Beam Diagnostic Instrumentation for PXIE

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Project X Meeting

Jan. 17,2012

Outline

- Functional Requirements
- LEBT Instrumentation
- MEBT Instrumentation
- Cryomodule Instrumentation
- End of Beamline Instrumentation
- Resources
- Issues

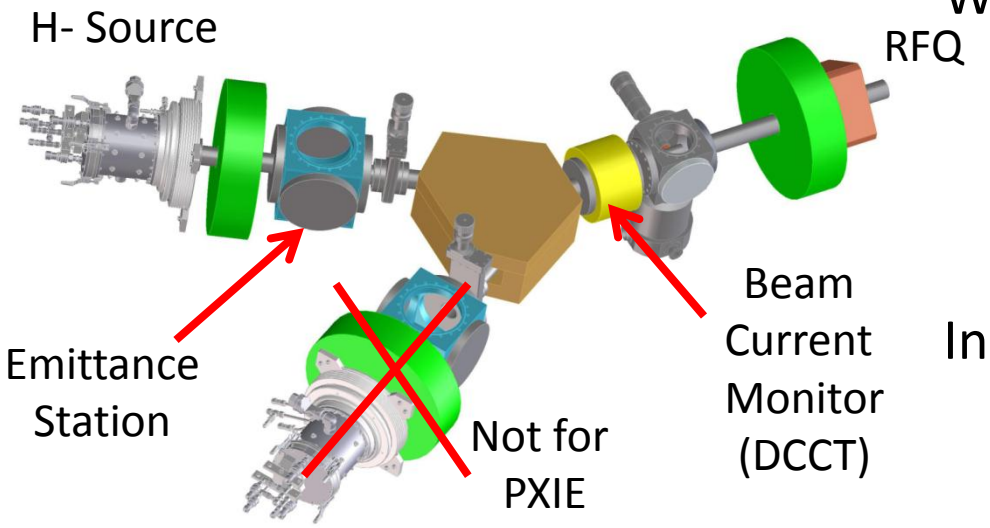
Functional Requirements

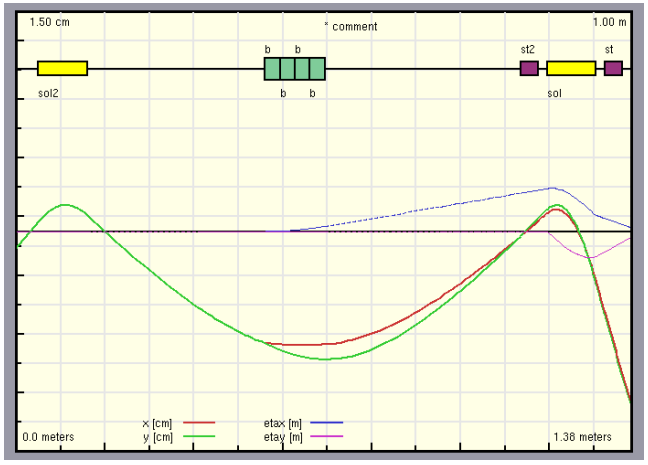
- What beam measurements are required to meet the goals of the PXIE program?
- Functional requirement guidelines:
  - Doc #966 – PXIE Functional Requirements Specification, Jan. 9, 2012
  - PXIE website:
    - MEBT Functional Specifications – Oct 20, 2011
    - MEBT BPMs Specifications – Oct 13, 2011
- "Operational" vs "Commissioning" Requirements
  - Operational Instrumentation required to monitor normal beam operations as well as identify potential problems
  - Commissioning instrumentation required to *characterize* beamline performance
    - Nominally a super-set of operational instrumentation
    - What defines a full set of beamline characteristics?

Highlights of Functional Requirements Spec, Doc #966

- Under "PXIE Goals" section:
  - Integrated systems test goals:
    - "Efficient acceleration with minimal emittance dilution through at least 15 MeV." *– transverse and longitudinal?*
- Under Table 2
  - 1.5: Normalized transverse RMS emittance: < 0.25 mm-mrad
  - 1.6: Normalized longitudinal RMS emittance: < 1 ev-us
  - 1.14: "Appropriate diagnostic systems shall be developed, installed and commissioned to verify and quantify all of PXIE requirements in this document."
- Under "Commissioning Requirements"
  - "The project requires flexibility to handle a phased commissioning of the accelerator components."

PXIE LEBT "Operational" Instrumentation





Working Parameters

- One 30 KeV H- source for PXIE
- 5 mA DC beam
- Two solenoids
- Continuous beam only

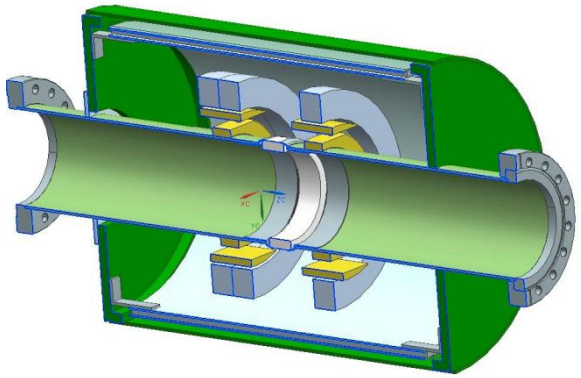
Instrumentation

- One beam current monitor - DCCT
- Emittance station → two Allison-type scanners
  - ~ 150 watts beam power
- Is any instrumentation supplied by LBNL?
- No real instrumentation issues

- Full LEBT characterization at LBNL
  - *Repeat at Fermilab?*

LEBT Instrumentation

- Current measurement
  - Fermilab to build DCCT if LBNL does not supply this
  - Modified version of NOVA DCCT
    - Design changes are minimal
    - DC to ~ MHz
  - ~ 0.3 FTE-years

