Project X Beam Diagnostic Instrumentation

Vic Scarpine

Project X Machine Advisory Committee
March 18-19, 2013

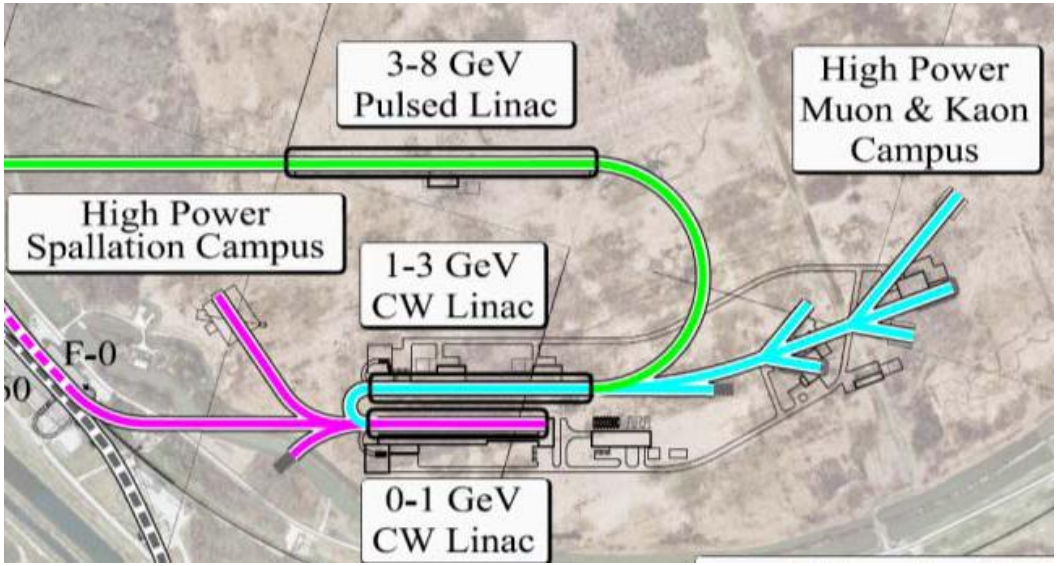
Scope

The scope of beam diagnostics are to identify and provide the instrumentation systems necessary to successful commission, characterize and operate all Project X sub-accelerators

- This presentation will only discuss beam diagnostic instrumentation required from the front-end through 8 GeV pulsed linac

Accelerator instrumentation sections:

- Ion source & LEBT
- MEBT
- 0-1 GeV CW linac
- 1-3 Gev CW linac
- 3-8 GeV pulsed linac
- Transport lines
- ~~Rings~~ - not in this talk



Measurement Goals

- Beam current
  - DCCTs, Toroids, High-Bandwidth Resistive Wall Current Monitors (RWCM)
- Beam position and phase
  - Warm and cold BPMs
- Beam energy and energy spread
  - Time-of-flight from BPM phase, spectrometer magnet
- Beam transverse profiles
  - Wire scanners, multi-wires, laser wires
- Beam transverse emittance
  - Allison scanner, slit-wire scanners, laser emittance monitor
- Beam longitudinal profiles
  - Wire-based bunch shape monitor, picosecond laser wires
- Beam halo
  - Vibrating wire, high-gain wires, laser wire, apertures, diamond detectors
- Beam loss monitoring
  - Ion chambers, neutron detectors
- Chopped beam extinction efficiency
  - High-Bandwidth RWCM, single (few) particle detection

List of ~ 15 unique instruments needed for Project X

Most to be developed and tested for PXIE

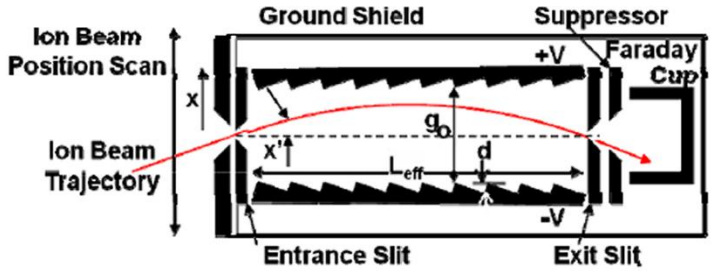
Source-LEBT Instrumentation

Beam Current

- Unchopped Beam Current
  - DCCT
- Chopped Beam Current
  - Toroid pickup

Beam Emittance

- Water-cooled Allison Scanner
  - Measurement at ion source
  - Collaboration with SNS



