Fermilab

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Status of the warm front end of PIP-II Injector Test

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PIP-II technical meeting

08 November 2016

Reports related to “warm” PI-Test since June 21, 2016

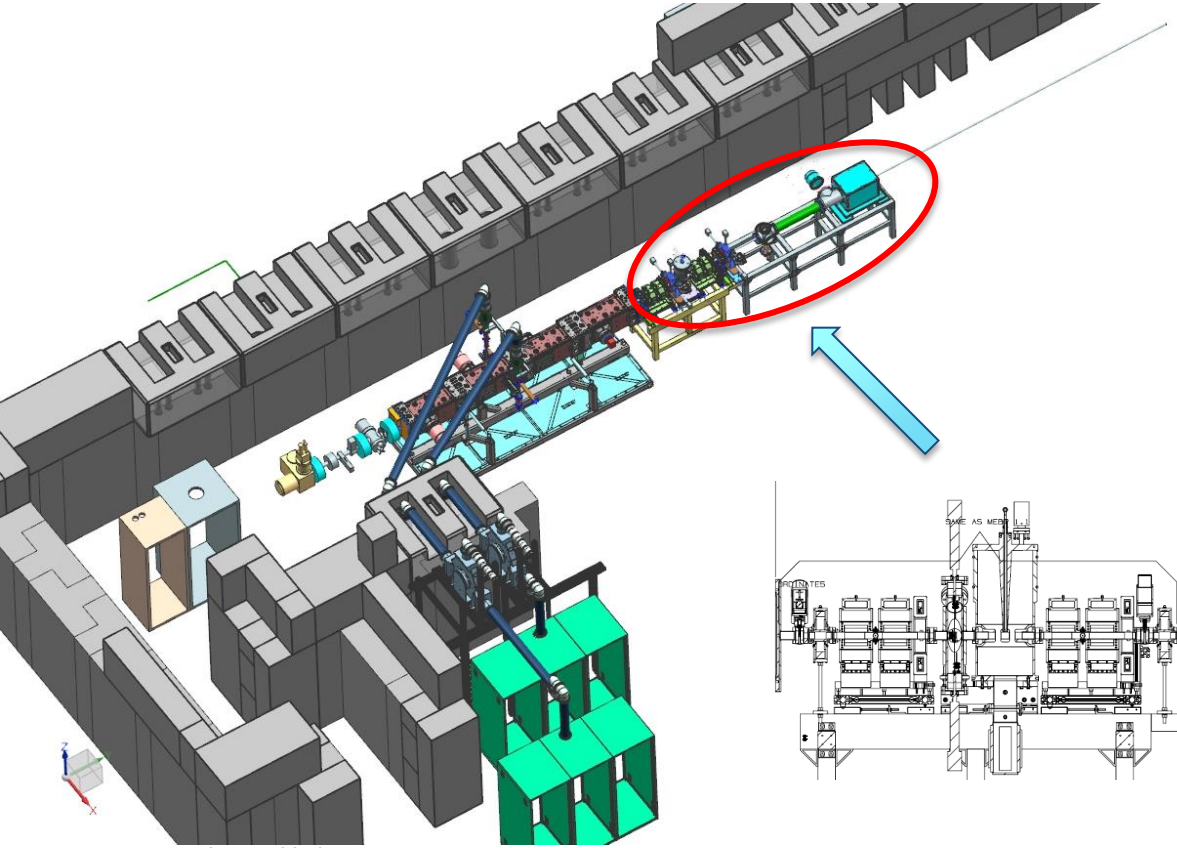
- See also at http://pxie.fnal.gov/PIPIImeetings/index.htm
  - July 5/2016: PXIE low level RF update, B. Chase, J. Edelen; Update on RFQ, J. Steimel
  - July 12/2016: Software for optics measurements, V. L. S. Sista; Optics measurements results, A. Saini
  - July 26/2016 -LEBT operation for RFQ, L. Prost
  - August 30/2016 -Resonance control system, A. Edelen
  - September 6/2016: Radiation simulations of MEBT dump, A. Leveling; Update on MEBT energy measurements, V.L.S. Sista
  - September 13/2016 -MEBT bunching cavity, J. Steimel
  - September 27/2016 - Laser wire development, V. Scarpine
  - October 18/2016 - Update on the RFQ coupler, S. Kazakov

