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# Beam Dynamics Newsletter

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second table provides a listing of computer codes used in the study and design of slow extraction systems. These tables are not yet complete but will appear on the workshop web site very soon. A preliminary version of the second table can be found in the appendix.

## 6.2 The 11th ICFA Mini-Workshop on high intensity and high brightness hadron beams - Diagnostics

John Galambos and Tom Shea, ORNL and Kay Wittenburg, DESY

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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 <a href="http://www.sns.gov/icfa">http://www.sns.gov/icfa</a>

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).

#### 6.2.1 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

#### 6.2.2 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.

#### Technique

must be carefully addressed.

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

#### 6.2.3 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 (2.1010 p, 10-8 mbar, 45 – 835 MeV/c). Accurate gas scintillation cross section measurements for N2 and Xe gas at high proton energies (1.4 to 40 GeV/c) were presented by M. Plum. The cross section obtained for N2 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 N2 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

IPM: Presentations by J. Dietrich, R. Connolly, P. Forck, E. Prebys, K. Wittenburg

IPMs are used in guite 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 <sup>3</sup>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, a-source, UV-light, 900 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.

 $\cdot$  A microchannel plate can amplify the electron signal by 104-106, which reduces the laser power requirement to 1W or less.

· Proposed laser is a solid-state, CW diode laser with fibre-optic output. Power  $\sim$ 1W and l= 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 (300ms). The laser beam can be swept with commercial optical scanners.

 $\cdot$  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

#### 6.2.4 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

	Profile_	Emittance	<u>BPM</u>	Beam Loss	Current	Mean Energy and Phase	Energy / phase Spread	Misc
<u>Planned</u> <u>Linacs</u>								
SNS Linac	Wire (low energy)	Slit & Collector <sup>2</sup>	Shorted strip, RF IQ receiver <sup>4</sup>	Ion Chamber5	Toroid <sup>7</sup>	phase from BPMs		
	Laser wire <sup>1</sup> (Superconducting region)	Beam Shape Monitor <sup>3</sup>	3	Liquid Scintillator <sup>6</sup>				
				Neutron detector	•			
RIA	Wire	Low energy: Slit/Collector	Shorted strip	Neutron detectors and medium and high energies	All energies: BCM, low and medium energies - Faraday cup	Phase:Resonant Pickup <sup>1</sup> at low and medium energy, Shorted strip everywhere	Bunch shape: all energies: wire/sec electron <sup>2</sup> at low energy SBD/GasProp. <sup>3</sup>	
		medium & high energy: wire/rms <sup>4</sup>				Energy:all energies-TOF, at low energy SBD/GasProp. <sup>3</sup>		
FNAL P Driver	Moveable single plane grids (48 wires, 0.5-1.0- 1.5 mm spacing) <sup>1</sup>		Single plane stripline, 0.5 mm resolution <sup>1</sup>	Argon Ion chambers <sup>1</sup>	BCT			
	slow single wire scanners							
	Ioniz. Type MCP Ampl., 48 strips 1.5 mm apart <sup>1</sup>					_		
J-PARC	Wire Scanner	Slit & Collector <sup>2</sup>	Stripline <sup>1</sup>	Ion Chamber <sup>3</sup>	Toroids(slow) <sup>4</sup>	Beam phase	Momentum	
(JKJ)					. ,	monitor <sup>6</sup>	analyzer (future plan)	

