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PIP-II Beam Instrumentation – Status and R&D

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PIP-II Machine Advisory Committee

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Outline

- Scope
- Measurements and Instruments
- PXIE LEBT and MEBT Instrument Status
- Beam Diagnostics R&D – non-invasive beam profiling
  - Laser profiling for H- beams
  - Electron beam profiler for proton beams
- Risks and challenges

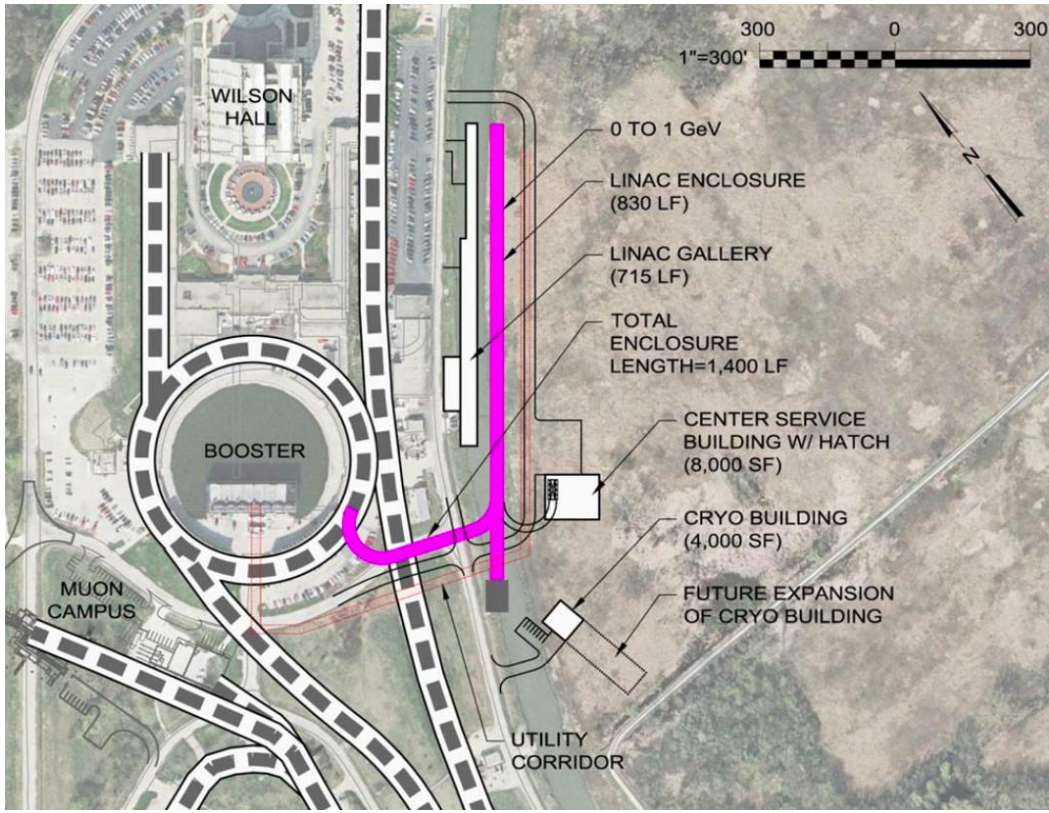
Scope

The scope of beam diagnostics are to identify and provide the instrumentation systems necessary to successful *commission*, characterize and operate all PIP-II sub-accelerators.

- *Present focus is development of instrumentation for PXIE*
- *PIP-II focus on pulsed operation with an eye toward CW*
  - *Impact on instrumentation choices*

Accelerator instrumentation sections:

- Ion source & LEBT
- MEBT
- Superconducting linac
- Transport lines
- Rings



PIP-II Beam Diagnostic Measurements and Proposed Instruments

- Beam current
  - DCCTs, Toroids, High-Bandwidth Resistive Wall Current Monitors (RWCM)
- Beam transverse position
  - Warm and cold BPMs
- Beam energy
  - BPM phase, movable BPM
- Beam transverse profiles
  - Wire scanners, laser wires, IPM, electron beam profiler, isolated beam scrapers