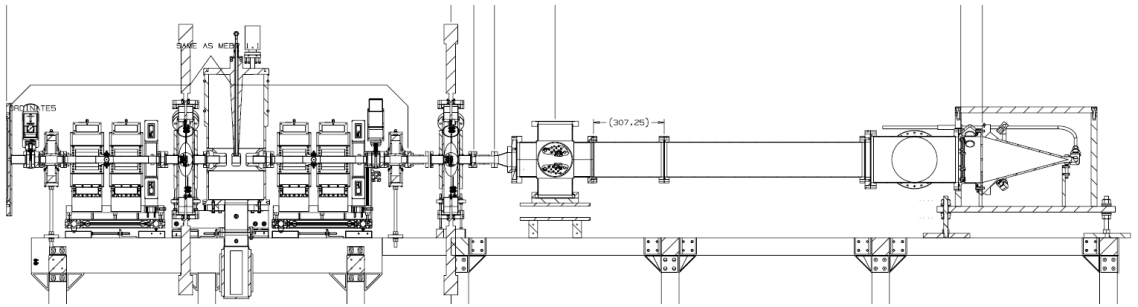
Outline

- Beam line and operational status
- Measurements
- Readiness of future components
- Plans

Present beamline configuration

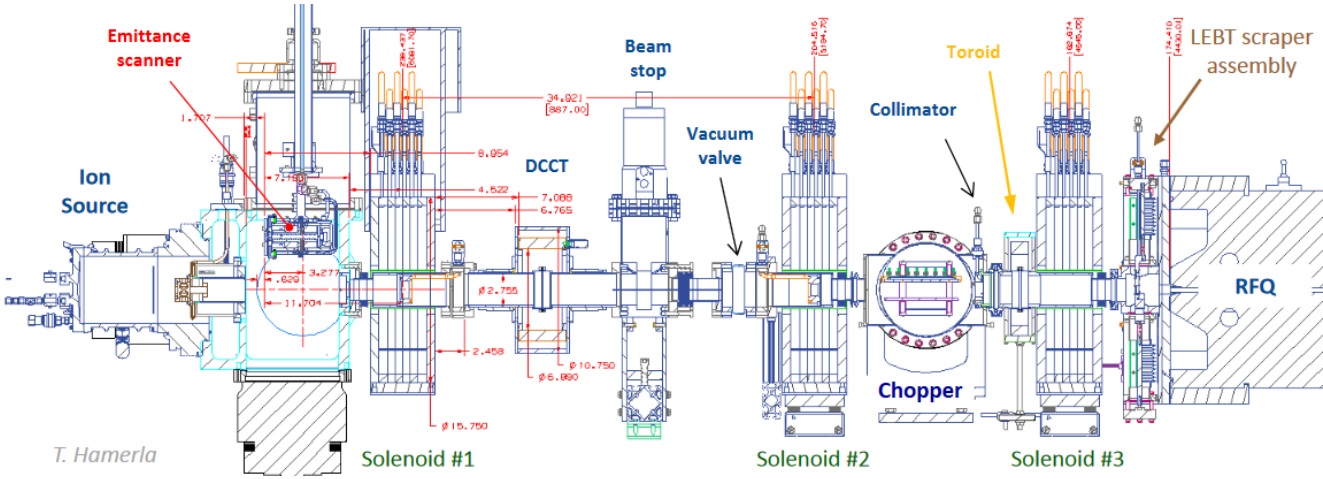
- Ion source, straight LEBT, RFQ, short MEBT, diagnostics line
- The cave has been re-configured; switching to interlocks
  - To address prompt radiation