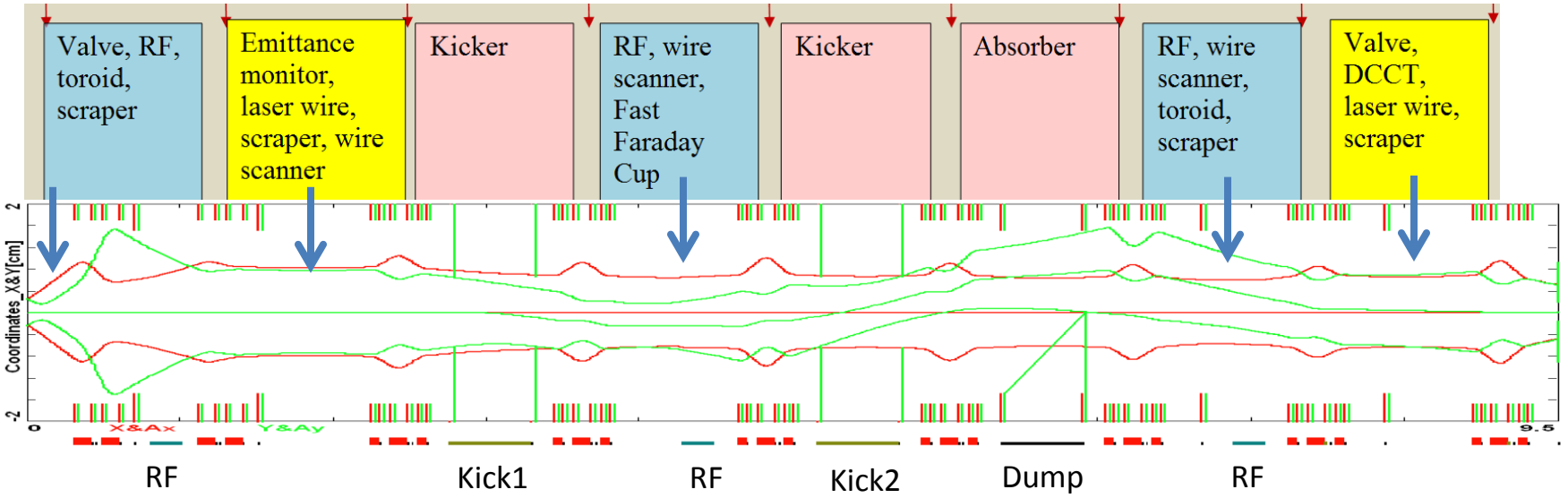


- Transverse emittance measurement
  - Fermilab to build two Allison-type probes if LBNL does not supply
    - Will use either LBNL or SNS design
      - Investigating if water cooling is needed
      - SNS is designing water-cooled unit
  - Still need vacuum chamber, motion system and electronics unless LBNL supplies
  - ~ 0.5 FTE-years
- *Are there any requirements to measure characterize beam out of LEBT at Fermilab?*
  - Emittance? Steering?

MEBT Functional Spec

Parameter	Unit	Value	Tolerance	Comment
Ion type		H-		
Output energy	MeV	2.1	1%	Same as input energy
Max frequency of bunches	MHz	162.5		
Operational input beam current	mA	1 - 10		
Nominal input beam current	mA	5		
Average output current	mA	1	≤ 1	
Particles per bunch	E8	1.8	0.4 – 4	30 pC/bunch, nominal
Bunch selection: Pass-through or remove[&]		Bunch by bunch		Programmable cyclical buffer 16,250,000 bunches or less. Buffer should be reloaded on the fly in 0.5 ms or less.
Residual charge of removed bunches *	Relative	$< 10^{-4}$		Relative to pass-through bunches
Beam loss of pass-through bunches *	Relative	< 5%		
Nominal transverse emittance*[#] (n, rms)	mm·mrad	0.27	0.1- 0.27	≤ 10% increase comparing with the input
Nominal longitudinal emittance*[#] (rms)	keV·nsec	0.8	≤ 1	≤ 10% increase comparing with the input
Beam displacement	mm	0	< 0.5	At the flange of HW cryomodule
Beam angle	mrad	0	< 0.5	
Scraping to transverse emittance[#] (n, rms)	mm·mrad	< 0.05		Pulse mode, 10 W average beam power

PXIE MEBT

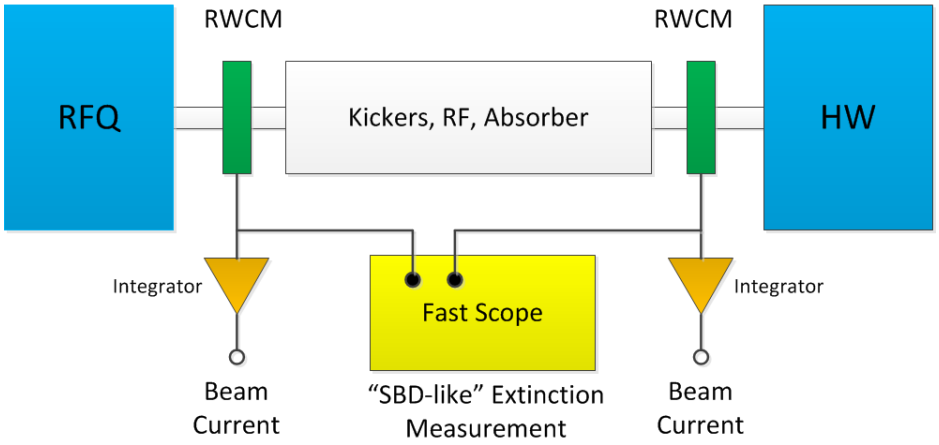


- Ion type: H-
- Output energy: 2.1 MeV, same as input
- Max bunch freq: 162.5 MHz
- Operational beam current: 1 – 10 mA
- Nominal input beam current: 5 mA
- Particles per bunch: 1.8e8 nominal
- Bunch extinction: < 1e-4

MEBT Operational Beam Measurements: (red = CW)

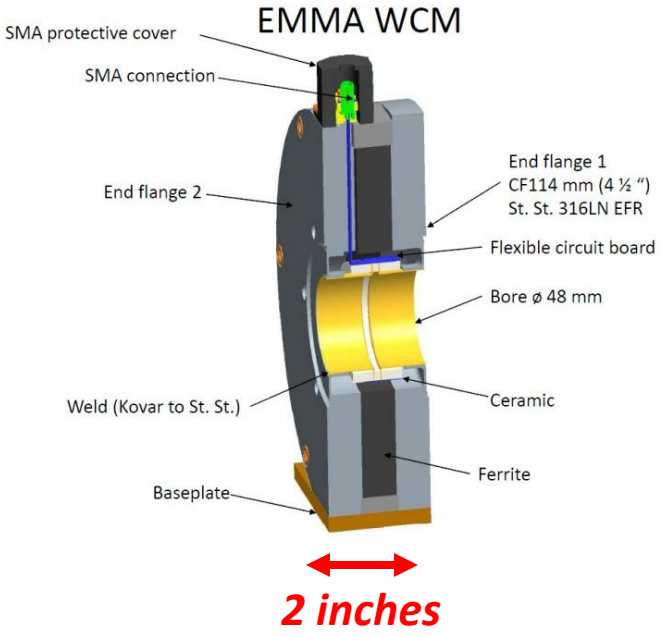
- Transverse position - BPMs
- Bunch Phase – BPMs
- Beam Current – RWCM
- Extinction - RWCM
- Transverse shape – wire scanners, laser wires
- Transverse emittance – slit/multiwire
- Longitudinal shape – Fast Faraday Cup, laser wires
- Absorber Profiler – OTR Imager

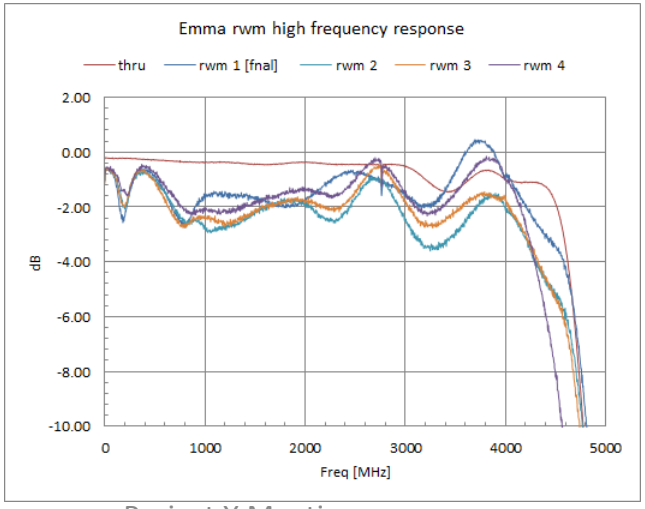
Extinction + Current Monitor



Use upstream and downstream Resistive Wall Current Monitors (RWCM)

