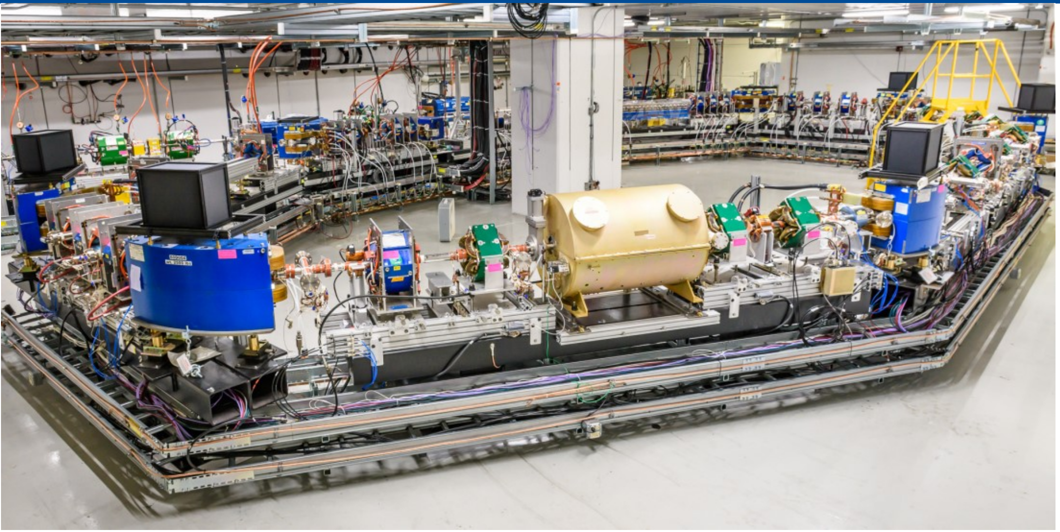


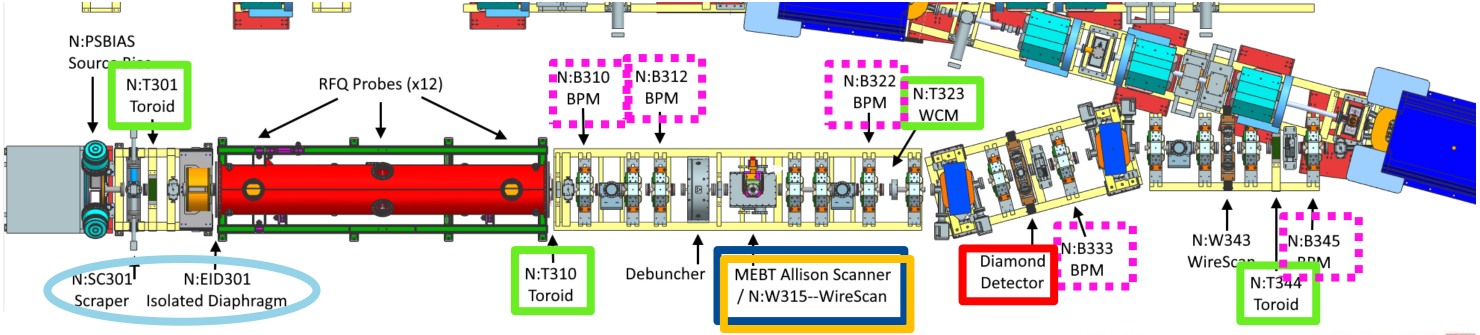
Proton Beam Diagnostics

Randy Thurman-Keup, Nathan Eddy, Aisha Ibrahim, Henryk Piekarz, Vic Scarpine, Arden Warner

IOTA/FAST Collaboration Meeting 2024

March 13, 2024

Proton Beam Diagnostics



Beam Position Monitors

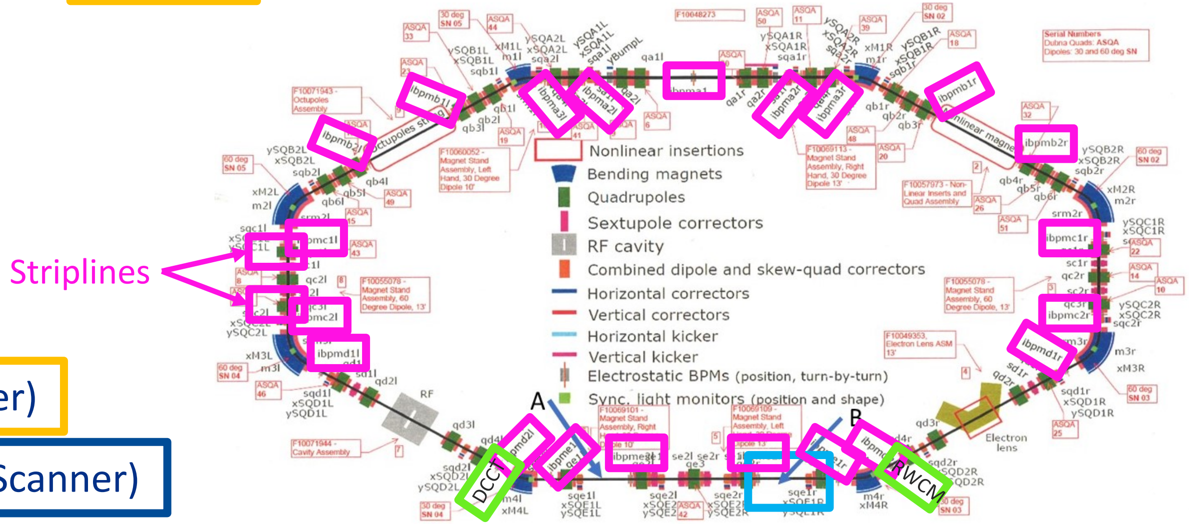
Beam Current Monitors

Ionization Profile Monitor

Diamond Halo Monitor

Wire Profile Monitor (Wire Scanner)

Emittance Measurement (Allison Scanner)