Large variety of instruments needed for PIP-II

- ***Develop many at PXIE***

- Beam transverse emittance
  - Allison scanner, slit-slit or slit-wire scanners, quadrupole scans
- Beam longitudinal profiles
  - Fast Faraday Cup, picosecond laser wires
- Beam halo
  - Vibrating wire, high-gain wires, laser wire, apertures, diamond detectors
- Beam loss monitoring
  - Ion chambers, neutron detectors, diamond detector
- Chopped beam extinction efficiency
  - High-Bandwidth RWCM, single (few) particle detection

Green = developed or under development for PXIE / PIP-II

Orange = developed or tested at other Fermilab accelerators

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LEBT Beam Diagnostics Status – *also see earlier talk "PXIE Warm Front-end Status"*

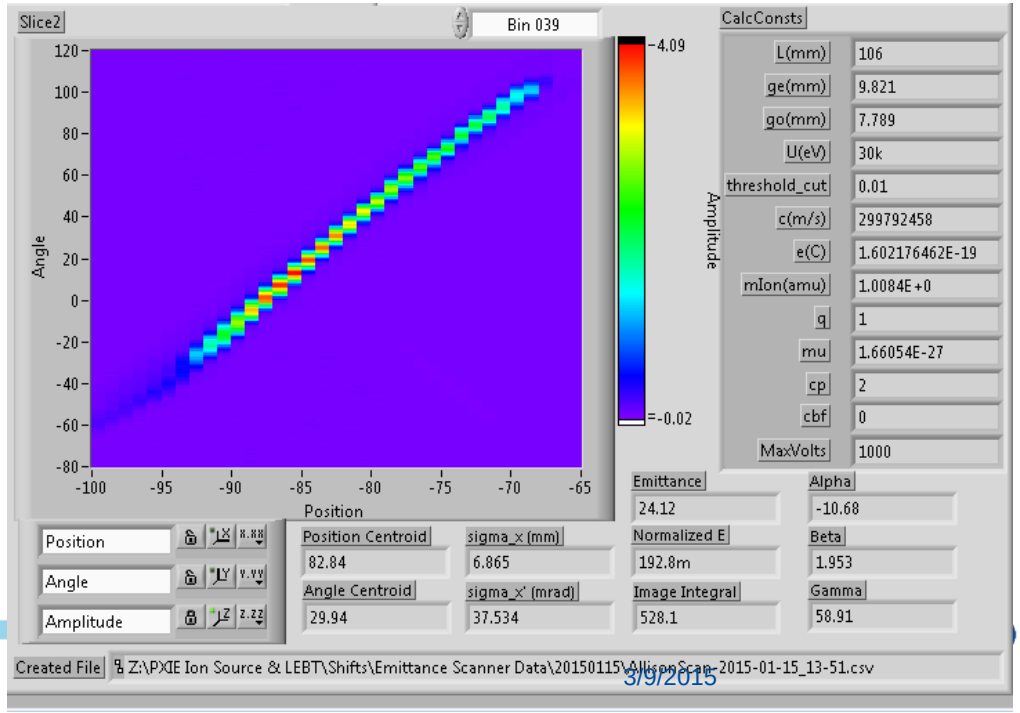
Much of past year has been in the development and support of the PXIE LEBT

Beam Current Measurements

- *DCCT, toroid and isolated electrodes*
- Beamline hardware installed
- VME-based readout electronics under development
  - Will allow for improved signal processing

Beam Emittance

- *Water-cooled Allison scanner operational*
- Installed at various location in LEBT



MEBT Beam Diagnostics Status – *also see earlier talks on "Warm Front-end Concepts and Status"*

Focus on RFQ commissioning:

- Beam current measurements
  - Toroids, isolated beam dump – purchased or have
  - Integrate into VME-based front-end - under development
- Beam position and phase
  - Warm BPMs - designed and being fabricated
  - DAQ system under development – based on previous design
- Beam transverse profiles
  - Electrically isolated beam scrapers – prototype under test
  - Integrate into VME-based front-end - under development
- Beam energy
  - Time-of-flight via movable BPM – under design
    - for RFQ/MEBT commissioning only
- Longitudinal bunch shape
  - High-bandwidth Faraday Cup - > 6 GHz BW – under design