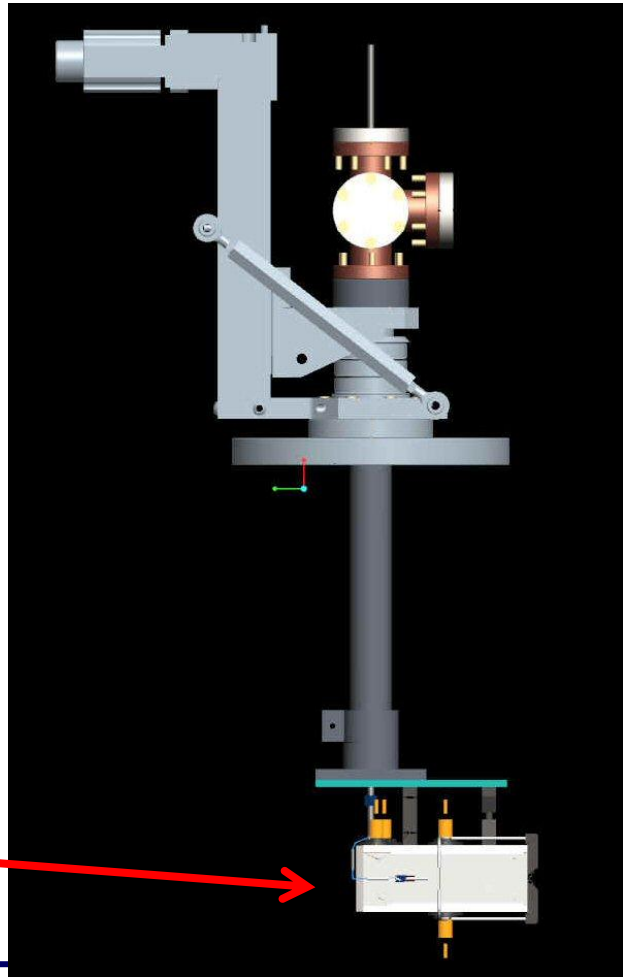
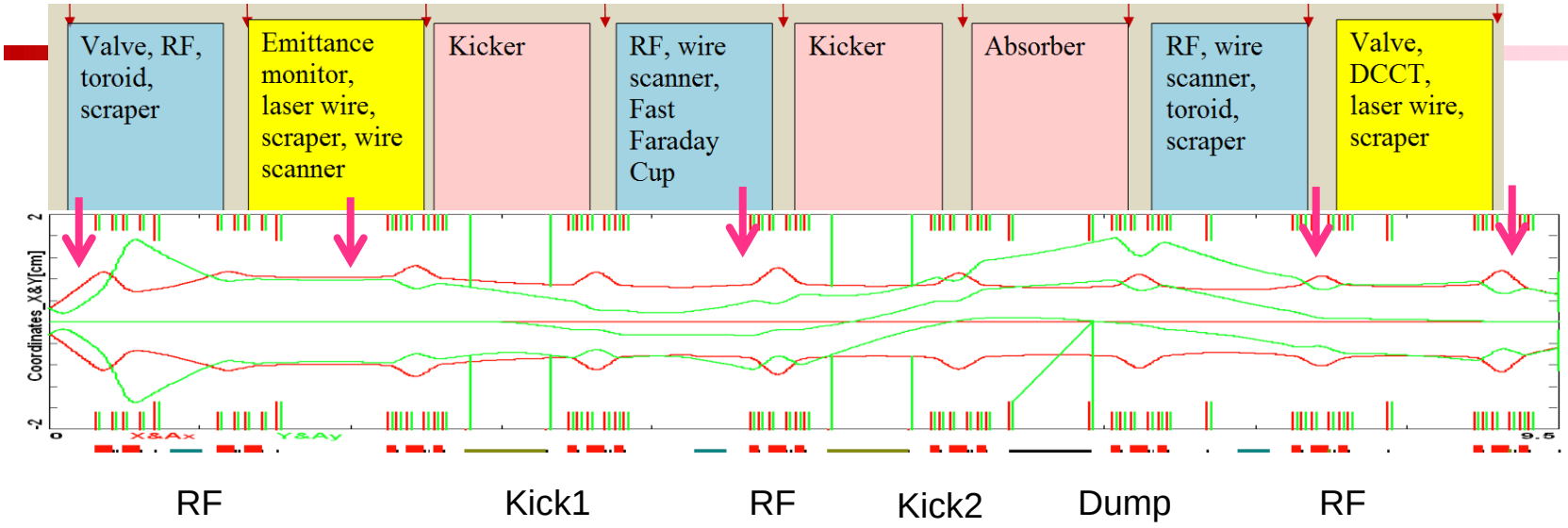