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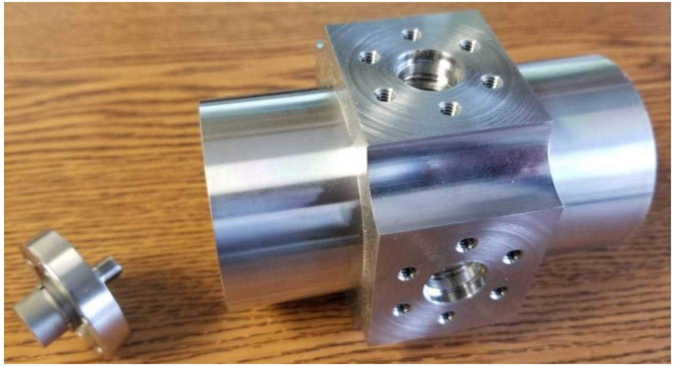
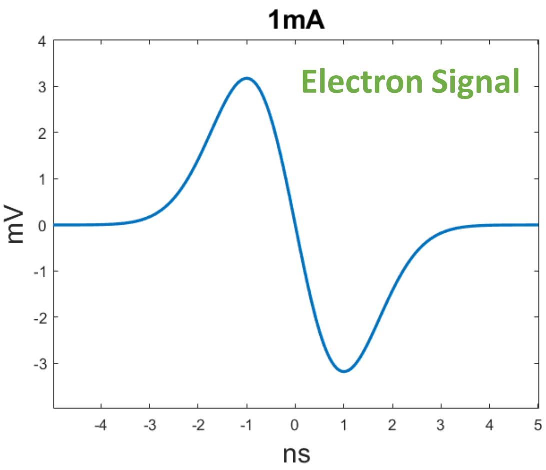
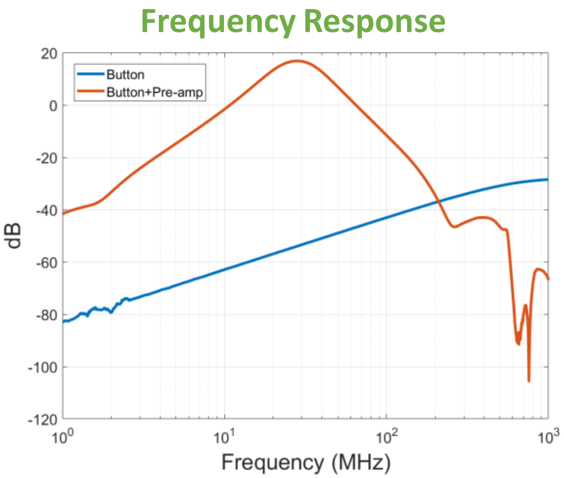
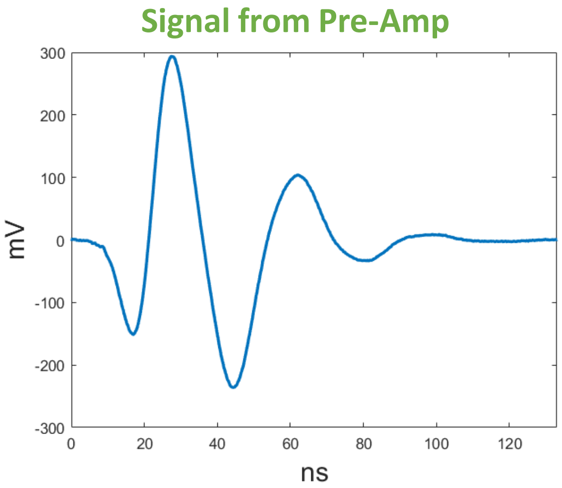
IOTA Beam Position Monitors

- BPM pickups in IOTA are 11mm button electrodes
  - To first order an 11mm stripline
  - Great for very short (few *ps)* bunches in FAST Linac
  - Stored bunch in IOTA ~700 *ps*
- Installed high-Z preamps & 30MHz band-pass filter









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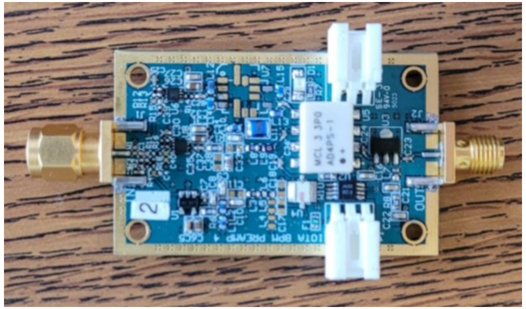
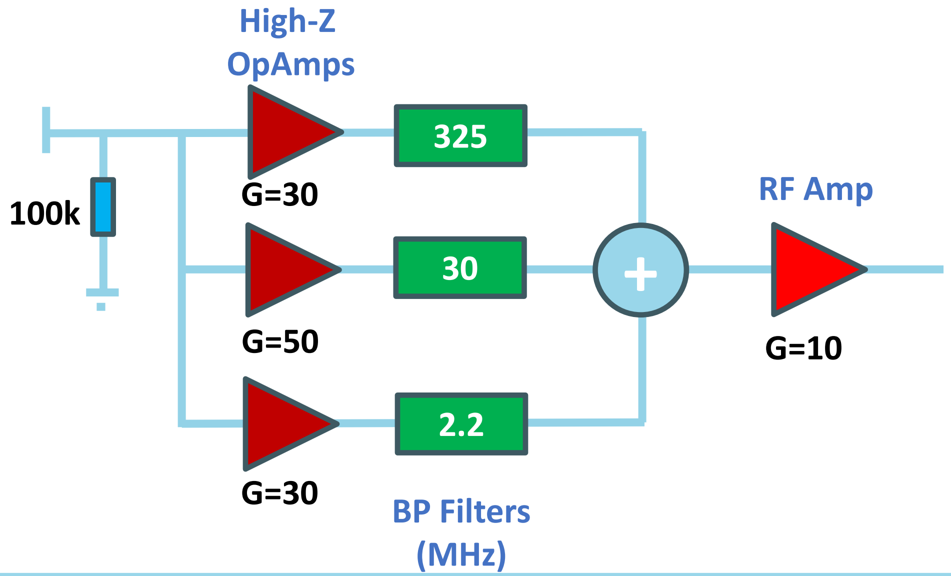
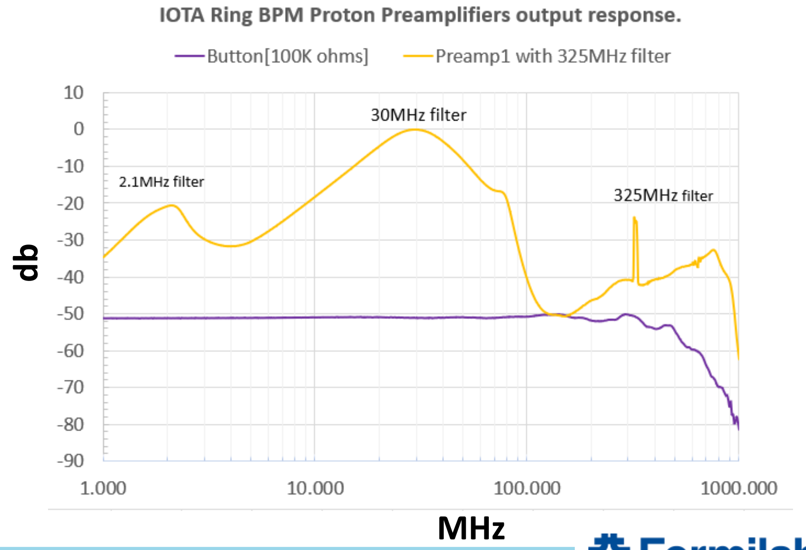
IOTA BPMs for Protons

- Proton injections will come in bunched at 325 Mhz and diffuse
- Can turn on 30 MHz RF for ~50% modulation of proton beam
- Eventually there will be 2.19 MHz bunching in IOTA (not to start)
- New Pre-Amplifier design to see all 3 frequencies