Ion source/LEBT

- Works reliably. Very low related downtime.
  - Recorded Ion Source sparks almost disappeared after replacement of the filament power supply
    - The actual number of sparks might be similar but no latching
- Regulation loops: beam current in DCCT and beam size at the RFQ entrance (with Solenoid #3 current)
  - Still not clear whether it helps to make MEBT parameters more stable overall

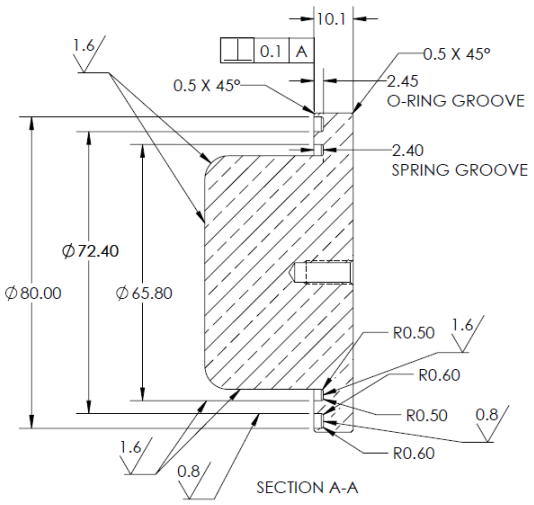


RFQ

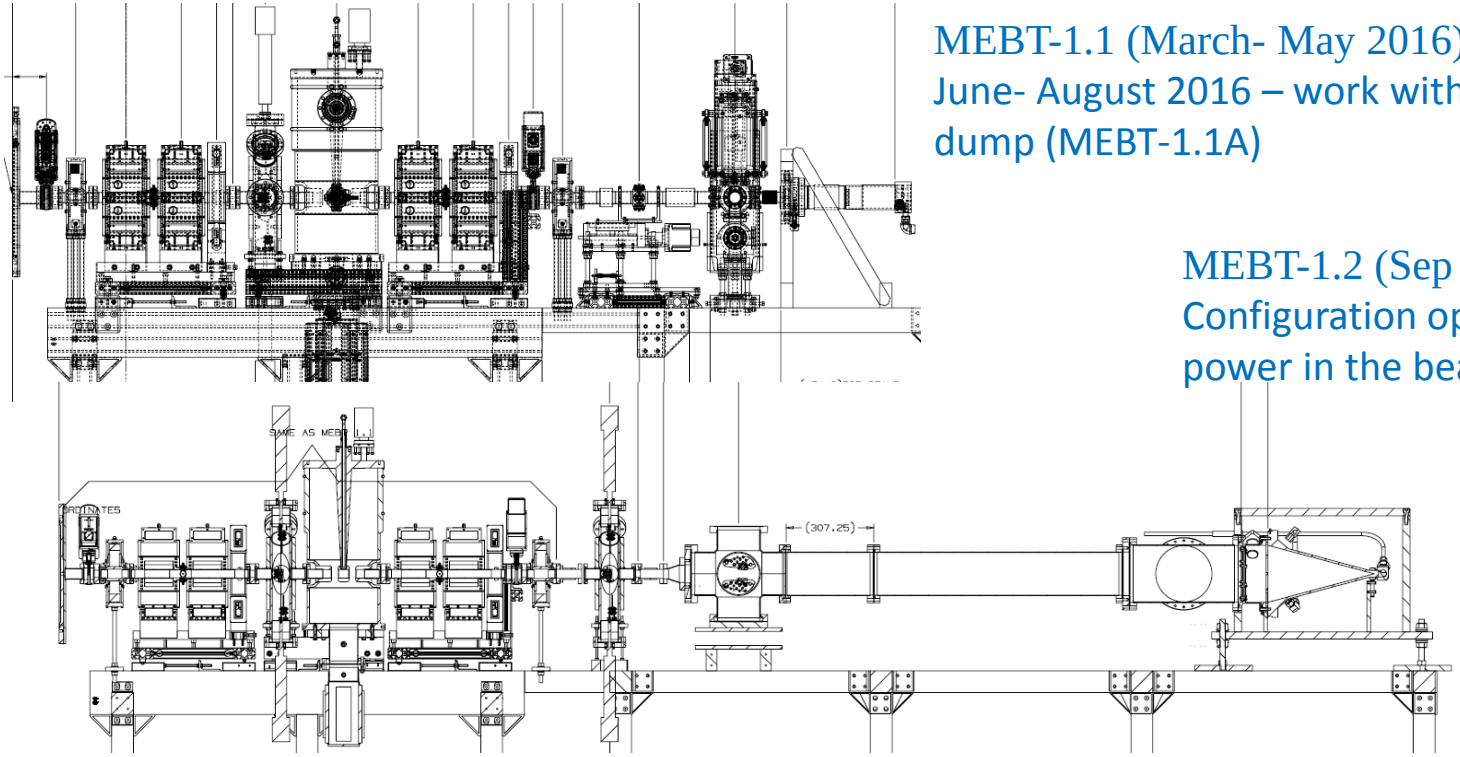
- Operate either in CW or pulse mode (typically 10 Hz, 4 ms)
  - Typically at nominal vane voltage of 60 kV
  - Most of trips are recovered in ~0.1 sec
  - In CW, several times a day “a bad trip”
    - Interruption that requires recovery with sequencer
- Applications were written to switch the RFQ on/off in both CW and pulse modes and automatically recover from trips
  - Cold start takes 20-30 min from turn on to nominal frequency
  - Trip recovery in CW takes from seconds to several minutes
- After coupler replacement, no problems
  - A spare coupler arrives in a week
- RFQ amplifiers: mainly reliable
  - Two cases of intermittent communication problems