Figure 1: Schematic of SNS Allison Emittance Scanner.

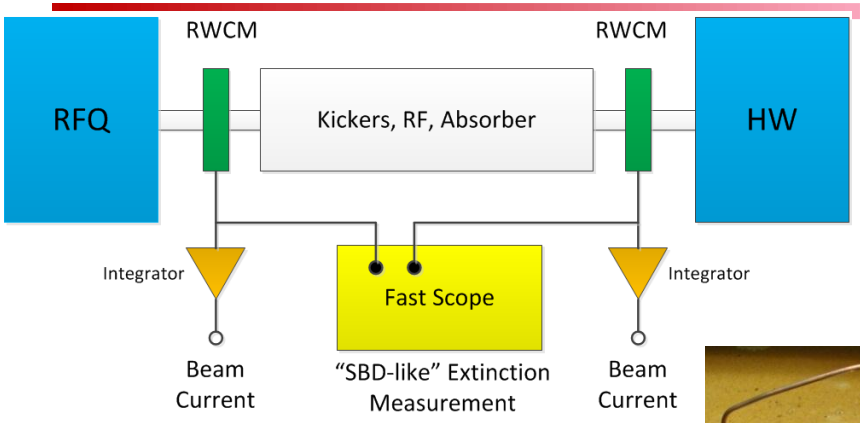
MEBT Instrumentation



MEBT Operational Beam Measurements: (red = CW)

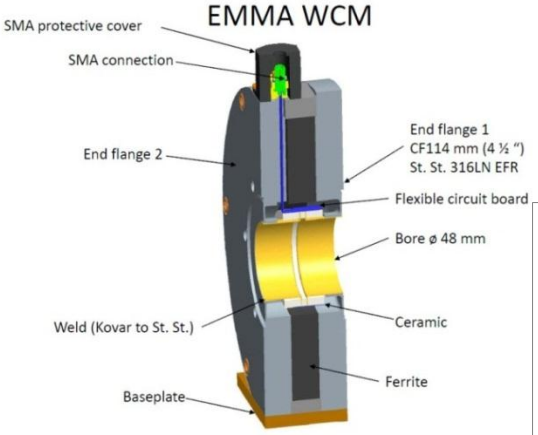
- Transverse position - BPMs
- Bunch Phase – BPMs → time-of-flight → beam energy
- Beam Current – RWCM (resistive wall current monitor)
- Extinction – RWCM with fast scope
- Transverse shape – wire scanners, laser wires
- Transverse emittance – slit/multiwire (low-res), double slit/Faraday cup (hi-res), Quad scans
- Longitudinal shape – laser wires, chopper, bunch shape monitor
- Absorber Profiler – OTR Imager or IR imager