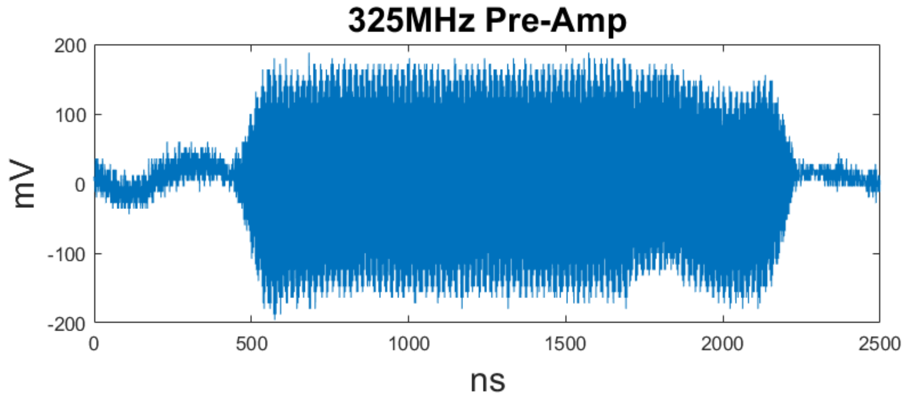


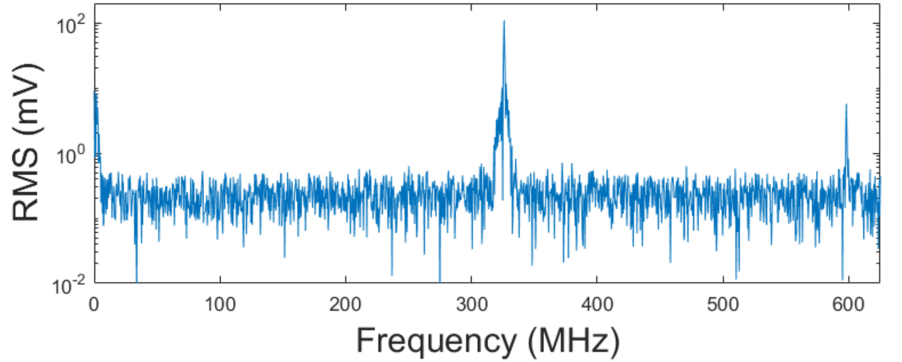


Proton Signal Estimates (Very Preliminary!)

- Consider 8mA injected in 1.7 μs pulse
- Use narrowband Digital Downconverter

- Estimated TBT resolution for button BPMs with new pre-amps
  - Injection bunched @ 325 Mhz - 100 μm
  - Stored beam 50% @ 30 MHz – 500 μm
  - Stored beam bunched @ 2.19 MHz – 200 μm
- Estimated TBT resolution for striplines
  - Injection bunched @ 325 MHz – 5 μm
  - Stored beam 50% @ 30 MHz – 20 μm





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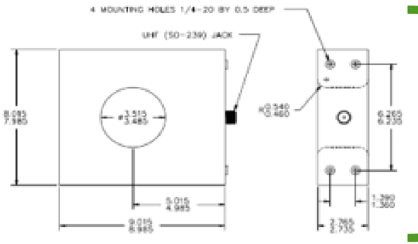
BPM Software Upgrades

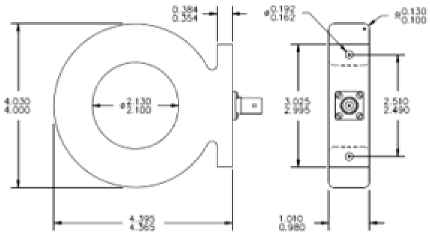
- The front-end server is now a 10 core / 20 thread linux server
- IOTA was one of the first implementations of the server front-end
- Considerable work has been done for Muon Ring & Booster BPM upgrades
- These updates will be implemented into IOTA
  - Will facilitate other quality of life improvements
  - Will support ACNET or EPICs
- The DAQ network for digitizer readout will be upgraded with a 100Gb/s switch
- ACORN is purchasing the switch and we will use the IOTA BPM system as a high bandwidth source (raw data) for controls testing (Data Lake)

Current Monitoring in IOTA Injector Proton Line

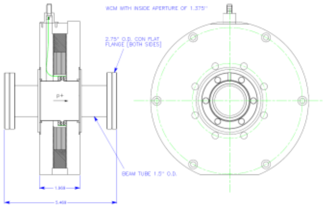
Pearson 3100
1V/A Sensitivity
BW: 40Hz – 7MHz



Pearson 2100
1V/A Sensitivity
BW: 125Hz – 20MHz



1.375" ID RWCM
BW: 10kHz – 4GHz



IPI LEBT Toroid (1)

- Measure the integrated intensity of the beam pulse at output of the source

IPI MEBT Toroid (2)

- Measure intensity near the end of the proton beamline, just ahead of the D604 bend magnet
- Measure the integrated intensity of the beam pulse, immediately on the output of the RFQ

IPI MEBT RWCM(1)

- Provide waveform information of beam pulse, upstream of the second MEBT Toroid

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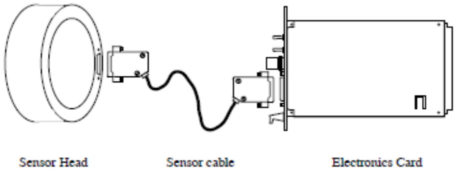
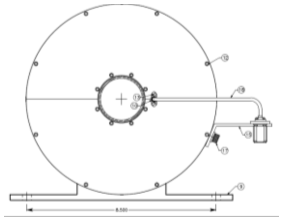
Current Monitoring in IOTA Ring

MPCT-S-113
10 μA rms
Resolution
BW: DC-4.2kHz



2"ID RWCM
BW: 5kHz – 5GHz



IOTA DCCT (1)

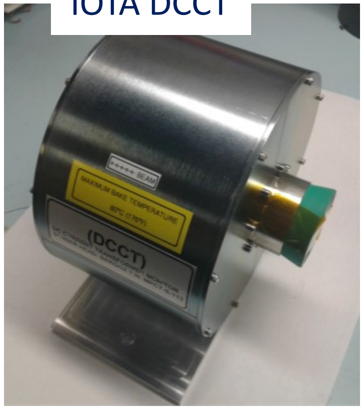
- Measure average beam current, once injected and circulating in IOTA ring

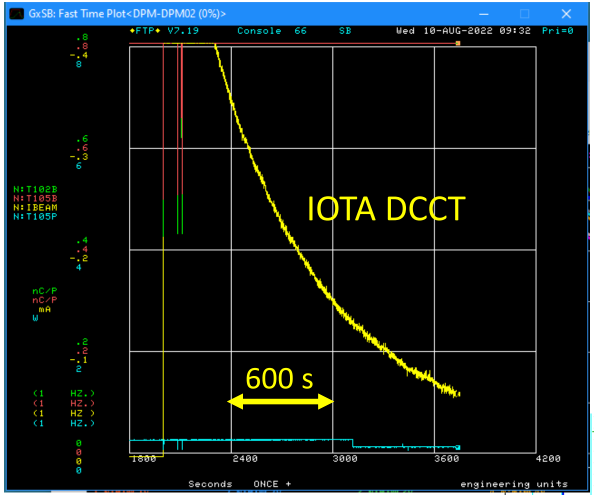
IOTA RWCM (1)