### STATUS OF INSTRUMENTATION (compiled at the 11<sup>th</sup> ICFA Miniworkshop)

					Toroids(fast)⁵			
<u>Existing</u> <u>Linacs</u>								
ISIS Linac	Wire scanners (low rep. rate only) in LEBT between preinjector and injector and in HEBT between injector and synchrotron <sup>1</sup>	Slit-and-collector in LEBT between preinjector and injector	Wire scanners (low rep. rate only) in LEBT between preinjector and injector and in HEBT between injector and synchrotron	Argon-filled ionisation chambers running alongside Tanks 2, 3, 4 and alongside HEBT beam line	Toroidal current transformers, three between preinjector and injector, three between tanks, five in HEBT	<ol> <li>In HEBT straight before debuncher, fast toroids, time-of- flight measurement of beam bunches using 1 GHz 'scope</li> <li>After debuncher, phase detection at 202.5 MHz on signals from capacitive pick-ups (see Note 2)</li> <li>See Note 3</li> </ol>	1. No energy spread measurement before debuncher 2a. After debuncher, by bending magnet and wire scanner (low rep. rate only) 2b. After debuncher, by monitoring time evolution of chopped beam in synchrotron	DT condition by monitoring X-ray dose rates from tanks⁴
INR (Moscow) Linac	Wire scanner, harp	Injection line - slit/collector, higher energies - rms with 3 to 5 wire scanners	Strip line, TM <sub>110</sub> cavity <sup>1</sup>	Photomultiplier without scintillator, ionization chamber	Current transformer, wall current monitor for short pulses	Absolute and relative energy- time of flight with two current harmonic monitors, phase - current harmonic monitor	Magnnetic spectrometer/bunc h shape monitor	Residual gas monitor <sup>2</sup> collector combined wit energy degrador for phase scan
LANSCE Linac and transport lines	Wire	Slit and collector <sup>4</sup>	Stripline w/ 50 ohm termination	Ion Chamber <sup>12</sup>	Toroid			Secondary emission current monitors
	Harp	rms with multiple profiles <sup>5</sup>	Capacitive (ring extraction line)	Liquid Scintillator	Faraday cups			Guard rings

								Absorber collectors <sup>10</sup>
LEDA Injector	Video using either viewscreens or background gas fluorescence	Off-line emittance measuring unit, measures part of r-r' space	None	None	Toroid (DC and AC) <sup>7</sup>	Power Supply potential		Potential on ring (Electron Trap) provides improved accuracy input toroidal current measurment.
					arc current			
LEDA Halo Line	Wire scanner/Halo scraper <sup>2</sup>	rms fits from 4 profiles with $\pi/2$ phase advance between profiles	Micro-stripline w/ 50 ohm termination <sup>3</sup>	lon Chamber⁵	Toroid (AC)	Cylindrical Capacitive, 50 ohm termination <sup>4</sup>		
		rms from single profile scanning upstream magnet		CsI Scintillator <sup>6</sup>	Wall current	Resistive wall current		
LEDA HEBT	Wire scanner	rms from single profile scanning upstream magnet	Stripline w/ 50 ohm termination <sup>3</sup>	Ion Chamber	Toroid (AC)			Beam Stop Power
	Background gas fluorescence using injected nitrogen. <sup>1</sup>		Capacitive (ring, ring extraction line)	CsI Scintillator				
							_	
GSI Linac	Harp, IPM, fluoresence	slit-grid, pepper-pot <sup>2</sup>	capacitive pick-up, 2 GHz bandwidth		Toroid (AC) <sup>3</sup>	capacitive pick-up⁴	particle-detector <sup>5</sup> , bunch shape monitor <sup>6</sup>	
IPNS Linac								
Source and 750 kV column		slit scanner, test stand only		CT'	СТ			
50 MeV Linac				CT, LM <sup>2</sup>	СТ			
50 MeV Line	′WS³, Scintillator⁴, SFC⁵	ESEM <sup>6</sup> , WS <sup>7</sup>	terminated strip-lines	liquid scintillator/PMT, CT	СТ	ESEM	ESEM	

CERN Linac	Slit & secondary emission grid <sup>2</sup>	Magnetic pick-ups	CT difference <sup>1</sup>	СТ		
BNL Linac	Slit-collector, WS	striplines	scintillators	Toroid, Faraday cup, FCT	TOF (not used)	

#### **Additional Notes:**

SNS: H- linac, 52 mA

DTL structure from 2.5 to 86 MeV, CCL structure from 86 to 185 MeV SC from 370 to 1 GeV (beta = 0.61 and 0.81 families)

 A prototype will also be in the lower energy MEBT. Highly desirable for superconducting region to minimuze risk of particle contamination of cavities.
 Transverse measurements. Temporary devices will be available during commissioning of lower energy MEBT and DTL systems
 Longitudinal measurement.
 Dual plane, 4 stripline design. position + relative phase ,402 + 805 MHz, direct IF digitizer @ 40 M Samples/sec
 Volume detector (N) (~10 kHz,)
 Photo multiplier, > 1 MHz response, MPS input.
 Fast current transformer, 15-50 mA