- Extinction -> 'SBD-like' monitor
  - Average over many bunches
  - < 1 Hz BW
  - Measure impact on adjacent bunches
- Beam current
  - Fast integrator
  - ~ MHz BW
- Flat freq response, 10 KHz – 4 GHz
- Already designed, ~ $10k/detector
  - May require adjustment for PXIE beam pipe diameter



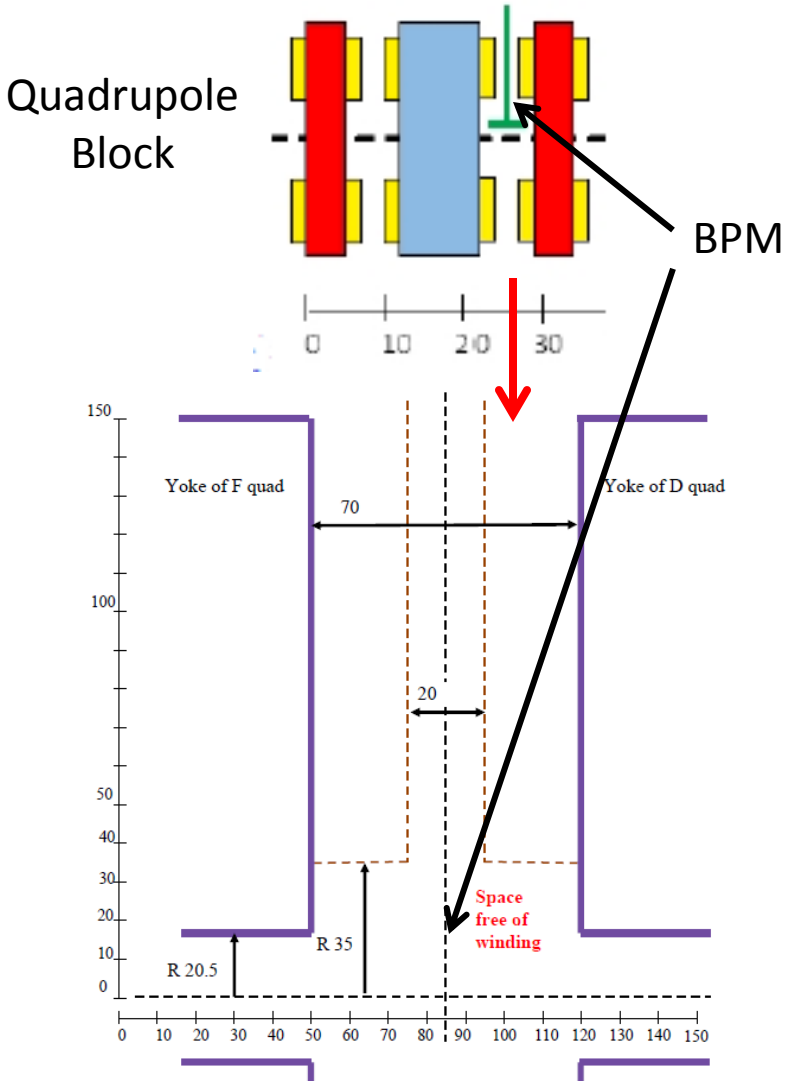


Warm BPM Requirements

Tight squeeze for MEBT BPMs

MEBT BPMs - 9 (one inside each quadrupole block)

- Each BPM station measures position in 3 dimensions
- Internal diameter - 35 mm
- Available length - 50 mm
- *Transverse resolution*
  - *0.1 mm (for a single 1μs macro-pulse)*
  - *0.01 mm (CW, 0.1 sec update)*
- *Accuracy of absolute positioning- 1 mm*
- *Phase resolution - 0.1 deg =* ***over 360 degrees?***
- Nominal intensity- 2E08 H- per 162.5 MHz bunch (range 0.2 - 4· E08 ppb)
- Typical rms beam half-size - 3mm
- Typical rms longitudinal half-size - 10 degree (162.5 MHz)
- Bakeable to 150C
- *The BPMs are welded in and cables are connected before the quads are mounted.*



Warm BPMs

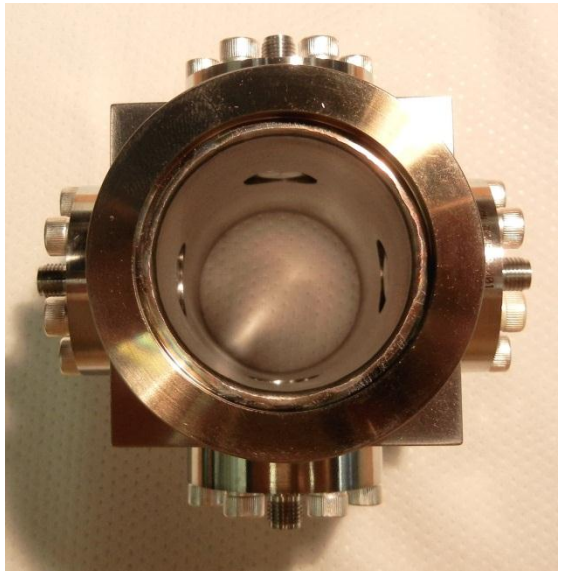
Button BPM design similar to A0/NML

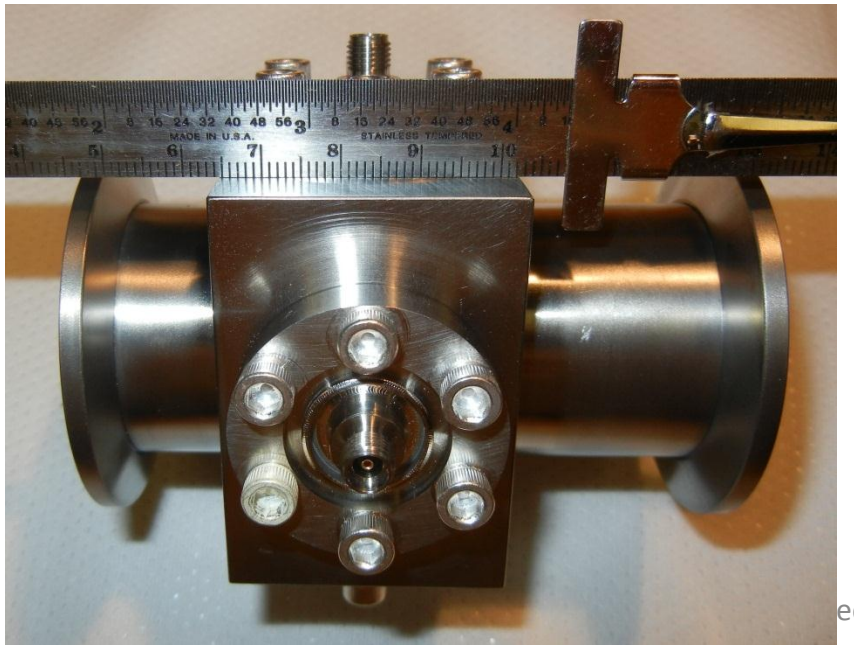
- *May need small redesign*
- *Can fit in limited size*