- Provide waveform information of circulating beam within IOTA

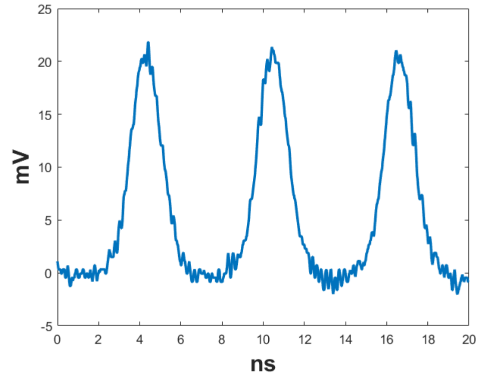
Current Monitoring

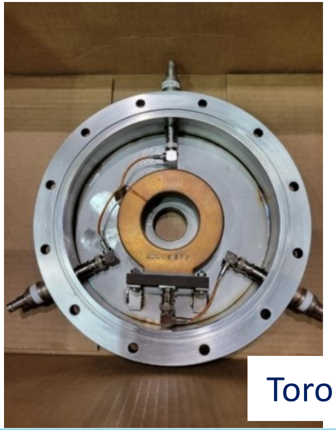
IOTA DCCT



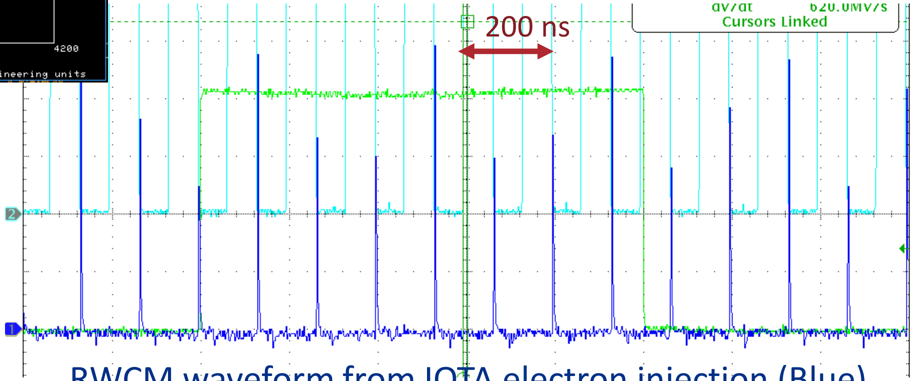


RWCM waveform from PIP2IT MEBT





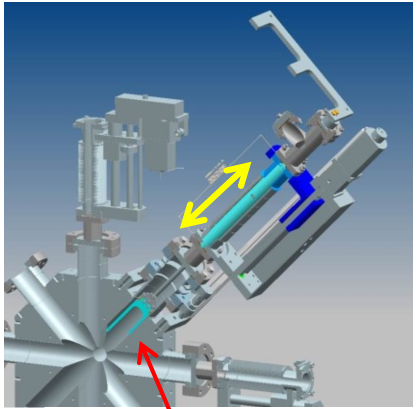
Toroid after RFQ

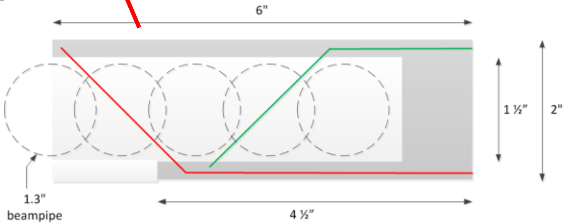


RWCM waveform from IOTA electron injection (Blue)

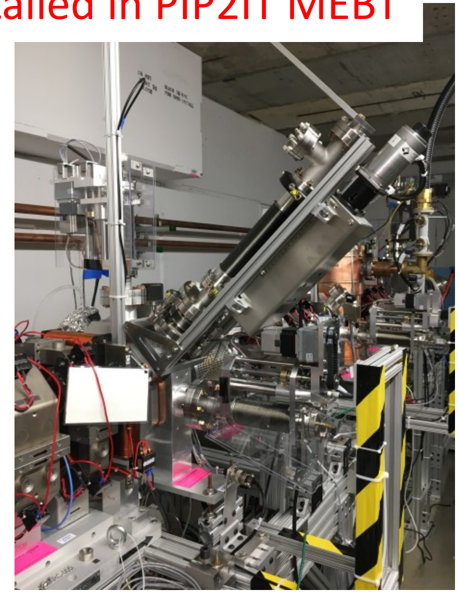
Transverse Profile Monitors

- Two-wire scanner designed, built and tested at PIP2IT
- Wire scanner installed in PIP2IT MEBT scraper housing. Now on loan to FAST/IOTA
- *Wire scanner has limited 1 ¼” beam aperture*



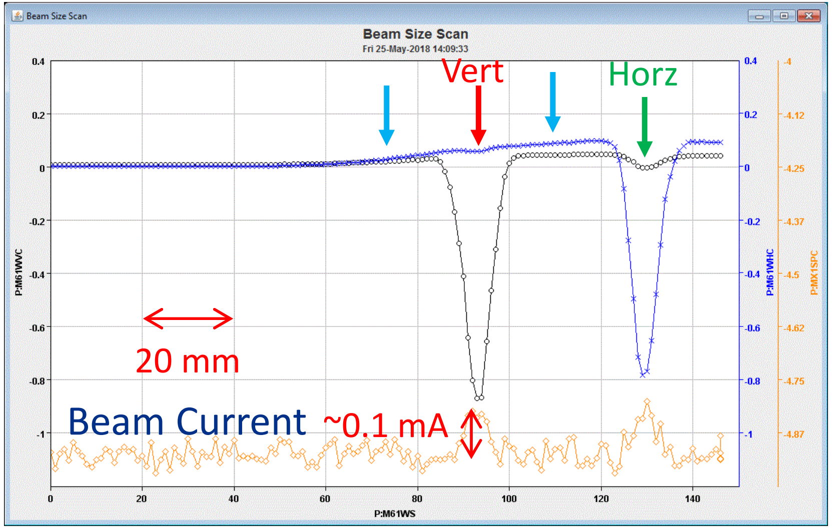


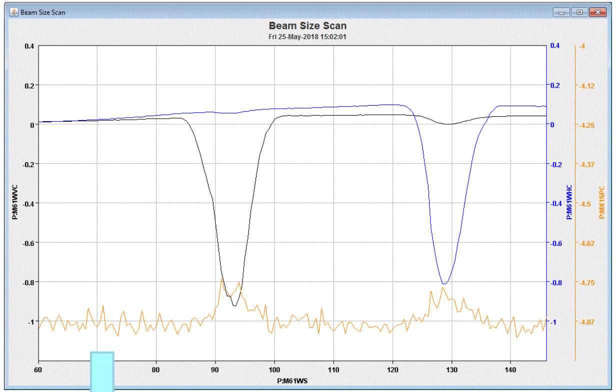
Installed in PIP2IT MEBT



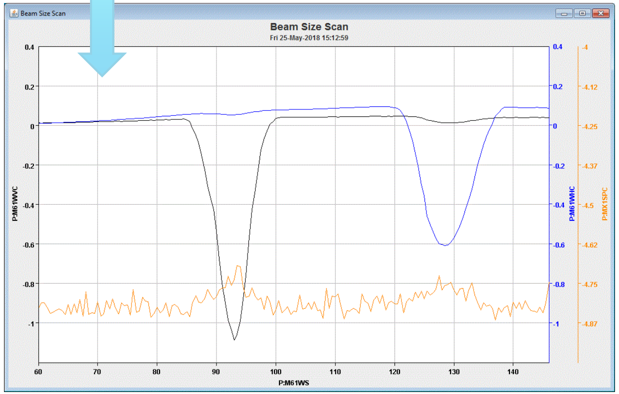
Wire Scanner Measurements from PIP2IT

- Unbiased 100 mm Tungsten wires
- Horz and Vert profiles of 2.1 MeV H-
  - Few percent loss of beam
  - Cross-talk between wires
- Background electrons in MEBT cause baseline shift
- Signal flips polarity – losing electrons