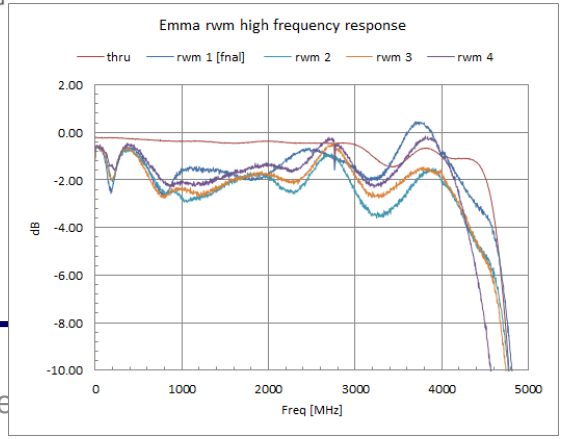
MEBT Chopper Extinction Measurement

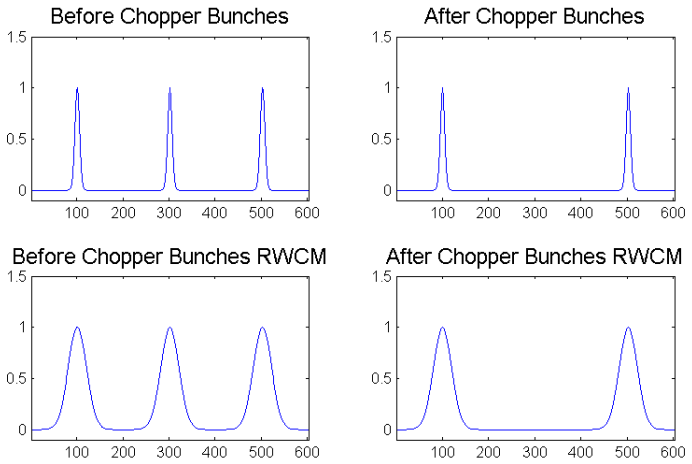


Use upstream and downstream Resistive Wall Current Monitors (RWCM)

- Extinction -> 'SBD-like' monitor
  - Average over many bunches
  - < 1 Hz BW
  - Fits to bunch shape
  - Measure impact on adjacent bunches