Direct digitization readout

- *Undersampling of 1st & 2nd harmonics*
- *Operation over 360 degrees of cavity phase needs study*
  - *Debunching effects phase measurement*
- *Synchronize to laser modulation*

Development and testing at HINS would be helpful to understand system performance





Transverse Emittance + Wirescanner + Laser Wire Unit

Three instruments located just before first kicker:

1. Slit/Multi-wire Transverse Emittance Monitors – pulsed operation
2. Three-wire (Horz, Vert, Diag) transverse wire scanner – pulsed operation
3. Transverse and Longitudinal Laser Wire – CW operation

Wire scanner + laser wire in single can – SNS design

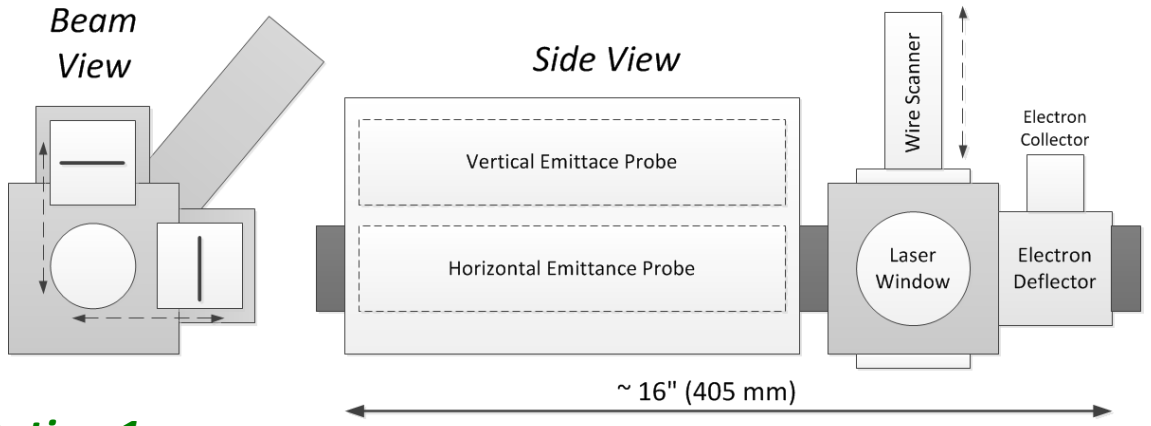
- Unit can be used between cryomodules without electron collector

Option 1:

- Use Fermilab-like emittance probes
  - Familiar system

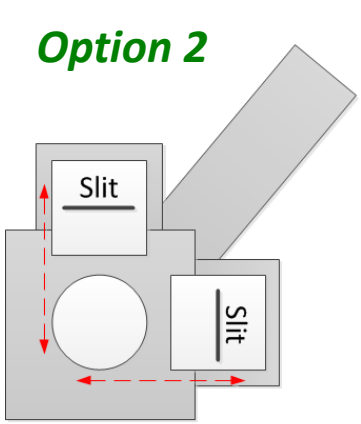
Option 2:

- Use separate slit and multiwire
  - Can dither multiwire
- Allows for laser wire to go between – save space

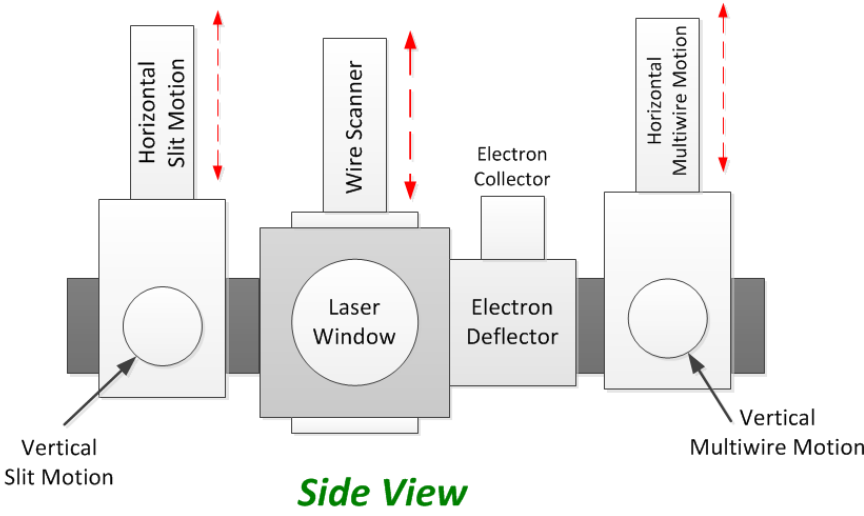


Option 1

Option 2



Beam View

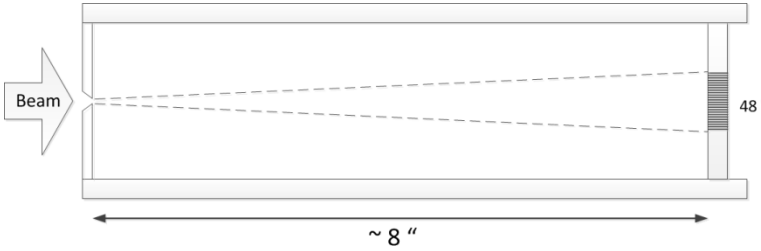


Side View

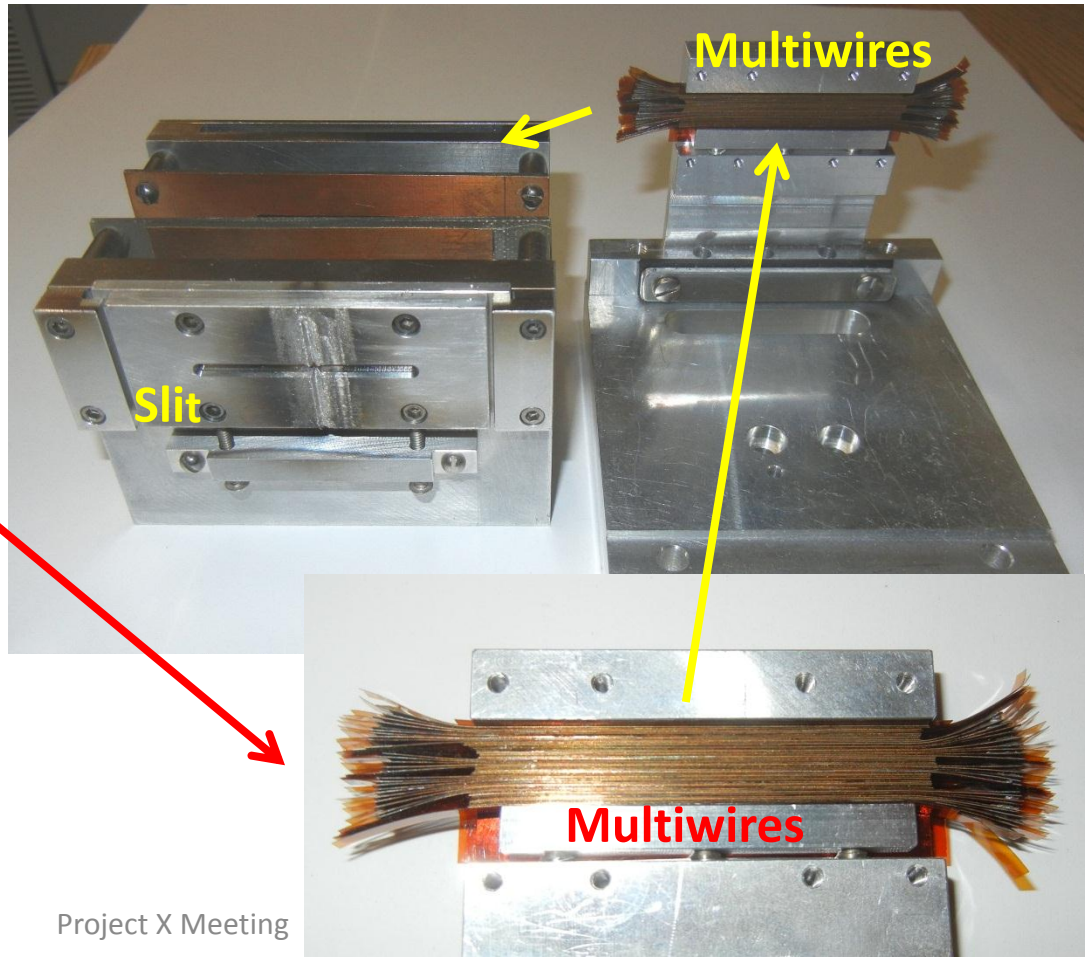
Fermilab Linac Transverse Emittance Monitor

