition 3.3 times smaller for Xe gas. The spectra and lifetimes for $N_2$ and Xe were also presented. Based on these measurements one can calculate the sensitivity of this monitor for different setups in accelerators. Some profiles were presented during the workshop, but it was pointed out that there are still unsolved questions: a) This kind of profile monitor is somehow sensitive to background, probably due to adjacent beam losses. b) in the literature one can find some measurements where the BIGS-monitors gave larger beam profiles than other types of profilometers (wire scanners, etc) in the same machine (see for example Refs. 1-3). Solutions discussed were a): moving the light detector far away from the beam, while having enough light from the scintillation and b): a black painted vacuum chamber. However, Ref. 3 claims that "the light produced does not result only from the incoming protons, but also from several secondary processes which create excited atoms". This should be a subject of further studies.

**IPM:** Presentations by J. Dietrich, R. Connolly, P. Forck, E. Prebys, K. Wittenburg
IPMs are used in quite a lot of proton accelerators around the world. Most of them give satisfactory results when collecting the electrons from the ionisation process in combination with a magnetic guide field of $\geq 1$ kG. For small bunch currents the use of the ions without a guiding magnetic field is also possible, but the space charge of the bunch will disturb the collection of the profile at higher bunch currents. Care should be taken in designing parallel guide fields. The turn by turn profile sampling capability of the IPM was shown by R. Connolly and other references (see for example Ref. 4), which enables the IPM to study injection mismatches (quadrupole or beam shape oscillations). However, a gas bump or gas jet inside the IPM might be necessary to increase the sensitivity of an IPM by some orders of magnitude. Nearly all IPMs use MCPs to create enough gain for signal detection. It was pointed out that the aging of the MCP (i.e. inhomogeneous decrease of the gain) is an important issue. The measured beam profile becomes larger, because the gain decrease is stronger at the centre of the profile than in the tails. The need for an online calibration tool was strongly recommended. Some possibilities were discussed like heated wires, $\alpha$-source, UV-light, $90^0$ turning of the MCP, beam steering to an unused area of the MCP, … there is still a large area for new ideas.
Sources of background and noise were discussed: RF-coupling to the anode strips might be suppressed by a clever design (?, somehow magic). Beam losses upstream as well as inside and close to the IPM should be avoided by a large aperture of the monitor and the adjacent beam pipes. It turns out, that an important issue for IPMs is the background due to electrons (secondary electrons, clouds) in the beam pipe. It was strongly recommended to extend the HV-electrodes by at least a few centimetres to get rid of the clouds before they can reach the detector.
An unexpected characteristic of the IPM at CERN was observed (B. Dehning): The measured beam width depended on the beam current by several tens of percent, while the beam width measured by a wire scanner was constant. More investigations are needed to understand this effect.

**Laser wire scanner ($H^-$ photoneutralization)** Presentations by R. Connolly, S. Assadi
This method has been used for transverse and longitudinal emittance measurements where transverse profiles of $H^-$ beams have been measured by laser photoneutralization. It is being used at the SNS for measurement of transverse beam profiles. Once a portion of the beam is neutralized by the thin laser beam, measurements can be made on the neutral beam, the removed electrons, or the reduced beam current with beam current transformer or BPM stripline. Experiments which measured the notch in beam current with current transformers and with BPM striplines were successfully performed at BNL and Berkeley.
R. Connolly proposed to detect directly the amount of electrons instead of the difference in the currents. This will have some advantages:

- Detection of electrons requires a far lower neutralization rate.

- A microchannel plate can amplify the electron signal by $10^4$-$10^6$, which reduces the laser power requirement to 1W or less.
- Proposed laser is a solid-state, CW diode laser with fibre-optic output. Power ~1W and $\lambda$= 975-980 nm. It is much cheaper than a high power Q-switched Nd:YAG Lasers.
- With CW laser and electron collection the beam can be scanned with optical scanner and one will get the full beam profile in one machine pulse (300µs). The laser beam can be swept with commercial optical scanners.
- Light might be transported from the laser to the beamline over optical fibres.

Drawback:

- Might suffer from beam loss background and electrons from gas ionisation.
- No longitudinal profile measurement possible

S. Assadi discussed the ideas of the complete laser wire system at SNS, including the laser light transport. It was pointed out that the jitter of both beams (laser and ion) has to be considered. Especially the jitter of different macropulses might disturb a precise profile determination when using the notch technique.

by K. Wittenburg, DESY

## *Recommended work for the future*

- Extensions of LEDA halo studies
- Similar studies for ring halo
- BSM for long pulses
- Electron detector as tuning device
- Further development of incoherent tune measurement techniques
- Enhanced use of machine model for loss monitor data

## References:


**1) Residual Gas Fluorescence for Profile Measurements at the GSI UNILAC**
P. Forck, A. Bank, GSI, Darmstadt, Proc. Eighth European Particle Accelerator Conference La Villette – PARIS, 3 - 7 June 2002

**2) THE LUMINESCENCE PROFILE MONITOR OF THE CERN SPS**
G. Burtin, J. Camas, G. Ferioli, R. Jung, J. Koopman, R. Perret, A. Variola, J.M. Vouillot CERN, Geneva, Switzerland, 7th European Particle Accelerator Conference, Vienna, Austria, 26 - 30 Jun 2000 - European Phys. Soc., Geneva, 2000.

**3) Optical Transverse Beam Profile Measurements for High Power Proton Beam** P. Ausset, S. Bousson, D. Gardes, A.C. Mueller, B. Pottin, IPN, Orsay; R. Gobin, CEA, Gif-sur-Yvette; G. Belyaev, I. Roudskoy, ITEP, Moscow, Proc. Eighth European Particle Accelerator Conference La Villette – PARIS, 3 - 7 June 2002

**4) SENSITIVITY STUDIES WITH THE SPS REST GAS PROFILE MONITOR**
F. Ferioli, C. Fischer, J. Koopman, CERN Laboratory, Geneva, Switzerland
5th European Workshop on Diagnostics and Beam Instrumentation, Grenoble, 2001