RIA: low energy:< 9.3 MeV/u, medium energy: < 80 MeV/u, high energy > 80 MeV/u
For the RIB Linac of RIA, diagnostics sensitive to beam intensities from 102 to 1011 particles per second are needed. Secondary electron/position sensitive micro-channel plate detector, surface barrier detectors, gas counters for detecting individual ions will be important.
1) Superconducting Resonator used as Phase Monitor
2) RF deflection of secondary electrons
3)Solid State Diode Detector or Gas Counter to verify beam purity.
4) Low-duty factor operation for these diagnostics using a beam chopper..

FNAL P driver 400 MeV Line 1) Integrating over injection 2) B163Hz - 20 MHz, injection turn resolution, 0.1%

J-PARC (JKJ) 1) Fast response. 2) Measured in the MEBT at 3 MeV 3) Argon gas
4) Beam current range 0.1 - 100 mA
5) Frequency response: 20MHz - 3 GHz, rise time: 500 psec
6) Using fast toriods. Energy is measured by TOF in principle, detecting a phase difference between RF components of the signals from two fast toroids at separated positions.

 ISIS linac is 70 MeV 202.5 MHz H– injector for ISIS 800 MeV synchrotron Four tanks: 665 keV input energy from Cockcroft-Walton preinjector – 10 MeV, 10 – 30 MeV, 30 – 50 MeV, 50 – 70 MeV Debuncher cavity in HEBT between injector and synchrotron At present linac runs with 20 mA pulses, ~200 µs long, at 50 pps In 2003, RFQ (already running on test stand) will replace Cockcroft-Walton, and will lead to 30 mA pulses within linac

1) Two "beam diluters" (each essentially just a pepper pot lid) are provided in LEBT between preinjector and injector to attenuate beam to 40% or 10% (or 4%) while setting up

2) Useful for monitoring variation of energy during pulse

3) "Threshold foils", viz blocks of graphite which just stop 30, 50 and 70 MeV protons are provided shortly after the end of the linac for rough energy identification

4) Excessive X-ray dose rate is symptom of excessive electron emission from drift tube surfaces within tank. High numbers of electrons inside tank lead to charge being deposited in RF window at rate higher than charge can leak away, and lead to window breakdown

5) On RFQ test stand, input and output beam emittances measured using slit-and-collector devices, output beam energy spectrum measured using novel gas scattering spectrometer (and, shortly, using magnetic spectrometer), output beam bunch width measured using coaxial target

INR Linac •Energy = 500 MeV

•Current 15 mA

•200 µs, 50 Hz

•Up to  $150 \ \mu$ A average 1) Now out of use. Both monitors and electronics were designed and fabricated improperly.

2)Big noise due to emission from the accelerating cavities. Is planned to be installed in the injection line.

LANSCE: 1) Nitrogen at 1 std. atm. Same type of ion chambers also used in personnel protection system.

2) Used for fast, ns time scales. Saturates on PSR extraction losses.

3) Fast, but less sensitive, so does not saturate on PSR extraction losses.

4) Slit and collector method used up to 100 MeV.

5) Used at 800 MeV.

6) Primary BPM system for ring, but only works well for injected beam with 201 MHz structure.

7) Only have a couple of these in the ring.

8) No profile measurements in ring, but measure profile immediately after extraction. Can deduce ring profile at any time by extracting early.

9) Have both fast and slow toroids.

10) Used after each DTL tank.

11) ANL-style, with LANL-developed high-bandwidth electronics at detector

12) Also use ion chambers for personnel protection (separate electronics from loss monitors)

LEDA: 1.) Background gas or luminescent monitor tested and compared with traditional wire scanner. Reported in BIW2000.

2.) Integrated wire scanner with halo scraper, typical 100000:1 range, charge detection method, stepper motor actuation.

3.) Dual plane, 4 micro-stripline design. Position processor, 350-MHz, Log-ratio technique + on-line calibration, +/- 0.1 dB over >75 dB range, digitizer @ 1 M Sample/sec.