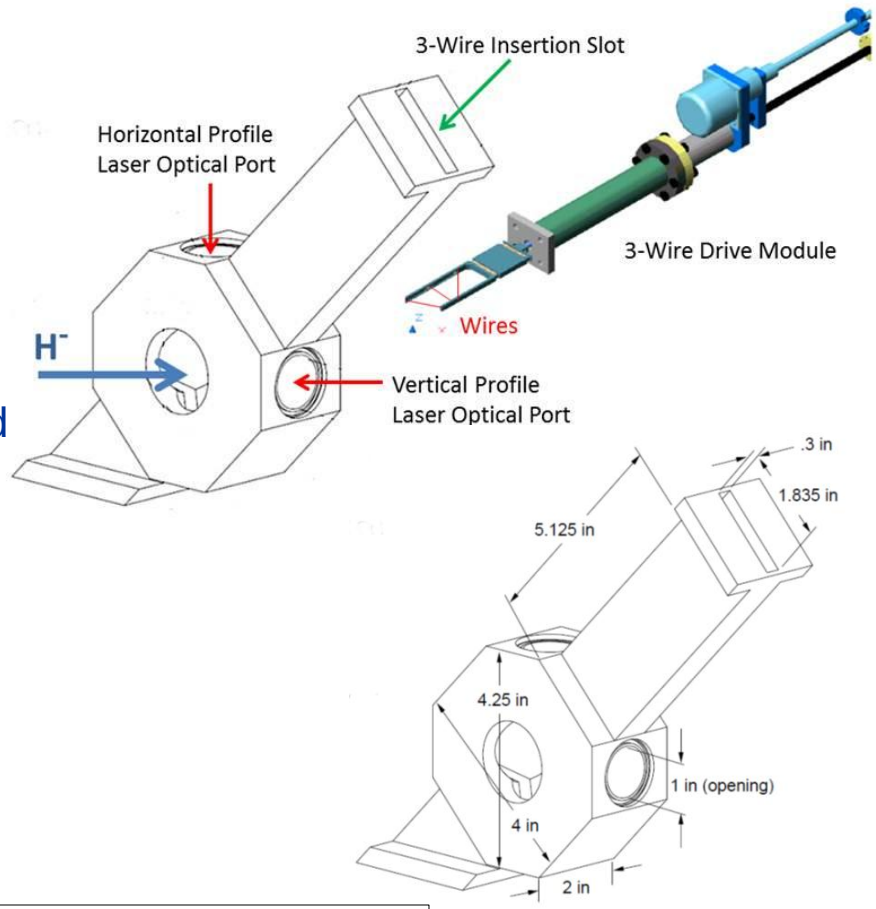




Combined Wire Scanner - Laser Wire Unit

Transverse 3-wire wire scanner plus laser wire module

- Hybrid wire scanner with laser ports
  - Modified version of SNS design
- Wire scanner in pulsed beam operation only
- Laser wire in either pulsed or CW beam operation
- Laser wire intended to measure transverse and longitudinal profiles
  - *Will different lasers be required for transverse versus longitudinal measurements?*
- Can wires or lasers measure profile tails/halo?
  - Transverse halo measurements with wire suffer from cross-talk
  - Halo measurement with laser suffer from scattered light effects



Locations: MEBT, between SC cryomodules, transport lines

Low-Power Transverse and Longitudinal Laser Wire

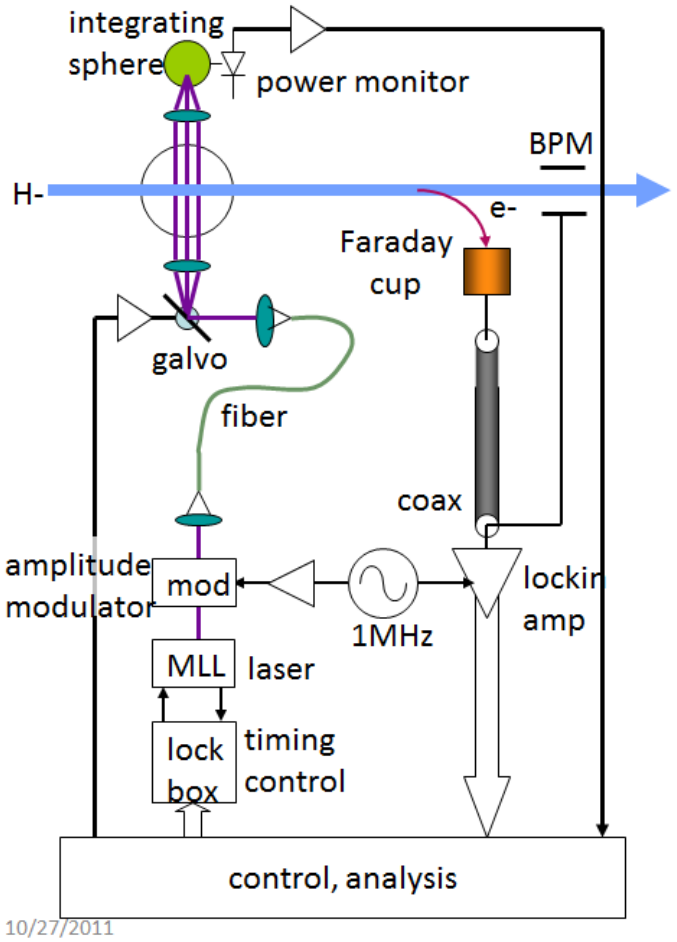
Mode-locked psec laser used to measure both transverse and longitudinal profiles

- Laser rep-rate is locked to accelerator RF
- Distribute modulated laser pulses via fibers
  - Narrow-band lock-in amp detects modulated signal
- Measure profiles by either:
  - Collection of electrons
  - Use BPM as notched-beam pickup would allow laser monitor to fit between cryomodules

Questions:

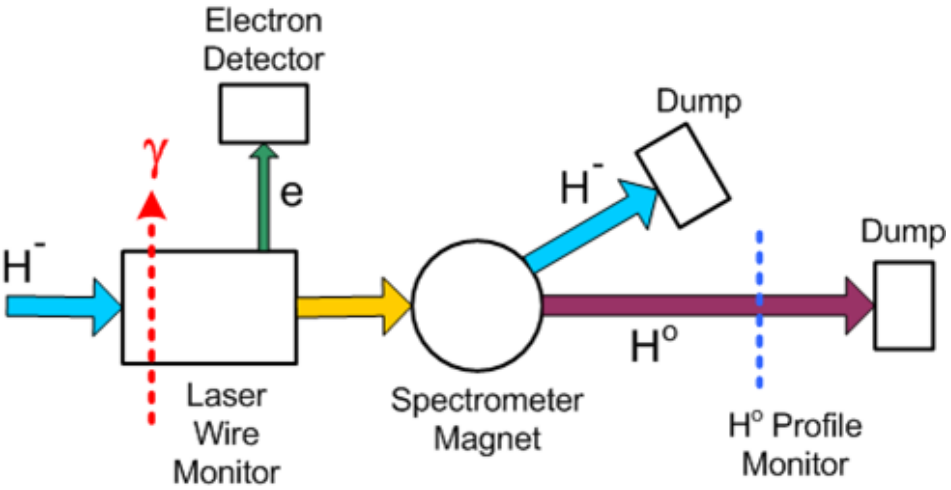
- What is the photodissociation efficiency?
- What are the noise issues?
- What are the nonlinear limits to power in the fiber?
- What signal-to-noise ratios and averaging times are practical?

Fall back laser wire option is to use high-power laser technique similar to SNS



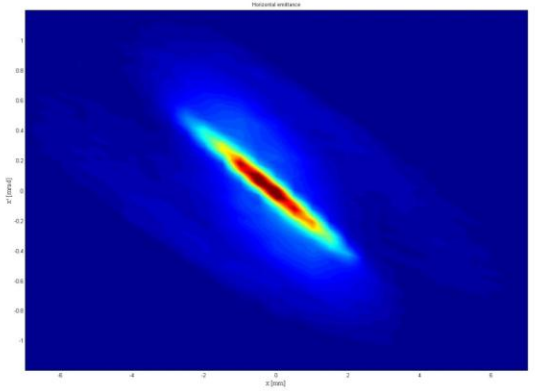
R. Wilcox, LBNL

Laser Wire Emittance Monitor

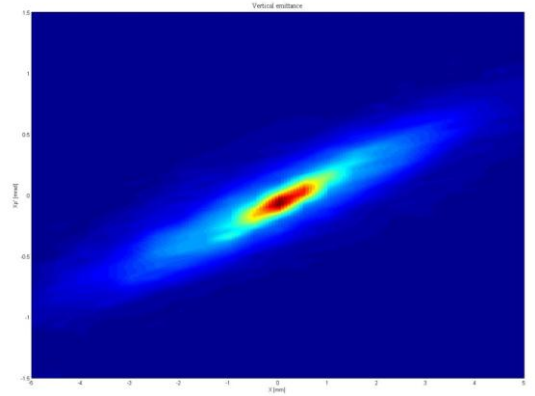


Preliminary SNS Measurements (Y. Liu)

Horizontal



Vertical

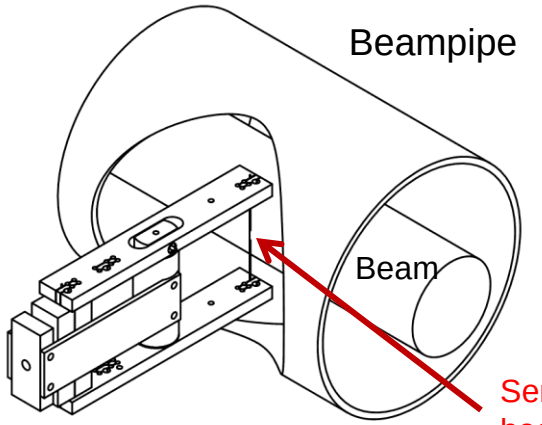


Laser Wire Emittance Monitor

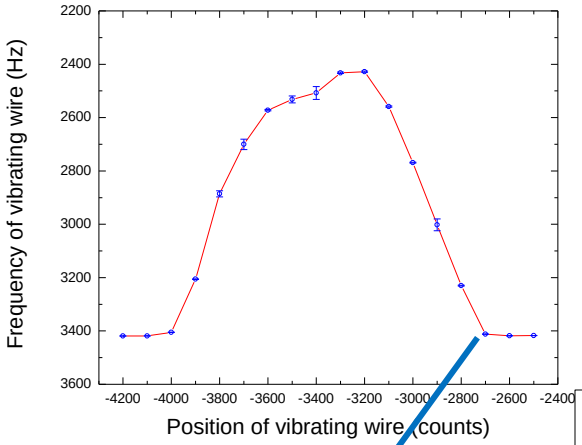
- Laser acts like slit → x
  - Generates H0
- H0 profiler measure H0 divergence → x'
  - Background from beam neutralization
- Demonstrated at SNS