RFQ resonant frequency offset

- Resonant frequency is found to be by 60 kHz lower than in specs (162.5 MHz)
    - Likely due to unforeseen mechanical deformations of RFQ body
- Difficult to compensate with wall- vane temperature difference
  - At the boundary of regulation in CW; ≥10 kHz offset in pulsed
    - -16.4 kHz/K vanes; +13.9 kHz/K walls; -2.5 kHz/K together
  - Now normally run at ~ -80 kHz offset
  - Not a problem for present running but better to correct before sending the beam into HWR
- Plan suggested by LBNL team: re-machine all 80 fixed plug tuners
  - Would not perturb field flatness
  - Discussing to do it in FY18



MEBT configurations



MEBT-1.1 (March- May 2016).
June- August 2016 – work with added SNS beam dump (MEBT-1.1A)

MEBT-1.2 (Sep 2016 - now).
Configuration optimized for high power in the beam dump

- Working with two doublets made of “prototype” magnets and one “prototype” bunching cavity
  - plan to demonstrate CW beam through RFQ in the present configuration

Modes of operation

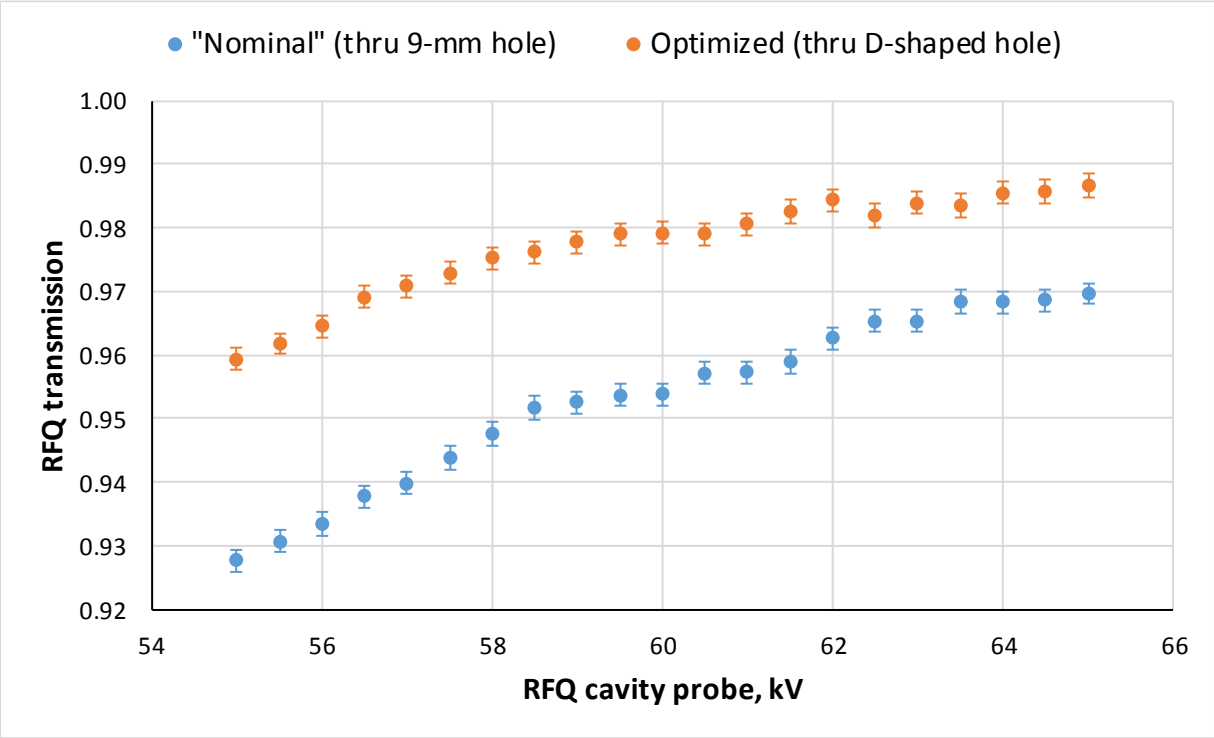
- Try to stay with “Diagnostics” and “Operational” modes
  - Presently only administratively (attentiveness of operators)
  - Will be implemented through MPS
- Diagnostics mode
  - Beam pulse width is limited to 20 μs; RFQ is in pulse mode;
  - All insertion devices are allowed; no limitations on beam interception
- Operational mode
  - No limit on beam pulse width; RFQ can be in CW
  - Insertion devices are not allowed
  - Scrapers must be close to the beam boundary. Their current is controlled.

Beam measurements

- RFQ energy – 2.11 MeV ±0.5% (spec 2.1MeV ±1%)
- Buncher characterization
- RFQ transmission and beam tuning at RFQ entrance (next)
- Checking calibration of MEBT magnets (see later)
- Quadrupole scans: emittance as low as 0.12 μm (rms n)
  - Beam sizes measured with scrapers at various quad currents
    - Recently done with Bill Marsh's program
- Pulse shape measurements with Fast Faraday Cup
  - First runs did not give satisfactory results
- Parameters variations during the pulse
  - Beam characteristics through the pulse were expected to be constant in MEBT. They are not. No explanation yet.
- Preparation for a high-power run (see later)