4.) Uses capacitive and resisive wall current monitors. < 0. 1s degrees at 350-MHz, 200+ kHz BW, > 45 dB dynamic range, full 2p measurment range.

5.) Standard volume detector. Operated from 10s kHz to few Hz.

6.) PM tube and CsI scintillator allowed for >10^7 dynamic range.

7.) DCCT from Bergoz with few 0.1 Hz to 100 Hz BW, ACCT from Bergoz with few Hz to near 1 MHz BW. Both capable of performing transmission measurements with range of few 0.1s mA to >100mA range.

IPNS 50 MeV H- linac

1) Pearson Coil and home-built, 100 mV/mA amplified, <20 MHz BW, full power

2) Loss Monitors--External Radiation Monitors (ERMs)

3) Wire Scanners, horiz. and vert., low power, reduced bandwidth

4) plastic scintillator and video camera (reduced bunch, low power)

5) Segmented Faraday Cup (reduced bunch, low power)

6) Energy Spread and Energy Monitor, terminated BPMs (longitudinal, full power)

7) stepping and stationary wire (temporal macropulse, low power, low BW)

GSI Linac all ions, up to 10 mA, pulse length 0.1 - 5 msec, frequency 36/108 MHz up to 18 MeV/u

1) Harp: dynamic shortening of pulse length, IPM: ion detection, no MCP, Fluoresence: equiped with Chevron MCP image intensifier

2) slit-grid: dynamic shortening of pulse length, pepper pot: Al2O3 viewing screen

3) GSI design, droop 0.5% for 5 ms, 0.1 microA resolution used for dynamic pulse shortening

4) using TOF, resolution > 1.e-4

5) attenuation by Rutherford scattering, used fast diamod and 50 Ohm MCP detectros, coincidence technique yield phase and energy of single particles

6) Uses secondary electrons from residual gas, prototype development

CERN Linac 1) Watchdog program monitors 2 consecutive pulses 2)Transverse and longitudinal emittances for single pulse

BNL Linac H- beam •Energy = 200 MeV •Current 35mA •500 μs, 7.5 Hz

•Up to 150 μA avg. for BLIP •Polarized proton 300 μA, 65% Polarization

	Profile	<u>Emittance</u>	BPM	<u>Beam Loss</u>	Current	<u>Misc</u>	<u>Tune</u>
<u>Planned Rings</u>							
SNS Ring	Wire (low intensity) IPM (high intensity) Luminescent <sup>1</sup> (proposed) Harp		Open strip <sup>2</sup>	lon Chamber <sup>3</sup> Liquid Scintillator <sup>4</sup>	Toroid⁵	e-detecors <sup>6</sup> beam-in-gap <sup>7</sup>	
J-PARC (JKJ) 3GeV Synchrotron	IPM SEM <sup>2</sup>		Diagonal cut ESM³ Stripline⁴	lon Chamber Scintillator	Toroids⁵ Wall current monitor	e-detectors beam-in-gap (proposed)	
J-PARC (JKJ) 50 GeV MR	gas sheet PM <sup>1</sup> SEM <sup>2</sup>		Diagonal cut ESM <sup>3</sup> Stripline <sup>4</sup>	lon Chamber Scintillator	Toroids <sup>5</sup> Wall current monitor	e-detectors beam-in-gap (proposed)	
FNAL P Driver	lonization type, MCP, 64 strips 1mm apart, L=3m	4	Single plane elliptic electrostatic PU <sup>1</sup>	Ar filled ion chambers <sup>5</sup>	Fast BCT <sup>2</sup> DCT <sup>3</sup>	100kHz - 0.6 GHz wall current monitor fast stiplines - 1m long, 50 Ohm for wide band diagnostics transverse dampers - 1m long	Single plane elliptic electrostatic PU <sup>6</sup>