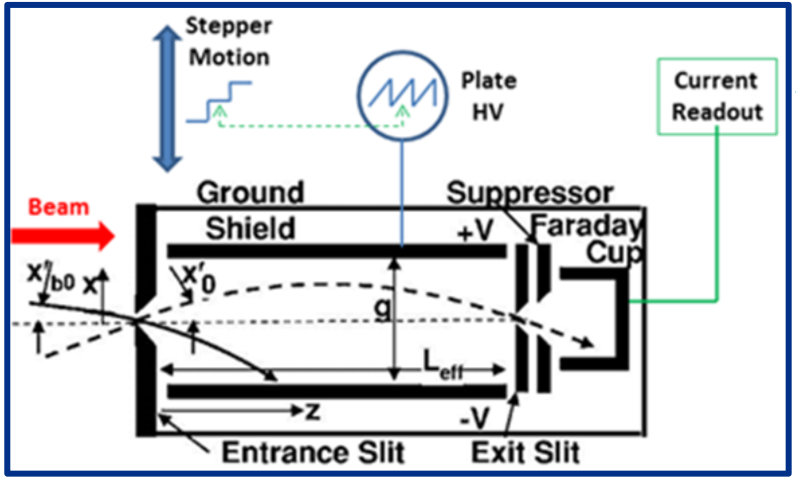


Change quadrupole focusing

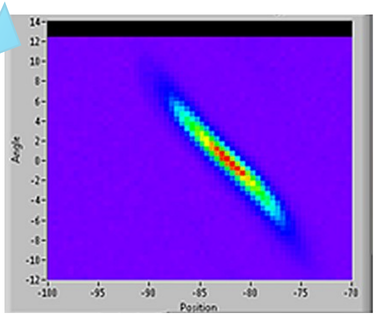


Transverse Emittance Monitors

- PIP-II WFE LEBT (30keV) and MEBT (2.1MeV) H-
  - Allison-style emittance scanners – built in collaboration with SNS
  - PC-based stand-alone data acquisition and controls
    - Labview-based DAQ software
  - Both were operational at PIP2IT. Now on loan to IOTA proton line.
  - Phase-space measurements taken in a few minutes



DAQ, HV, and motion control, and analysis



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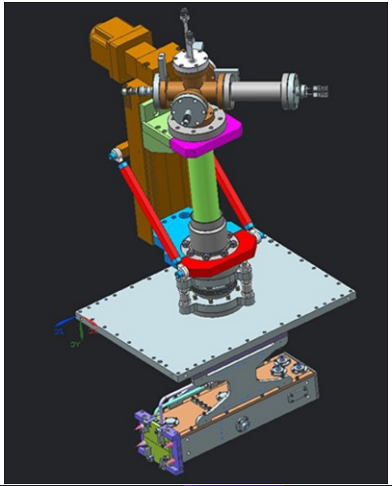
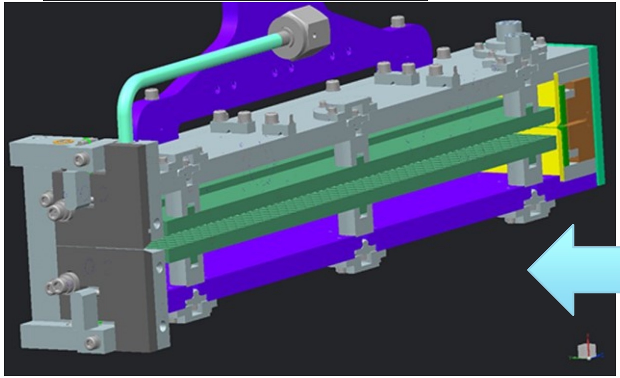
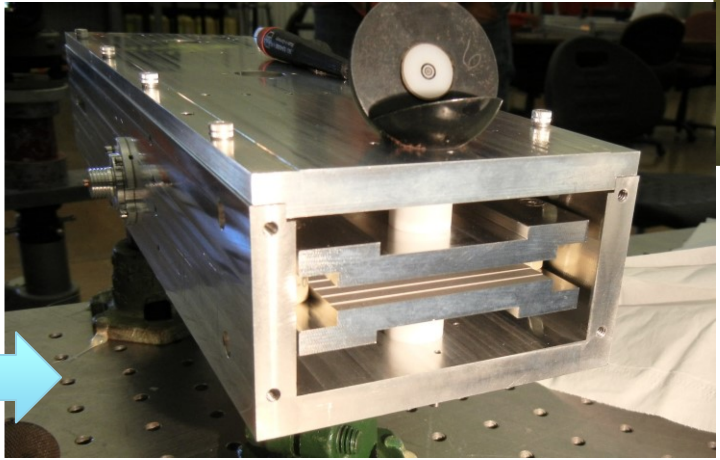
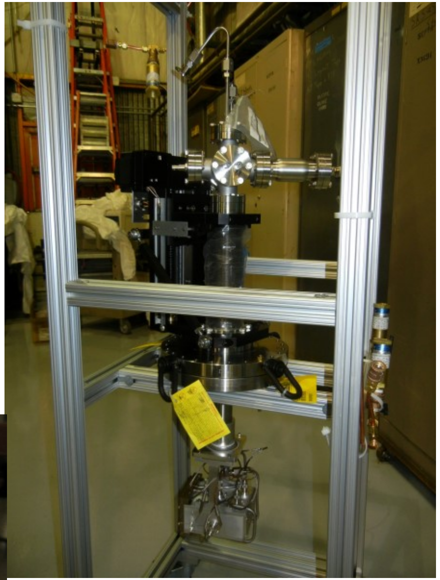
Allison Scanner