Transverse emittance measurement based on single slit followed by multi-wires.

- Slit/multi-wire assembly is scanned across beam to build 2-D phase space.
- Primary measurement of ~90% beam
  - Not intended for halo
- *Required: angular scan range of ~ +/- 12 mrad with ~0.5 mrad resolution*
  - *48 wires at 4 mil spacing, 8" behind slit*
- Issues/Risks
  - Damage to entrance slits even in pulsed mode
    - Is water cooling needed?
  - Cross-talk between wires
  - Calibration of 48 separate readout channels



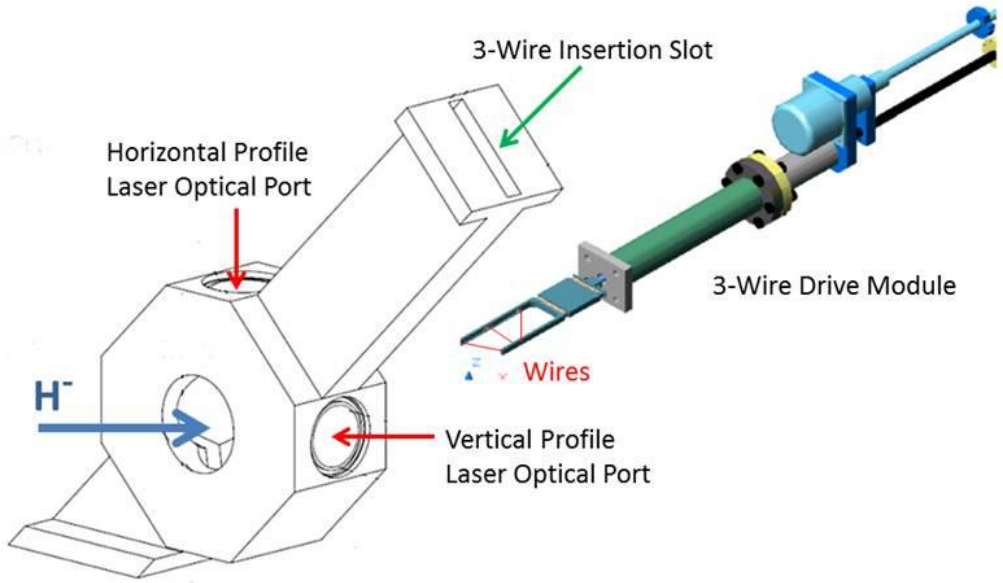
Option 1



Wire Scanner + Laser Wire Unit

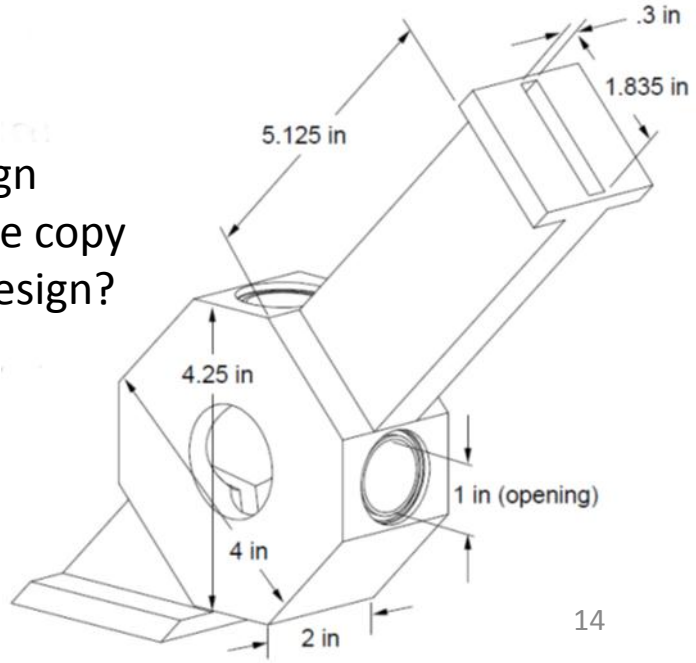
Transverse 3-wire wire scanner plus laser wire module

- 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 can measure transverse and longitudinal profiles
  - *Will different lasers be required for transverse versus longitudinal measurements?*
  - *Will different electron collection detectors be required for transverse versus longitudinal measurements?*
- Is profile measurement across entire aperture required?
  - Can wires or lasers measure profile tails/halo?
  - What size optical windows are required?
  - What is transverse resolution requirement?
    - 10% of one sigma?
  - What is longitudinal resolution requirement?
    - 10% of one sigma?



SNS Design

- Can we copy SNS design?