CERN LHC	wire (lin. low intensity) <sup>5</sup>	synchroton light <sup>7</sup>	button <sup>8</sup>	Ion Chamber <sup>11</sup>	Toroid	quadrupolar BPM <sup>14</sup>
	IPM (all intensities) <sup>3</sup>		few strip <sup>9</sup>	ASEM <sup>10,12</sup>		
	luminescent <sup>4</sup>					
Existing Rings:						
CERN Rings: BOOSTER, PS	wire rotative <sup>1</sup>		electrodes	ASEM <sup>10</sup>	Toroid	quadrupolar BPM <sup>13</sup>
transfer l	SEM grids		electrodes	ASEM <sup>10</sup> ion chambers <sup>11</sup>		
SPS Rinc	wire (lin. low int., rot. high int.) <sup>2</sup>	synchroton light <sup>6</sup>	electrodes	ion chamber <sup>11</sup>	Toroid	e-cloud strip det.
	IPM (all intensities) <sup>3</sup> luminescent <sup>4</sup>					
transfer l	OTR screens		buttons	lon chambers <sup>11</sup>		
ISIS Synchrotron	residual gas monitor <sup>1</sup>		single plane split induction electrodes⁵	Argon filed coaxial cables	Toroid <sup>6</sup>	Thermocouples <sup>7</sup>
	single wire 'halo' monitor <sup>2</sup> multi wire single turn <sup>3</sup>					Beam Chopper <sup>®</sup> Beta Kicker <sup>9</sup>
		emittance determined from profile monitors				

FNAL Booster	one horizontal and one vertical IPM with turn- by-turn data acquisition slow single-wire scanners at injection point	see devices under "Profile" for transverse emittance wall current monitor for longitudinal emittance	4-electrode stripline type pickups (~50) AM-PM electronics operating at fundamental RF frequency (38-53 Mhz) <sup>1</sup>	"Tevatron" style ion chambers in tunnel (~60) Uncalibrated plastic scintillator / phototube devices at selected locations to see fast losses <sup>2</sup>	AC toroid with Hereward feedback DCCT	"Time-of-Flight" relative energy monitor in 400MeV injection line ~ 6GHz bandwidth wall current monitor for longitudinal instability diagnostics, mountain range displays, and bunch length detector	Pinger for horizontal tune measurement (vertical pinger temporarily? appropriated for extraction gap creation)
		Multi-wire harp type profile monitors in injection and extraction lines	AM-PM electronics operating at injected bunch frequency (200MHz) on just a few BPM locations	Interlocked rad. detectors (chipmunks) outside tunnel provide useful "average" beam loss information (~50)	Wall current monitor for bunch-by-bunch intensity information	Wall current monitor for low level RF system phase feedback	
DESY Rings DESYIII	fast <sup>5</sup> wire scanners (up to 220 mA) IPM <sup>1</sup> (first prototype was tested many years ago)		inductive pick-up <sup>7</sup>	Scintillator <sup>8</sup>	Toroid <sup>10</sup>	"stepping wire" (in preparation) <sup>2</sup> 3 resistive wall monitors <sup>13</sup>	
PETRAp	fast <sup>5</sup> wire (up to 160mA) IPM <sup>1</sup> (sensitive, correct beam width at small bunch currents only )		capacitive pickup (button) (for e and p) <sup>12</sup>	Long segmented lon Chamber (planed)	Toroid <sup>9,10,11</sup>	"stepping wire" (in preparation) <sup>2</sup> 2 resistive wall monitors <sup>13</sup>	