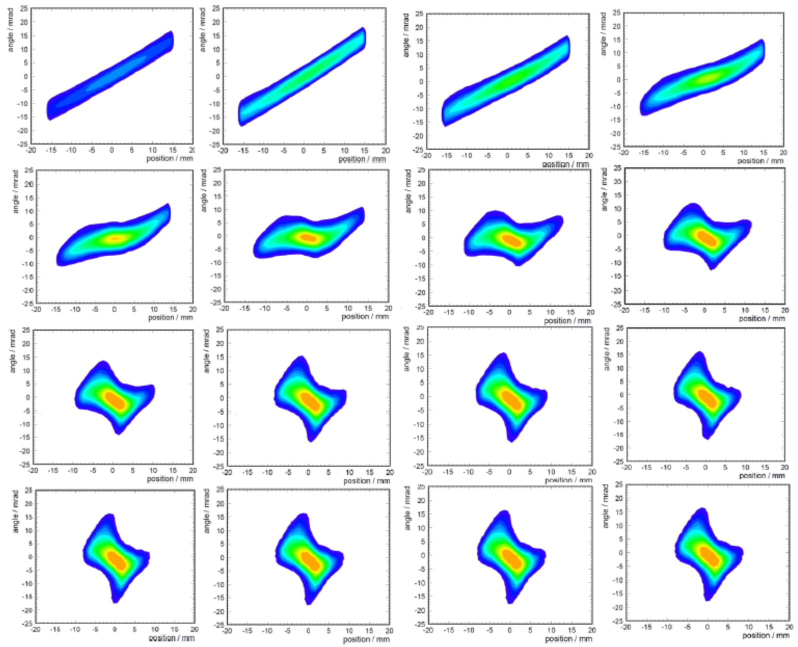




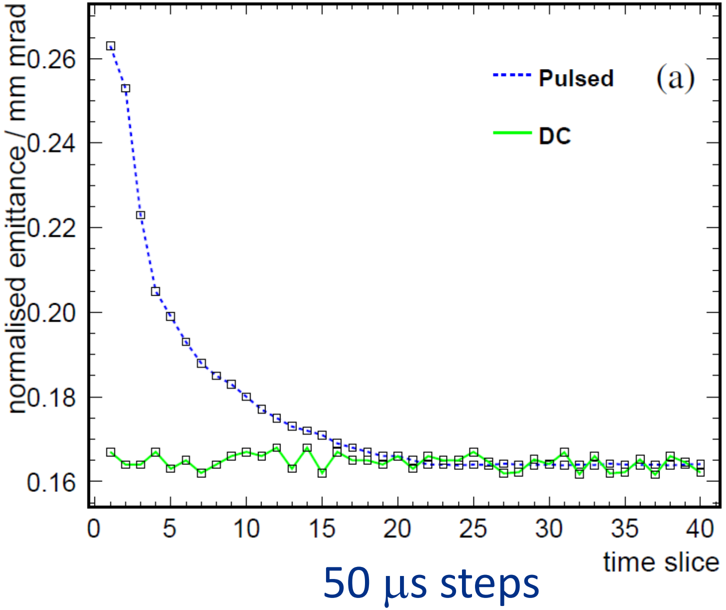




PIP2IT LEBT Phase Space Evolution for H- Beam



Evolution of phase space along a 2 ms, 5 mA H- beam pulse for pulsed ion source beam.



Emittance evolution for ion source pulsed versus DC beam. Pulsed beam shows neutralization of H- beam.

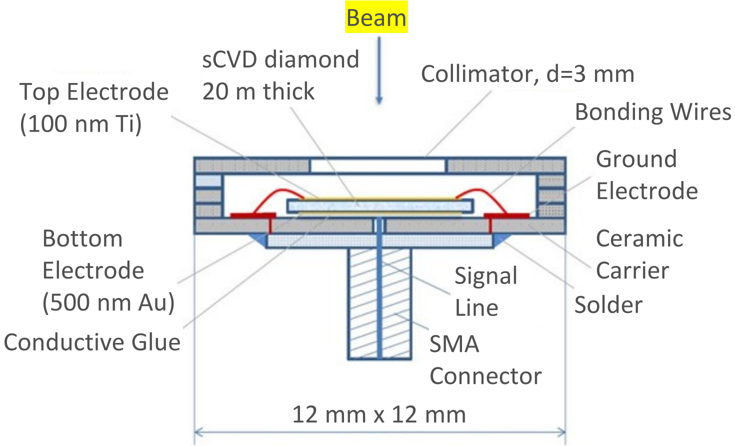
Fermilab

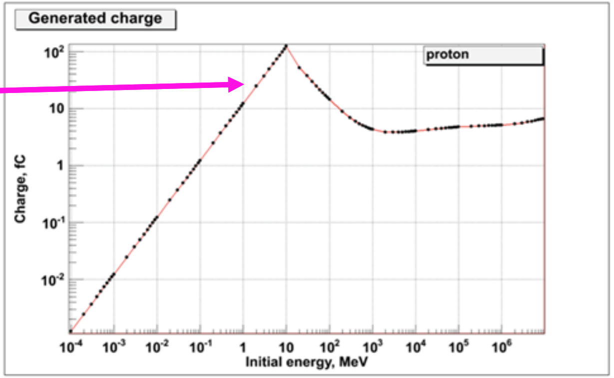
Diamond Detectors

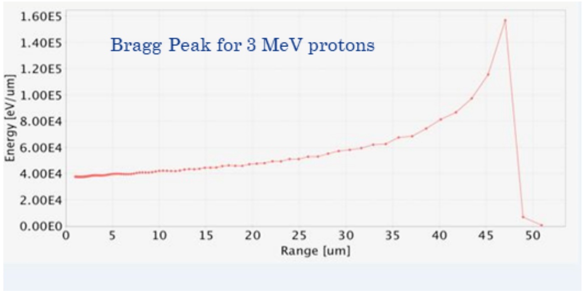
- Chemical Vapor Deposition (CVD) diamonds are readily available commercially and are radiation hard semi-conductor devices
- Available as Poly- crystalline (pCVD) and single crystalline structures (sCVD).
- Possible to design detectors with precise shapes and uniform properties suitable for loss monitor detection in accelerators.
- Advanced electronics allows for the pico-second structure of the diamond response to be fully exploited
- Wide range applications in accelerators
- Current interest
  - beam halo development
  - single particle proton detection (extinction measurements)
  - low energy proton loss monitoring (< 10 MeV).

Diamond Detectors – Low Energy Loss Monitor Test at PIP2IT

- 20-micron Single crystal diamond structure tested at 2.1 MeV
- Results:
  - A clear loss signal well correlated with beam intensity and position was detected
  - Charge pileup avoided in this setup (thin detector is below the Bragg Peak) Penetration depth for 2.1 Mev protons is ~ 27 µm
  - Charge deposition ~ 35.3 fC