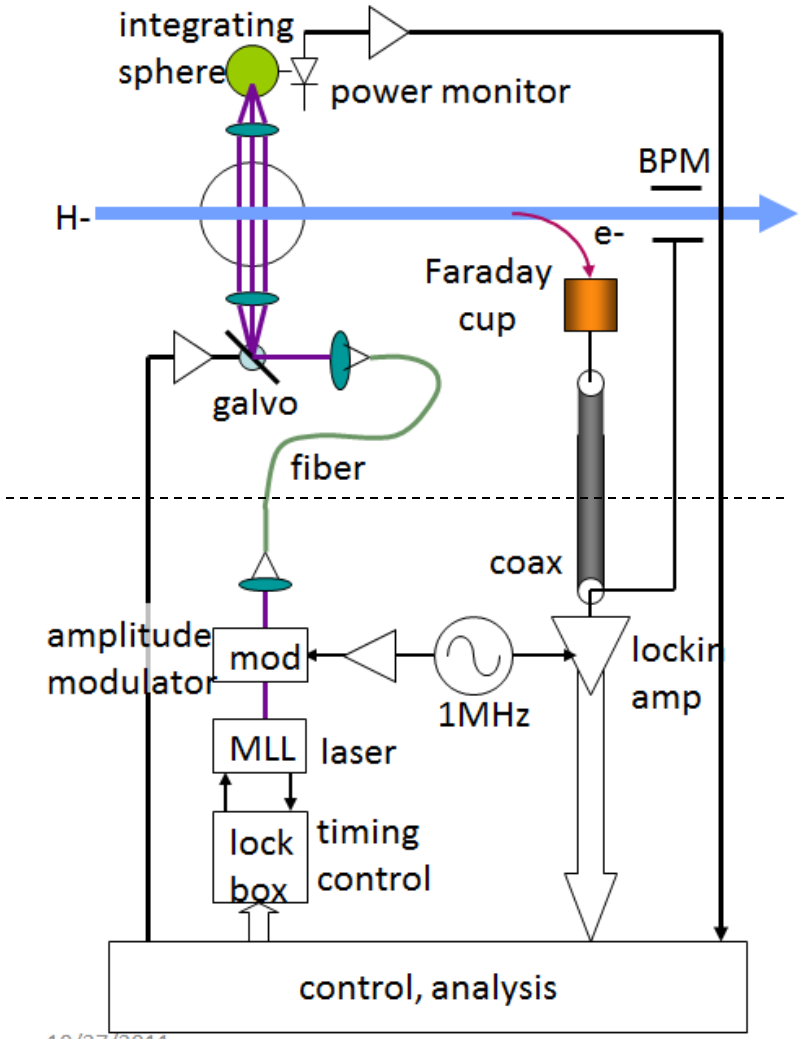
Transverse and Longitudinal Laser Wire

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

- Laser rep-rate is locked to 162.5 MHz RF
- Distribute laser via fibers
- Narrow band lockin amp detects modulated signal
- Upper components are in tunnel, lower are in a laser hutch
- Measure profiles by either:
  - Collection of electrons
  - Use BPM as notched-beam pickup would allow laser monitor to fit between cryomodules

Questions:

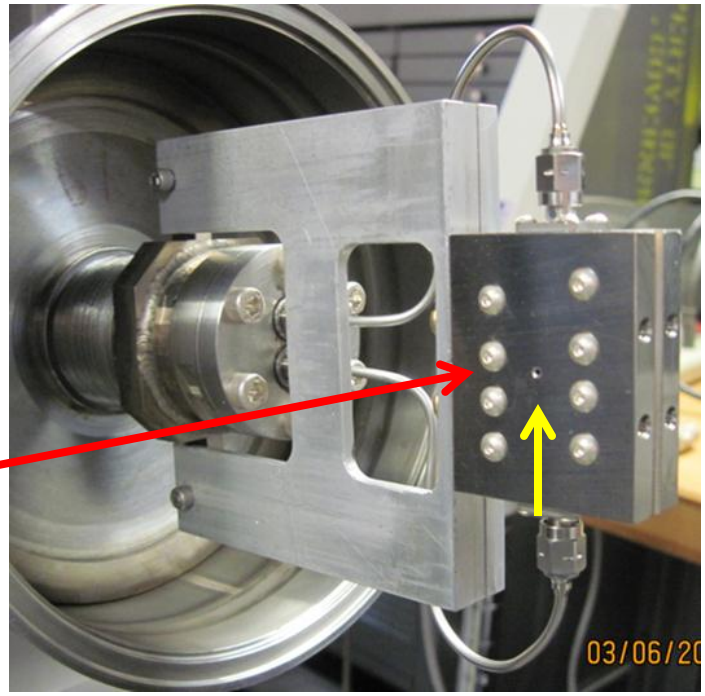
- What is the photodissociation efficiency?
- What are the noise issues?
- What are the nonlinear limits to power in the fiber?
- What signal-to-noise ratios and averaging times are practical?
  - *R&D at HINS would be valuable*

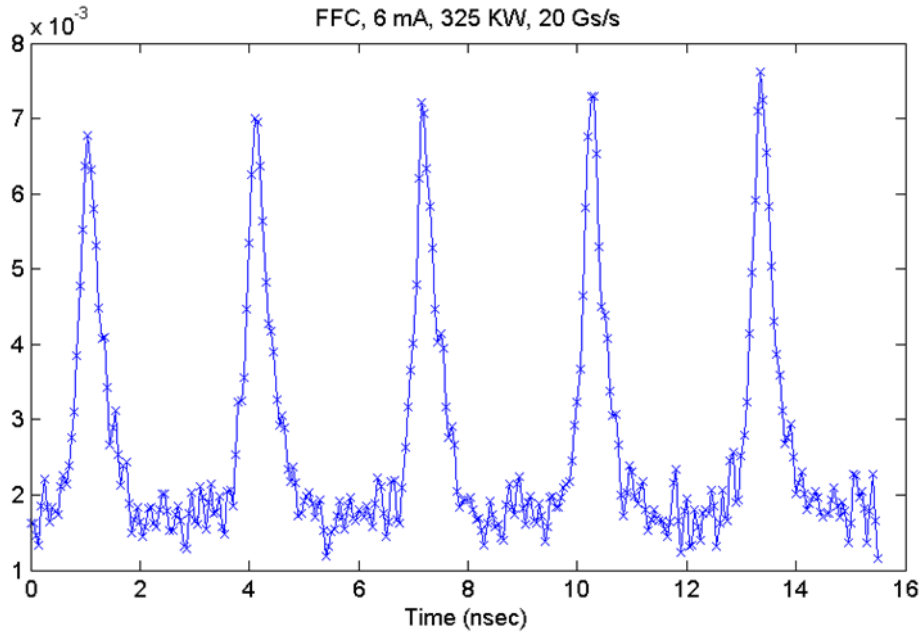


10/27/2011

MEBT Instrumentation

1. Longitudinal Measurements - Water Cooled Fast Faraday Cup
   - Collaboration with SNS (designers and pickup builders)
   - Up to ~ 10 GHz BW
   - Non-cooled tested at HINS
2. Absorber Profiler – OTR Imager
   - Use OTR signal from absorber to measure beam position and shape
   - If MEBT is "radiation hot" then camera choices all limited
   - Folded optics design needed to prevent absorber sputter
     - Need to be able to swap-out mirrors
     - Image quality (focus) needs to be studied – can breadboard this in optics lab