HERAp	OTR Screen (proposed, for injection <sup>6</sup> ) IPM <sup>1</sup> (sensitive, correct beam width at small bunch currents only ) fast <sup>5</sup> wire (up to 160mA)		Directional coupler Pickup (Stripline) <sup>12</sup>	PIN diode BLMs (counting mode) <sup>3</sup>	Toroid <sup>9,10,11</sup>	BLMs at scrapers <sup>2,4</sup> "stepping wire" (in preparation) <sup>2</sup> fast wall current pick-up for bunch length measurement	
LANSCE Ring	None in ring <sup>8</sup>	rms from profiles of extracted beam	Stripline w/ 50 ohm termination <sup>6</sup> Capacitive <sup>7</sup>	lon Chamber <sup>1</sup> Liquid Scintillator <sup>2</sup> Vacuum photo diode <sup>3</sup>	Toroid <sup>9</sup> Wall current	e-detectors <sup>11</sup> Pinger e -sweeper	
GSI Synchrotron	IPM <sup>1</sup> HARP <sup>2</sup>	IPM <sup>1</sup> transverse Schottky <sup>3</sup>	capacitive pick up⁴	plastic scintillator⁵	Toroid AC <sup>6</sup> Toroid DC <sup>7</sup>	longitudinal Schottky <sup>8</sup> , capacitive pickup <sup>9</sup> tomography <sup>10</sup>	Tune: exciter + pickup (BTF) <sup>11</sup> , transverse Schottky
IPNS IPNS Ring PTS Transfer Line	IPM <sup>1</sup> (horiz.), RWM <sup>2</sup> (long.), CT <sup>3</sup> (long.) SSEMs <sup>5</sup> , SWIC/PAS <sup>6</sup>	SSEMs, SWIC/PAS	PIE <sup>4</sup> electrodes SSEMs, SWIC	PMT/scintillators, CT ICs <sup>7</sup>	CT CTs <sup>8</sup>	RFA (electrons)	PIE electrodes
BNL Rings							

	Transverse: IPM,	Transverse:	shorted stripline, 25	ion chambers (TeV Style)	DCCT, WCM	Buttons	coherent:Kicked
	Luminesence	Schottky,	cm long, single +				tune,
		Luminesence	dual phase				incoherent:
RHIC							SCNOTTIKY+ PLL
	Longitudinal: WCM						
		VVCIVI, SCHOttky					
400							
AGS							

#### **Additional Notes:**

#### SNS : 248m storage ring

< 1.3 GeV P

up to 1.44x 1014 ppp (1 msec storage)

gas ionization system
 Dual plane, 4 stripline design. position + relative phase , 65M samples/sec
 Volume detector (N) (~ 10 kHz,)
 Photo multiplier, > 1 MHz response, MPS input.
 Fast current transformer, 15 mA - 100 A
 Related to e-P instability - need 100 MHz response
 To measure residual beam in the extraction gap, < 1.e-4 of nominal beam intensity</li>

J-PARC (JKJ) 1) Under R&D for high intensity beam.

2) Using metalized thin films for high intensity is under R&D. Planned to install in inj. / ext. beam transport lines.

3) For COD measurement / single pass

4) Fast response.

5) Wideband frequency is covered by several toroids.

FNAL P driver 16 GeV Synchrotron

1) 100 mm length, Turn-by-turn measurements, ± 1.0 mm
 2) 1.5 kHz-20 MHz, 5 V/A, 245 mm ID, Turn-by-turn measurements, 0.1% error
 3) 245 mm ID, Resolution 10 mA, 500 Hz drift 5mA/24 h
 4) turn-by-turn time resolution
 5) V=0.11 cc, Time resolution 0.1 ms
 6) , 100 mm length FEE, Resolution of 0.01 tune units,kick of a few tenths of a mm

LHC / CERN Rings: 1) 20 m/s

2) 0.6 and 6 m/s

3) e-detection, commisioning phase, intensity dependence observed in the SPS

4) commisioning phase, backgrond problem in the SPS

5) total allowed beam intensity 1 E13, in last weeks lower threshold observed in the SPS, under investigation

6) light from the edge of a bending magnet

7) light from a undulator at 450 GeV and at 7 TeV from a the edge of a bending magnet
8) mounted on the quad mag, cold
9) near IP and some special
10) Aluminium Cathode Electron Multiplier
11) 1 liter N2 at 1 atmosphere
12) few units for the observation of fast losses
13) radial magnetic field detection, no common mode sigbal, bunch lendth 200 ns
14) strip line

ISIS Ring 163m, 70-0800 MeV RCS, 50 Hz. 2x1013 ppp, Harmonic 2 RF System

1) Single detector stepped over beam width.

2) halo position determined by measured beam loss on adjacent BLM.

3) used for 1st turn orbit setup with a beam stop.