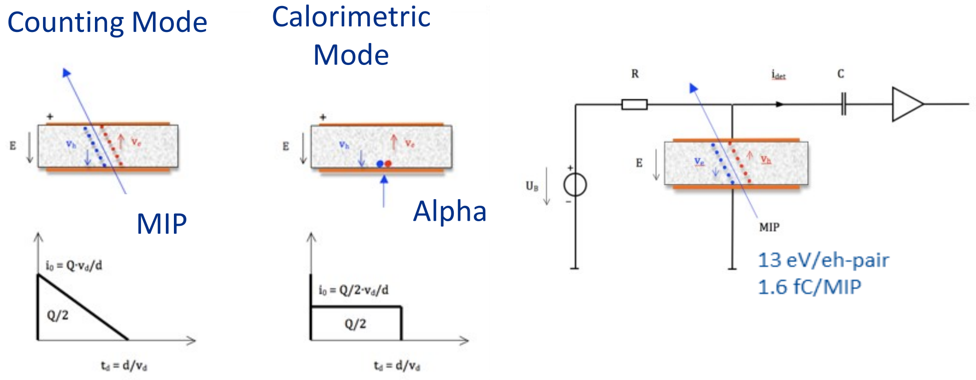


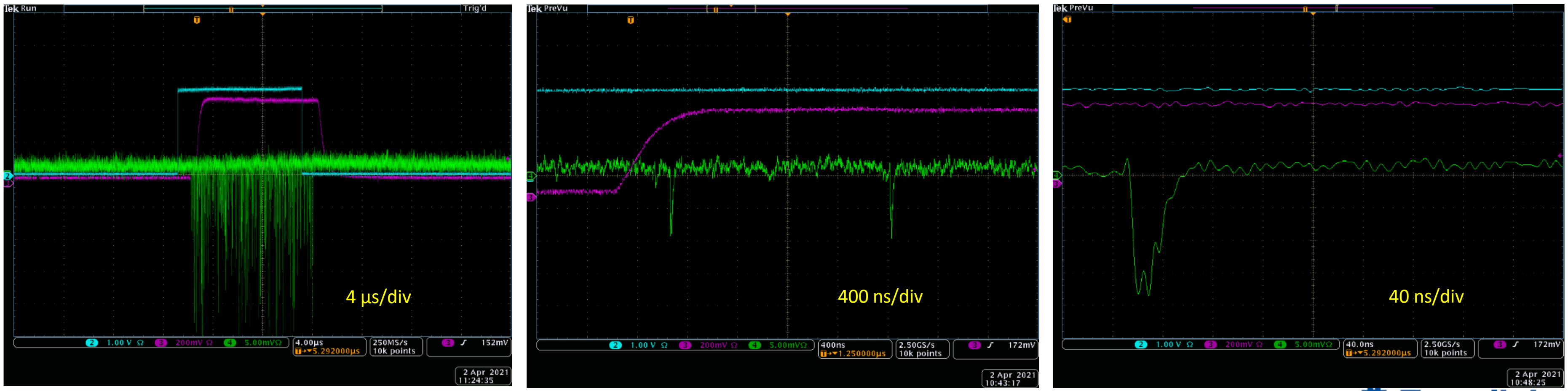


Diamond designed to be 20 microns to avoid charge pile-up

Diamond Detectors – Low Energy Loss Monitor Test at PIP2IT

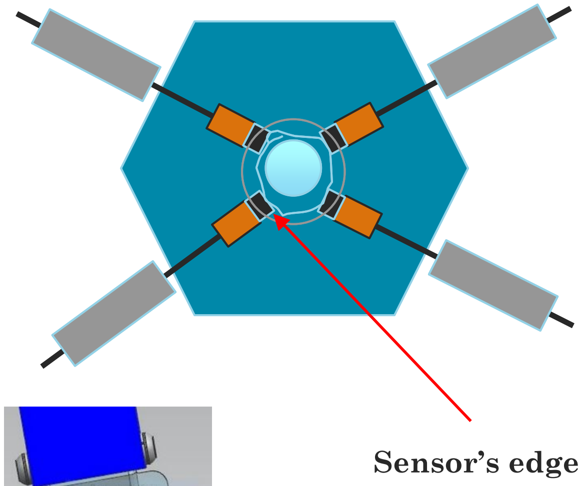
- Signal processing MPS application
  - A counting or integrator algorithm will be used
  - Fast digitization and FPGA monitoring of low energy H- losses (< 10 MeV)



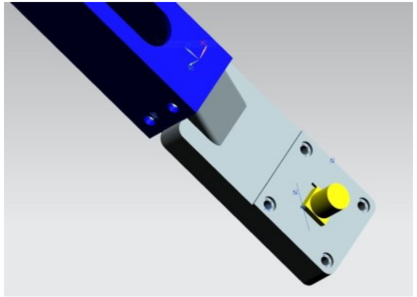


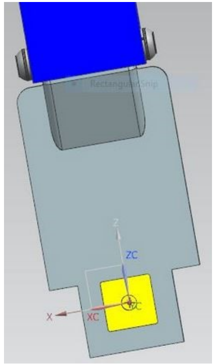
Diamond Detectors – Potential applications

- SCVD loss/halo/current monitor with theses specifications
  - 20-micron thickness to avoid charge pile-up
  - Full RF shielding
  - Customizable so edge of crystal can be close to beam
  - Open design detector
  - Sensor sized to measure current
  - 2 GHz, 40 dB broadband Amplifier
  - 50 Ohm impedance – can use any length of cable



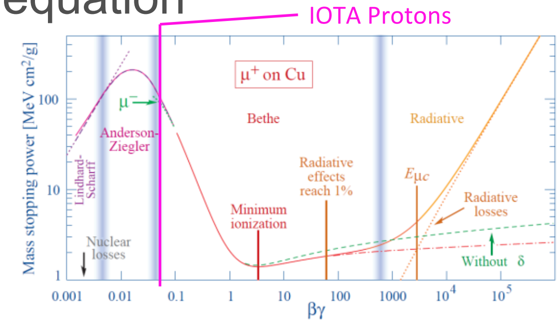
Fully exposed edge mounted designs



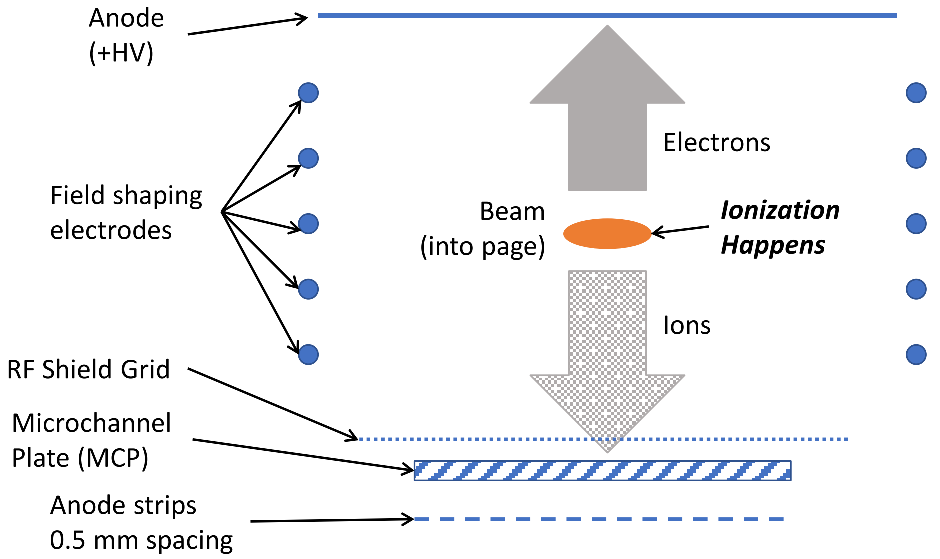


Ionization Profile Monitors (IPM)

- Beam interacts with residual gas producing ion/electron pairs
- Ionization rate follows Bethe energy loss equation



- Ions collected by via electric field across beamline
- Amplified by microchannel plate (MCP)
- Signal extracted via conductive strips