RFQ transmission

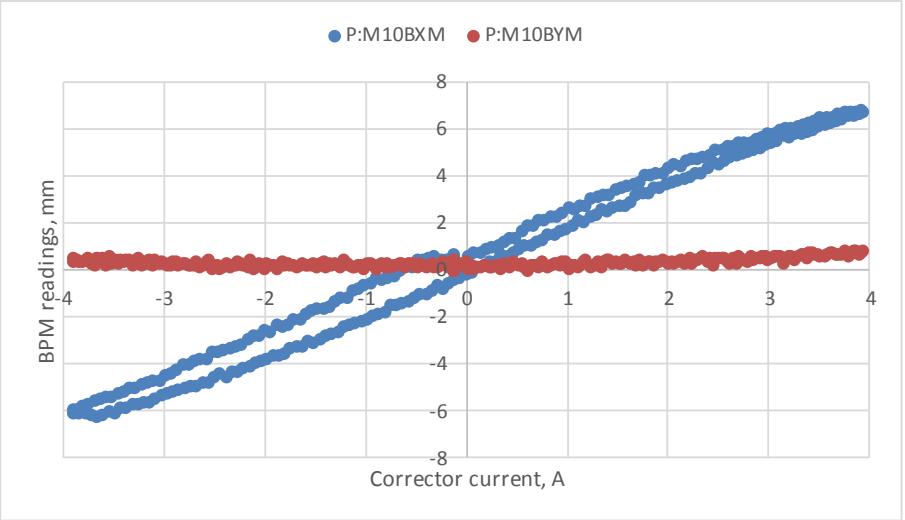
- Calculated from comparison of readings of two identical toroids at the entrance and exit of the RFQ
- Routinely ~95%; optimized ~98% (spec ≥95%)
  - Increase of RFQ voltage >60 kV may add ~1% (60 kV nominal)



RFQ transmission vs RFQ vane voltage. 5 mA beam. Error bars are statistical errors. Uncertainty claimed by Instrumentation is 2%. Simulations predict >99% at voltage above 60 kV.

Magnet calibration

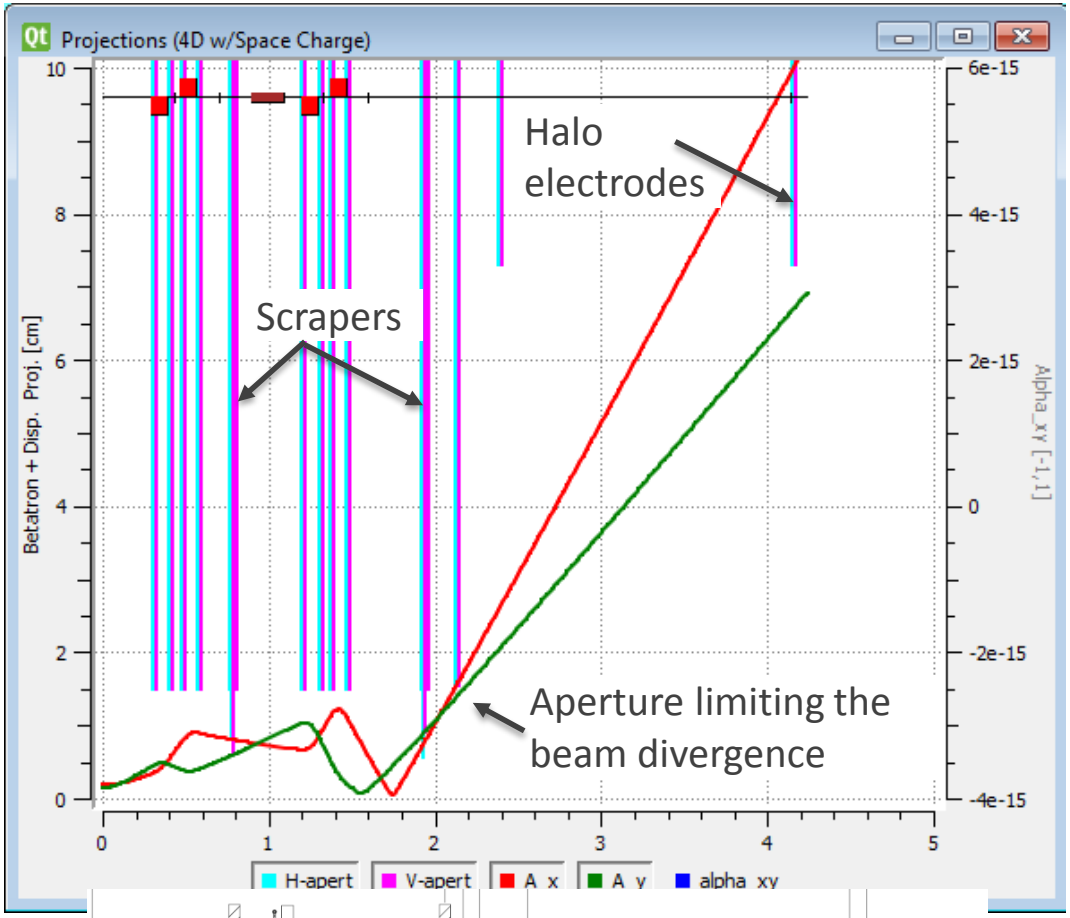
- Checked corrector calibrations vs BPMs and scrapers
  - Corrected errors or various magnitude
  - The most accurate diagnostics is scraper positions, ~1%
  - For correctors, the limiting factor is hysteresis and non-linearity
    - With no special measures, the slope d(deflection)/d(current) may vary up to 10%
    - Agrees with simulations and magnetic measurements within this uncertainty
- Quadrupole beam-based calibration has a similar uncertainty and level of agreement
  - Will rely on magnetic measurements