4) Scintilators used for single turn injection and extraction beam diagnostics

5) 200 MHz bandwidth, switching gain devices for use with high intensity and chopped beams. Used for transverse measurements and summed for longitudinal measurements

6) Resolution range 1x1010 to 4x1013 protons

7) Thermocouples placed on dipole vacuum chambers downstream of beam collector systems to prevent dipole damage

8) electrostatic chopper in jection line controls injection pulse length from <1 turn to full intensity (160 turns)

9) Fast h and v kicker magnets (rise time ~ 1 us, duration ~ 0.5 ms) perturbs orbit for transverse lattice measurements.

FNAL Booster Ring: multi-turn H- charge exchange injection at 400MeV with 200MHz bunch structure, typically 12 turns

200MHz structure washes out in few turns, then beam is semi-adibatically captured in Booster harmonic 84 buckets (38 MHZ at 400MeV) accelerate to 8 GeV in 33 millisec (15 Hz resonant magnet circuit) RF harmonic = 84; frequency 38-53 Mhz typical injected intensity 5E11 to 7.5E12 typical high intensity injection-to-extraction efficiency 70% 1) blind from injection until RF capture (~25-30 turns) 2)sub-microsecond timescale

DESY: 1) gas ionization monitor system

2) For tail measurements
3) 10 MHz response, counting mode
4) PMTs and PIN diodes
5) up to 1 m/s, upgrade planed
6) for max. 10 bunches only, to measure the quadrupole moment
7) 30 kHz-250 MHz Bandwidth
8) Photomultiplier, > 10 MHz response.
9) DCCT slow current transformer typ PCT or M-PCT, 0-200 mA, res: 0.5 mA, CD - 100kHz
10) AC Fast current transformer, 30 kHz - 20 MHz, Cal: 1011 p/V, res: <<10mA, meas. precise transport efficiency</li>
11) difference of 9) and 10) = coasting beam
12) Broadband readout (<96 ns)</li>
13) for bunch length, timing and feedback; 2 MHz - 1 GHz bandwidth

LANSCE Ring:

1) Nitrogen at 1 std. atm. Same type of ion chambers also used in personnel protection system.

Used for fast, ns time scales. Saturates on PSR extraction losses.
 Fast, but less sensitive, so does not saturate on PSR extraction losses.
 Slit and collector method used up to 100 MeV.
 Used at 800 MeV.
 Primary BPM system for ring, but only works well for injected beam with 201 MHz structure.
 Only have a couple of these in the ring.
 No profile measurements in ring, but measure profile immediately after extraction. Can deduce ring profile at any time by extracting early.
 Have both fast and slow toroids.
 Used after each DTL tank.
 ANL-style, with LANL-developed high-bandwidth electronics at detector
 ANL-style, with LANL-developed high-bandwidth electronics from loss monitors)

GSI Synchrotron - all ions, space charge limit < 1012, ions (charge dependent) up to 12 GeV/u, fast and slow extraction, electron cooling possible, 218 m circumference

MCP + wire array readouut, ion deflection (new development: B field and electron detection, MCP + phosphor + CCD)
 First turn diagnostic
 for debunched beam, capacitive pick up plates
 show box type, high impedance pre-amp, 100 MHz bandwdth
 counting mode, max. rate ~ 5 MHz
 for injection, 1 Mhzbandwidth passive transformer, 0.1 microA resolution
 DC bandwidth, 50 kHz, 1 microA resolution
 for momentum spread of DC beam
 bunch shape observation bandwidth 100 MHz (high impedance) bandwidth 1 GHz (50 Ohm)
 phase shape reconstruction using capacitive pickup
 frequency sweep or while noise excitation

#### IPNS Ring 450 MeV RCS, 30 Hz

1) Position and Profile System (PAPS)--only weak magnetic field (3-4 G, ave.) present; residual from combined-function magnets (full power, 5 kHz)

2) Resistive Wall Monitor (full power, wide-band)

3) Pearson Coils (full power, <20 MHz)

4) split-can pair, horizontal and vertical (full power, < 50 MHz)

5) Segmented Secondary Emission Monitors (full bunch, low power)

6) Segmented Wire Ionization Chamber, Au-coated, W wire, 2 mil (0.03 mil Au) / Position And Size monitor (package 2 m in front of target, full power)

7) Ionization chambers

8) Pearson coils and Bergoz MPCT (full power, reduced BW)