Status – Warm and Cold BPM Development

Warm and cold BPMs pickups prototyped

Requirements:

	Accuracy	Precision
Position, μm	10	30
Phase, degrees of 162.5 MHz	0.05	0.2
Relative intensity, %	1	3

HWR/SSR1 Cold BPM Prototype (ANL)

Bunch-by-bunch measurements in MEBT chopper region - oscilloscopes

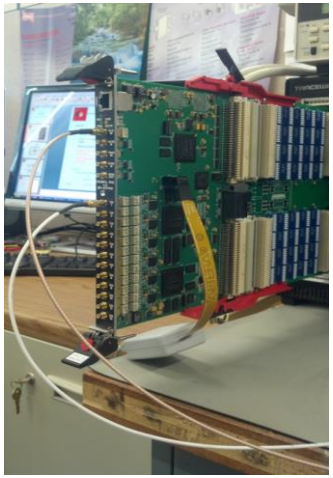
Synchronize signal detection

- Allows for lock-in detection for laser wire

Four button Warm BPM

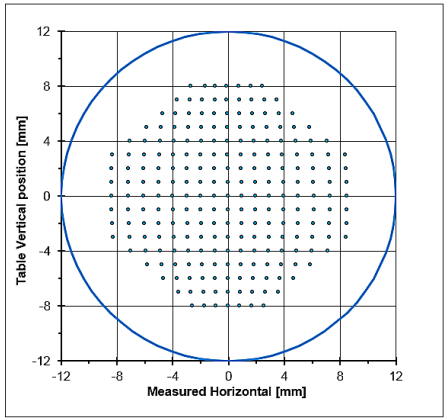
DAQ with FPGA-based electronics for CW and pulsed beam

