Longitudinal Laser Wire at SNS

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Spallation Neutron Source
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Spallation Neutron Source

- Neutron scattering facility to research properties of materials
- 1 GeV Protons create neutrons through spallation in Hg target

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power on Target</td>
<td>1.4 MW at 1.0 GeV</td>
</tr>
<tr>
<td>Pulse on Target</td>
<td>1.5 E14 protons (24µC)</td>
</tr>
<tr>
<td>Production</td>
<td>~1000 mini pulses of ~24mA avg over 1ms at 60Hz</td>
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<tr>
<td>Study</td>
<td>1-50 mini pulses, 1-5Hz</td>
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</tbody>
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**Longitudinal size measurements**

- **BSM (Feschenko device)**
  - Wire is used to strip electrons
  - RF deflector selects particular phase
  - Interceptive technique
  - Impossible to use in production

- **BPM amplitude measurements vs. BPM position**
  - Requires cavity scan and cavity blanking
  - Impossible to use in production
  - Requires beam dynamics model

- **Laser wire**
  - Number of striped electrons is negligible for ion beam
  - Completely non-intrusive
  - Can be used in production or studies
Theory of operation

Laser detaches the electrons from the 2.5MeV H\(^+\) ions in the MEBT. The detached electrons are deflected by a magnet to be collected by an MCP.
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Current

945 ns

1 ms macro-pulse

2.5 ns

Frequency offset

12.5 ns - δ

laser

Phase shift

12.5 ns

φ₁
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Layout

[Diagram of a layout with labeled parts such as Quadrupole, Rebuncher, Chopper, Chopper Target, Diagnostics box, Beam-Profile Monitor, and a detector pointed out.]
Layout

transport line
Layout
Layout

Laser table – 3rd floor

- Optical Fiber
- 30m fiber
- Camera
- Fiber Probe
- Mirror
- PBS
- Motorized Stage
- X - scan
- BS
- VW
- Power Meter
- H- beam
- Collector
- Chopper
- Magnet
- Transport line
Mira 900 Ti:sapphire mode-locked laser

- pumped by a 10W Verdi-V10 solid-state laser
- synchronized to a stable RF source at 80.5MHz with a Coherent Synchro-Lock controller.
- pulse width (FWHM) of 2.5ps.
- peak power is variable up to 5kW.
- 30m long polarization-maintaining LMA fiber from Nufern
- fiber output pulse width ~ 10ps
- photo-ionized electron charge over one macro-pulse ~10pC
- wavelength 800nm
Experiment setup: Frequency Offset

- Laser
- 80.5Mhz + Δf
- Current Source
- Magnet
- HV
- MCP
- Amp
- Settings
- Read backs
- Data

Graph showing data with 1ms interval.
Phase shifting can be tricky

- Two phase shifters connected in series
- Phase vs. bias non-linear
- Amplitude vs. bias not flat
- Second phase depends on first bias due to amplitude being non-flat
- Calibration independent phase measurement needed
- Photodiode inside laser enclosure connected to lock-in amplifier serves for phase monitoring
- Phase shifter needs to be buffered or it will contaminate base 80.5MHz and lock-in won’t measure phase correctly
Data acquisition

MCP/magnet – custom
Phase measurement: SR844
Signal digitizing: NI 5105
Read back: NI 6229
Integration: PXI crate

Phase settings
Magnet/MCP settings
All setting readbacks
Phase Measurement
Raw Waveform
Can we average background?

If we stay at the same phase for several pulses, we can significantly reduce noise by simple averaging over total number of samples.

It works for background, signal and phase measurement.

Averaging is fast at 60Hz
Averaging of background at 60Hz

Collect background (no laser involved) data ~ 60Hz. Partition data in batches of 1000. For every pulse calculate integral $I[t]$ over $[t_0, t_0+10\mu S]$. For every $t$ average the integral over batch.

For several $t$ plot $I[t]$ vs. batch number
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Averaging doesn’t work for 50μS pulse

Background conditions change at short pulse and low repetition rate

No slow drift anymore

Unknown origin of “jumps”

Looks like some sort of slow charging/fast discharging behavior

Limits measurements of low current beams ~ 7mA

Impossible to measure no space charge beams
Sanity check – “quadrupole” scanning

Quadrupole focusing

Plot transverse size vs. quadrupole strength.

Fit with parabola

Calculate transverse emittance.

RF focusing

Plot longitudinal size vs. rebuncher amplitude

Fit with parabola

Calculate longitudinal emittance.

Model for different input Twiss

* Measurement

RMS bunch length(deg. @80.5 MHz)

Rebuncher amplitude (a.u.)
Conclusions

• The LBSM is operational

• We can reliably measure production beam at 60 Hz with accuracy of at least 0.5° (or even better with averaging)

• Background during production full beam is no issue.

• The measured bunch size is ~10°, but design size is ~15°. It is hard to come up with a measurement imperfection that shrinks the bunch.

• Background during accelerator studies with 50uS beam are affected by fast evolving background that prevents us to measure low current beams.

• We will continue exploring our options to reject background:
  – Will try faster detector to detect 80.5MHz
  – Will try optimizing magnet field to improve signal/background ratio
  – Will try to find the source fast changing background