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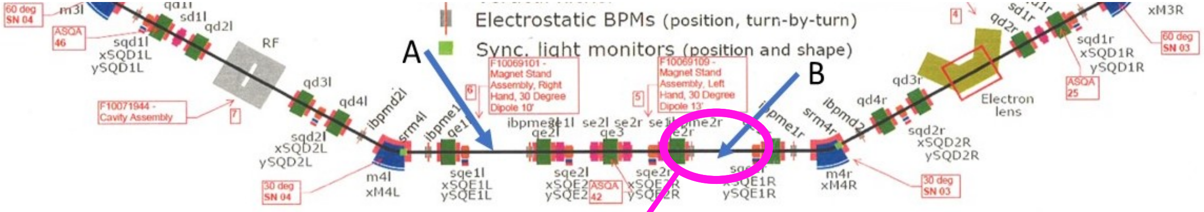
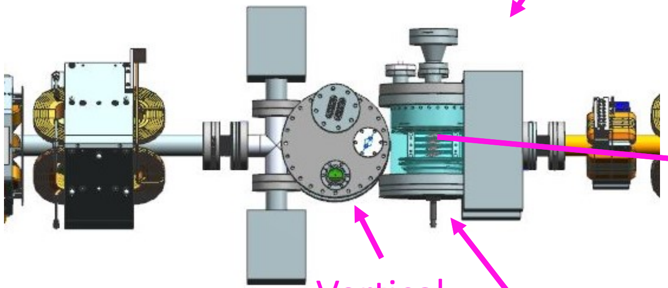
IPM Planned(?) Location

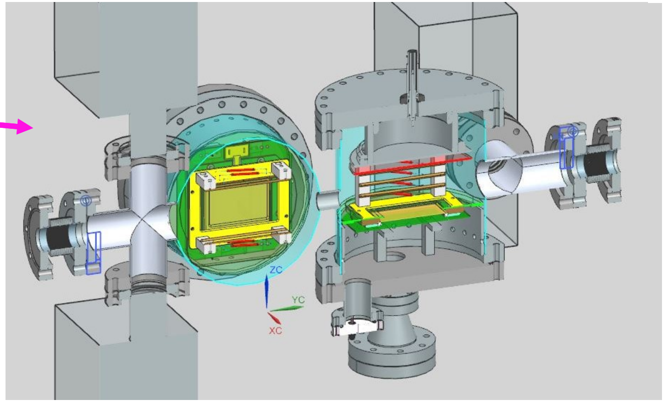


Dipole Corrector Magnets



Vertical

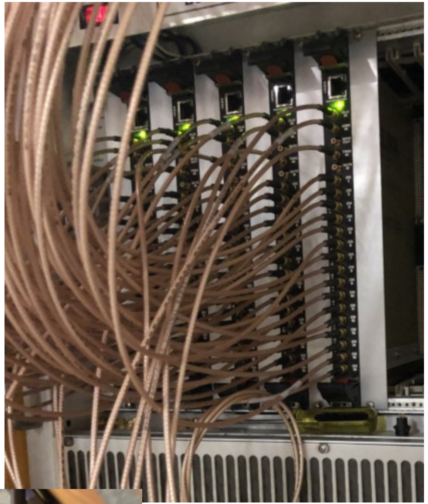
Horizontal



IPM Design

- Design based on Booster design
  - Use same data acquisition electronics
  - Firmware modifications
- Gas injection to overcome ultra-high vacuum
- 30 mm vacuum apertures to reduce gas leakage to ring
  - Might be limiting aperture for beam
- Electric field of 16 kV for collecting ions
- Anode readout strips with 0.5 mm spacing (transverse profile resolution)
- Preamps have 1 MHz bandwidth (should handle turn by turn)

Digitizers

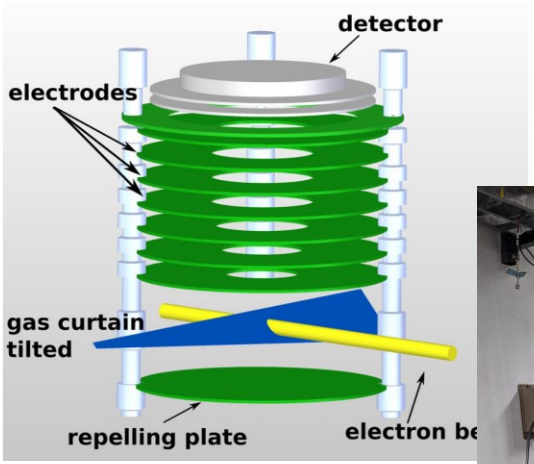


Preamps

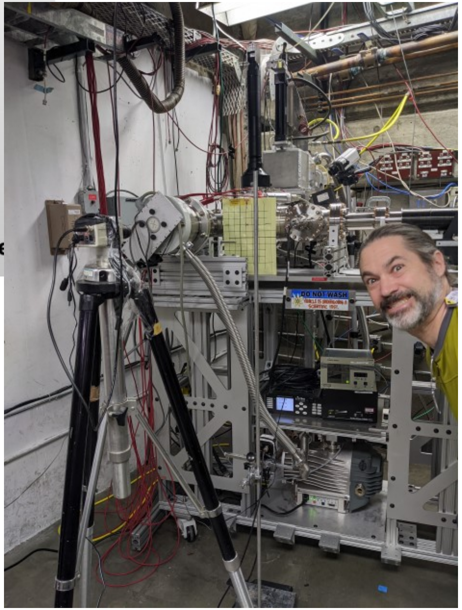
Fermilab

Gas(or Metal) Sheet IPM

Higher molecular density without spoiling main vacuum



S. Szustkowski
M. Backfish
D. Crawford
E. Prebys
J. Santucci



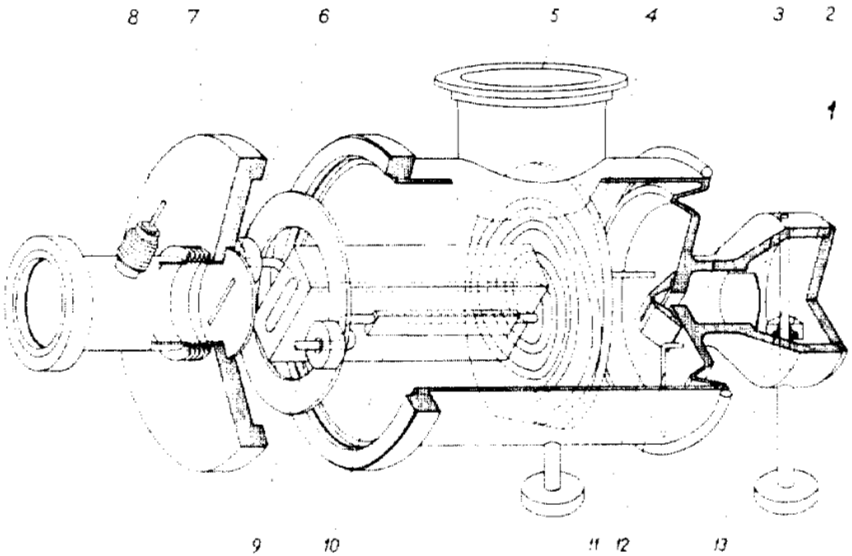


Fig. 2 : Exploded view of the sodium curtain generators

circa 1975, ISR

Questions?