- 12 channels
- 14 bits, 250 MSPS
- Different operational modes



Stretched wire mapping

- Simulating low-β corrections



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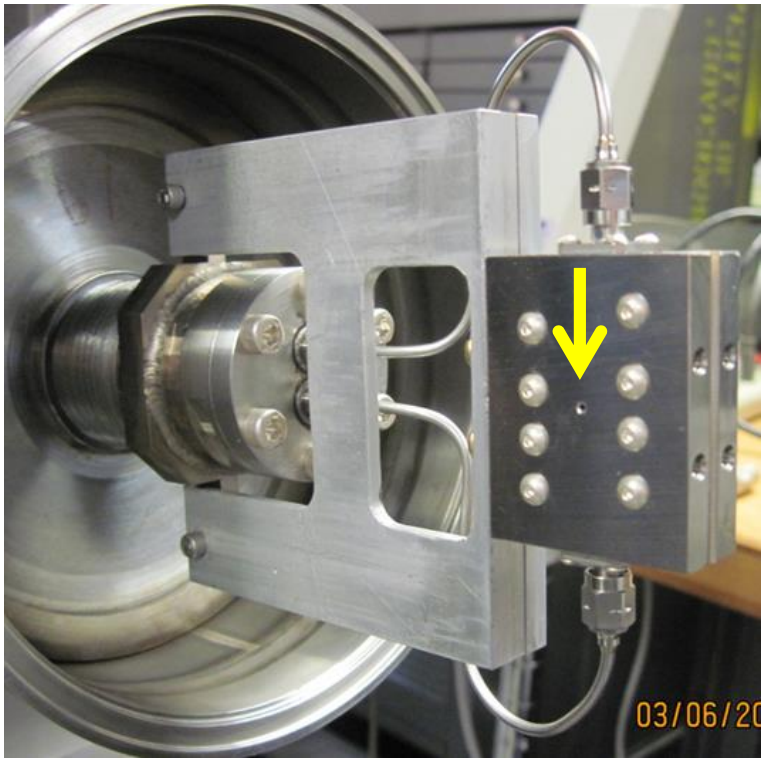
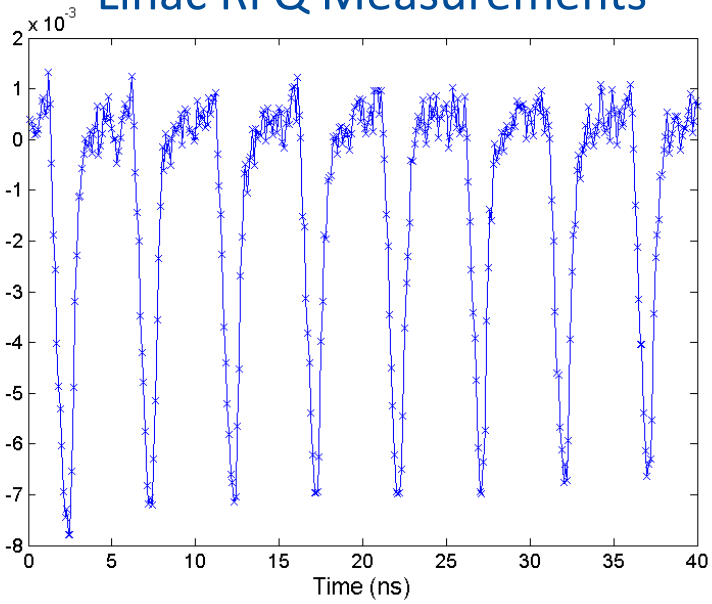
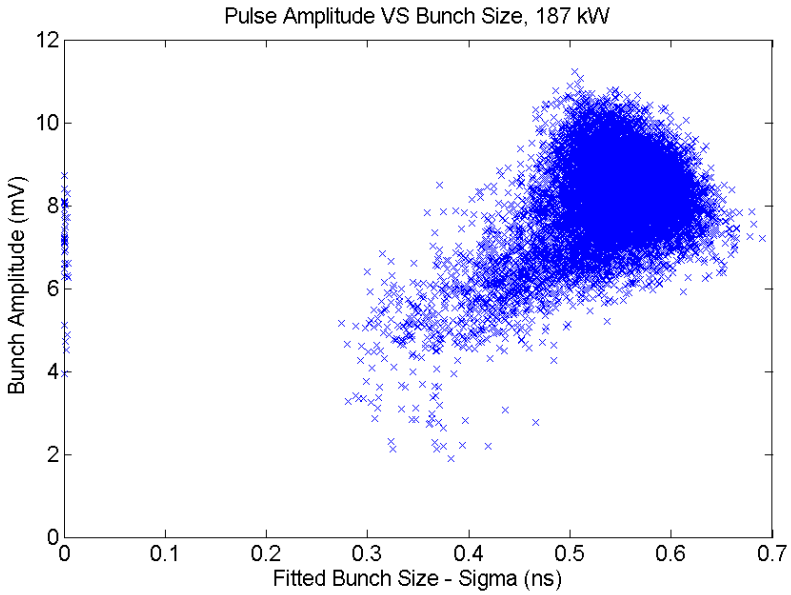
Longitudinal Bunch Length – Fast Faraday Cup



- Designed by SNS
  - Beam damage at HINS (2.5 MeV protons)
  - We are redesigning
- Tested at HINS and Linac
- High Bandwidth (> 6 GHz)

Linac RFQ Measurements





R&D – Laser Diagnostics Development – Low-power transverse and longitudinal laser wire