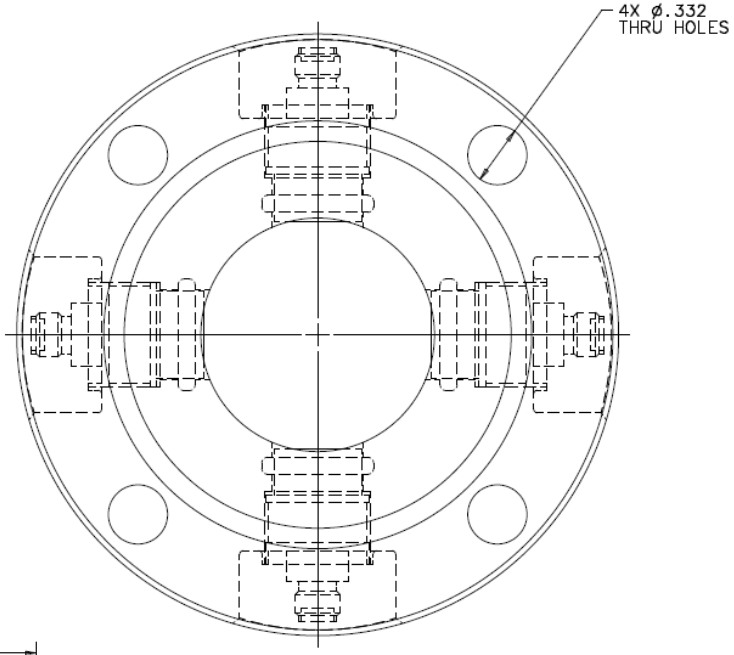


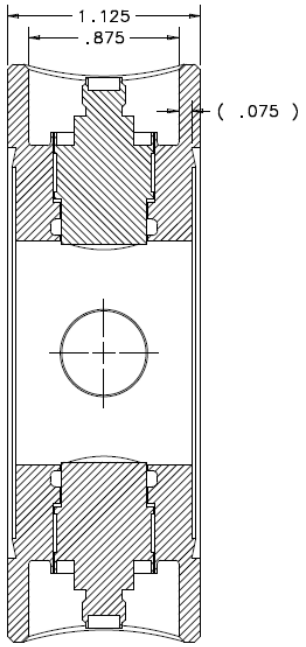


Cryomodule Instruments - BPMs

Transverse Beam Position and Longitudinal Phase - Cold BPMs

- Same performance requirements as warm BPMs
- Same electronics/software as warm BPMs
- What are the main issues for cold BPMs?
  - Mechanical alignment stability
- Manfred working with ANL on cold BPM design



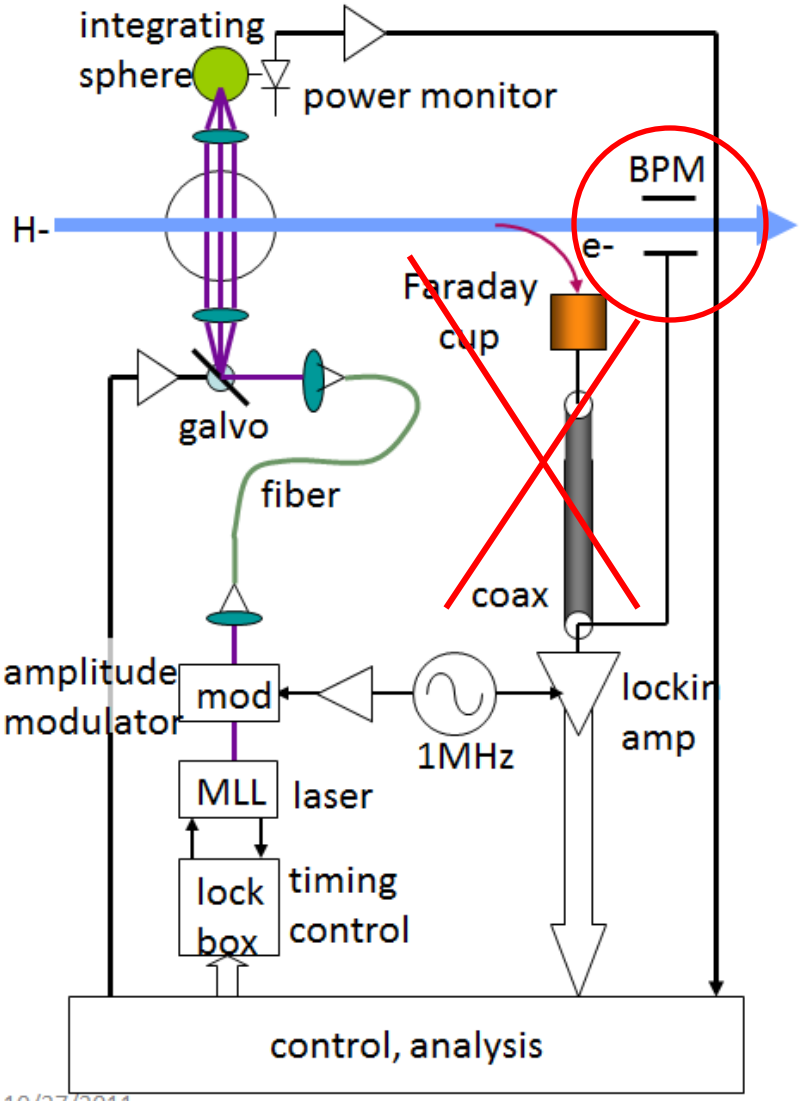


Preliminary Cold BPM Design

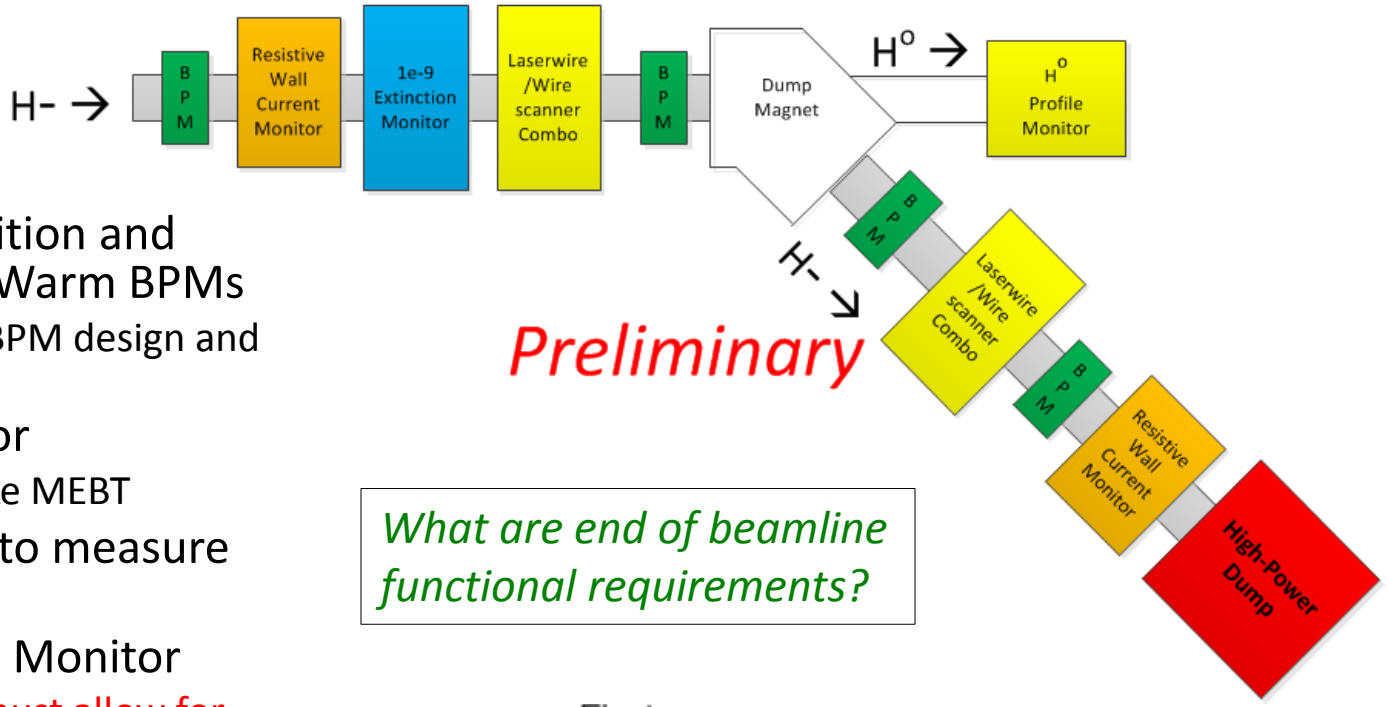
Cryomodule Instruments - Profiles

Transverse Profiles - Laser wire between cryomodules

- Use wire scanner + laser wire unit without wire scanner
- Measure profiles using BPMs in cyromodule
  - Measure change in bunch intensity
  - Electrons swept away by solenoids
  - Need BPMs to have “locking amplifier” capability – no problem
- May also be able to get longitudinal profiles
- Need to understand systematic backgrounds