Operate at the end of 1 GeV, 3 GeV and 8 GeV linacs

Vibrating Wire Halo Monitor

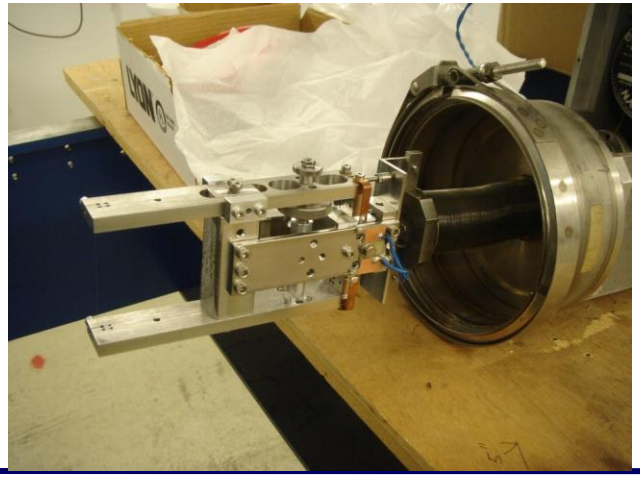


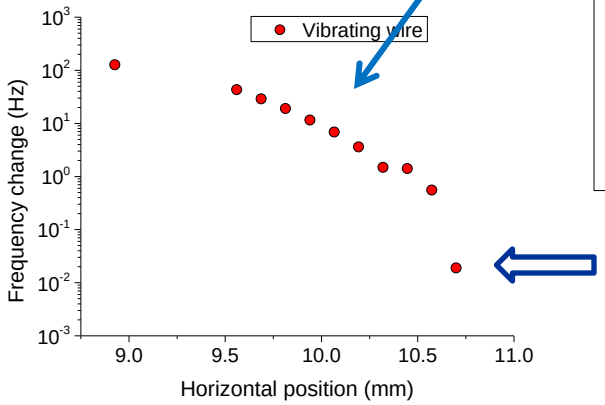
Temperature change affects the tension of sensitive wire and results in the shift of resonance frequency of the vibrating wire in permanent dipole magnets.



Preliminary measurements made at HINS

Moses Chung, FNAL





Note: Frequency change is very sensitive to ambient temperature, mechanical vibration, and magnetic field

Vibrating wire may have much higher dynamic range in the halo region

Preliminary Estimates of Instrument by Location

	Current	Position/ Phase - BPM	Trans. Profiles	Trans. Emittance	Long. Profiles	Halo	Beam Loss+	Extinction
LEBT	2	----	----	1	----	----	----	----
MEBT	2	9	4	1	1	2	TBD	1
1 GeV Linac	2	1 per FE	1 per CM *	__	1 per CM *	4	2/1 per CM	__
3 GeV Linac	2	1 per FE	4	__	4	2	2/1 per CM	__
8 GeV Linac	4	1 per FE	4	__	4	2	2/1 per CM	__
1 GeV Trans Arc	2	1 per FE	4 to 6	1 *	1	__	1/1 per FE*	__
3 GeV Trans Arc	2	1 per FE	4 to 6	1 *	1	__	1/1 per FE*	__

FE = focusing element
CM = cryomodule

* = laserwire
+ = charged/neutral

Technical Challenges

- Many Project X beam diagnostic instruments are based on previous designs
  - Most are low technical risk
  - Medium risk items
    - MEBT extinction measurement
    - Wire scanner – laser wire combination unit
  - Higher risk items
    - Low-power laser wire
    - Laser transverse emittance monitor
    - Vibrating wire halo measurements and transverse and longitudinal tails/halos in general
- Largest risks involve either laser-based measurements or halo measurements

Advancing R&D at PXIE in these areas will mitigate risk for Project X