$$H^- + \gamma \rightarrow H^0 + e^-$$

162.5 MHz, psec mode-locked laser (MML) used to measure both transverse and longitudinal profiles

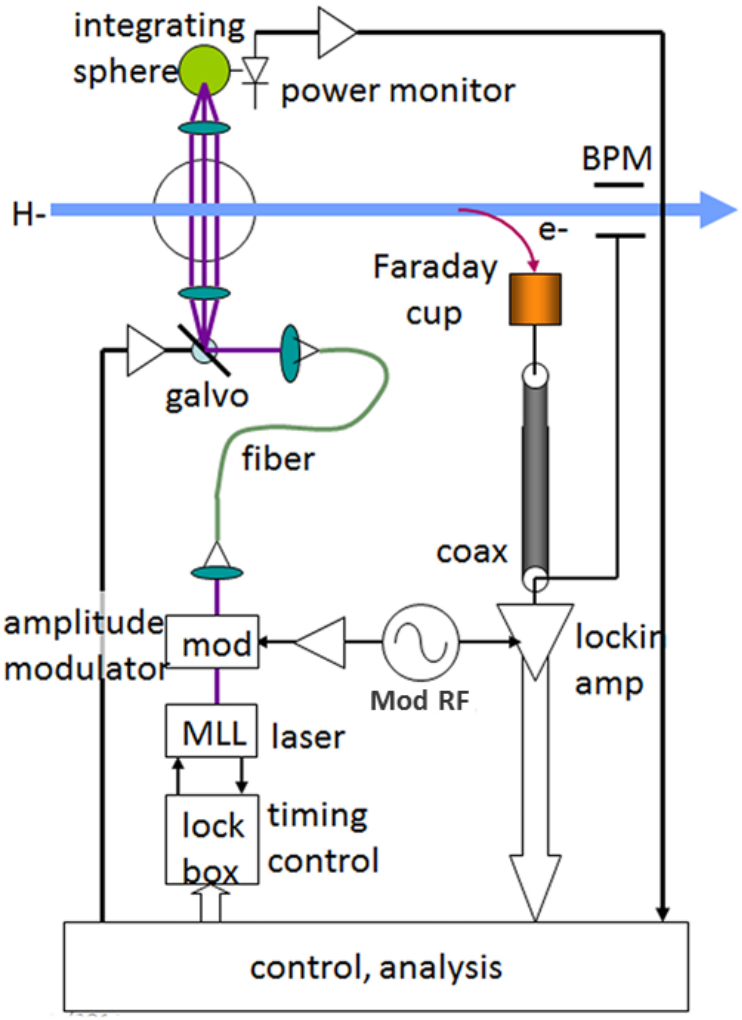
- Laser rep-rate is locked to accelerator RF
- Amplitude modulate laser pulses
- Distribute modulated laser pulses via fibers
- Measure profiles by either:
  - Collection of electrons
  - Use BPM as reduced-beam pickup
    - Allows laser monitor to fit between cryomodules
- Narrow-band lock-in amp detects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

Questions:

- What are the noise issues?
- What are the power nonlinear limits in the fiber?
- What signal-to-noise ratios and averaging times are practical?
- What are the accelerator systematics?

Status

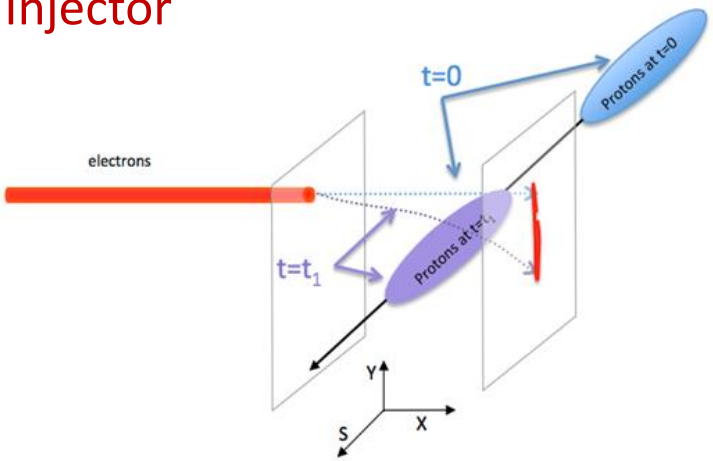
- Test system at PXIE - infrastructure development underway
- Laser design/development underway
- System commissioning end of 2016



R. Wilcox, LBNL

R&D – e-Beam Profiler (EBP) for Main Injector

- Electron beam deflection technique (working implementation at SNS)
- Prototype installed into Main Injector