End of Beamline Instruments



Transverse Beam Position and Longitudinal Phase - Warm BPMs
- Same as MEBT BPM design and functionality

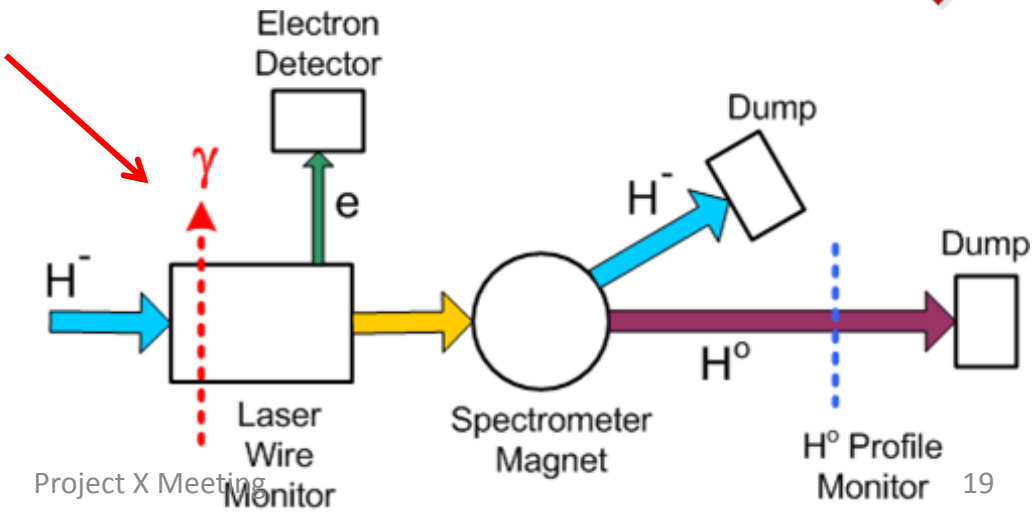
Beam Current Monitor
- Two RWCM – like MEBT

Profiles in dump line to measure energy spread

Laser Wire Emittance Monitor
- Dump magnet must allow for neutral beam to go straight

1e-9 Extinction Monitor
- What will this be? - great student project
- Can it be the same as MEBT 1e-4 extinction monitor?
  - needs study

What are end of beamline functional requirements?



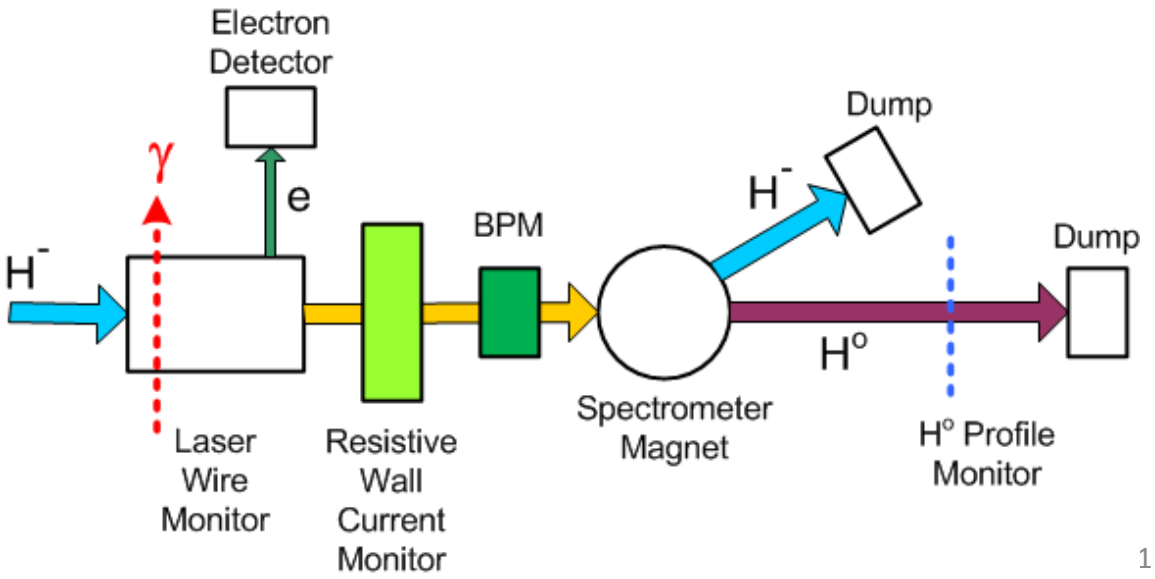
Instrumentation Department Bodies

1. LEBT DCCT – Aisha Ibrahim + Dallas Heikkinen
2. LEBT Emittance Monitors - ? (vic)
3. MEBT Transverse Emittance Slit/Wire Monitor – Gianni Tassotto + Dan Schoo
4. MEBT/Endline Transverse Wire scanner + Transverse/Longitudinal Laser Wire – Vic Scarpine + Andrea Saewert+ SNS
5. MEBT Current/Extinction RWCM – Randy Thurman-Keup + Brian Fellenz + Manfred Wendt
6. MEBT Water Cooled Fast Faraday Cup – SNS + Manfred Wendt
7. MEBT OTR Imager – Vic Scarpine + Randy Thurman-Keup
8. MEBT/Endline Warm BPMs – Nathan Eddy + Manfred Wendt + Alexey Semenov
9. Cryomodule Cold BPMs – Nathan Eddy + Manfred Wendt + Alexei Semenov
10. Cryomodule Laser Wire – Vic Scarpine + Andrea Saewert
11. Endline Current Monitor - Randy Thurman-Keup + Brian Fellenz + Manfred Wendt
12. Endline 1e-9 Extinction Monitor - ?
13. Endline Laser Transverse Emittance Monitor – Vic Scarpine + Andrea Saewert

Issues

1. Is entire PXIE cave hot? Can we make source/RFQ/MEBT area low radiation area for electronics?
2. What is PXIE commissioning scenario?
   - What hardware needed beyond "Operational"?
3. What can HINS help with now (after H- source install)?
   - BPM development especially for phase measurements and synchronization to laser
   - Laser wire development
     - Transverse & longitudinal profile + transverse emittance
   - RWCM extinction measurements
     - Use laser to knock out bunches

Proposed test setup for HINS



Conclusion

- Operational diagnostics have been identified
  - Many designs slight modifications of existing systems
- PXIE commissioning plan would help identify other needed diagnostics
- Instrumentation device leaders have been identified for most pieces
  - Need to increase engineering efforts