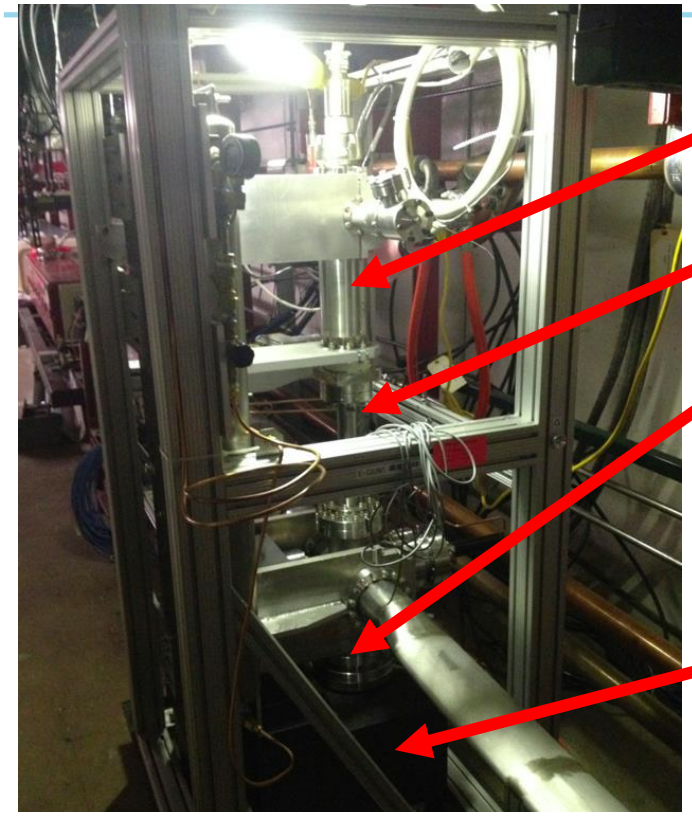


Electron beam is deflected by electric and magnetic fields of the protons

Deflection vs. impact parameter provides information about the proton beam transverse profile

- e Beam Profiler will utilize a raster scan analysis
  - Potentially provides the transverse profile as a function of longitudinal position for a single bunch
    - Possible to measure head / tail profiles (split bunch in half)
  - Slow part of scan is across beam using one turn per data point
  - Resolution depends on
    - Size of e beam (100-200 um) relative to p beam (Beta is large)
    - Linearity of deflecting fields
    - External magnetic fields
    - Synchrotron oscillations
  - Can average over many bunches if not raster scanning
    - Sit at single longitudinal point

R&D – e-Beam Profiler for Main Injector - Status



Electron Gun (upstream of Q622)

- Gun has been installed
- Mumetal shielding in place
- Tunnel cable terminations mostly done

- HV distribution boxes being worked on
- Deflector power supply being worked on
- MI-62 cable terminations not yet done
- Plan to install HV box in tunnel this summer

Plan to begin commissioning after summer shutdown

PIP-II Preliminary Estimates of Instrument by Location

Instruments only up to Booster

	Current	Position/ Phase - BPM	Trans. Profiles	Trans. Emittance	Long. Profiles	Beam Loss	Bunch Extinction
LEBT	2	----	----	1	----	----	----
MEBT	2	9	4 + 2*	1	2*	TBD	1
Super-conducting Linac	1 per WS	1 per FE	1 per CM *	—	1 per CM *	2 per CM	—
Linac to Booster Transfer Line	2	1 per FE	4 to 6 *	1	1 *	1 per FE	—

FE = focusing element
CM = cryomodule
WS = warm section

* = laserwire

Risk and Challenges

- Non-invasive beam profiling
  - For H- beams – SC Linac
    - Laser-based profile monitors
      - Transverse and longitudinal profiling
  - For proton beams - Rings
    - Ionization Profile Monitors (IPM)
    - Electron Beam Profile (EBP) monitors
- Tails/Halo measurements and mitigation
  - Control of losses in Recycler
- Strong competition for resources
  - Effects timeline of diagnostics development