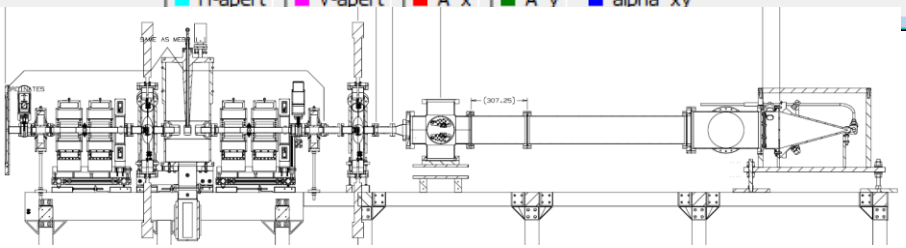


BPM reading vs current of upstream corrector

Preparations for high-power run

- Beam should fill almost entire dump aperture to test at full power
  - B. Hartsell's simulation: ≥20mm rms beam size for 21 kW
  - Using "halo electrodes" at the dump entrance
- Need to pass the beam without large scraping at vacuum chamber



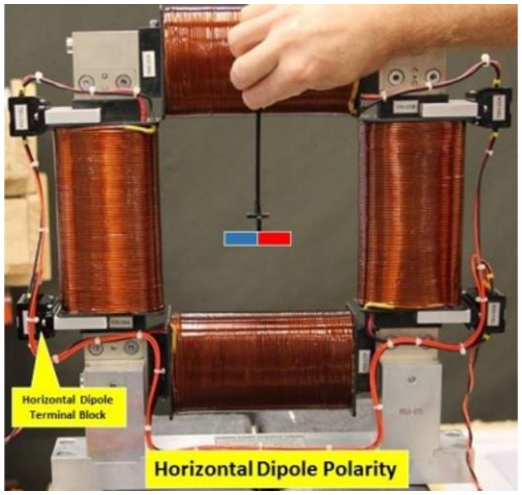


OptiMX simulation of the 3σ beam projections. Initial Twiss are from RFQ simulation. Peak current is chosen 130 mA (for 5 mA CW). Transverse emittance 0.12 μm (rms., n). Scrapers are shown at measured 3σ.

Components status - Magnets

Quadrupoles after delivery to BARC

- All magnets have been produced in India
  - All dipole correctors delivered to Fermilab
  - Measurements of the first triplet are complete at BARC
  - 4 triplets are supposed to be delivered to Fermilab in Nov 2016
  - Girders and vacuum chambers are ready
  - 3 more triplets are scheduled for delivery in Dec 2016
    - Enough for assembling full-length MEBT
  - Spares and prototype replacements in 2017

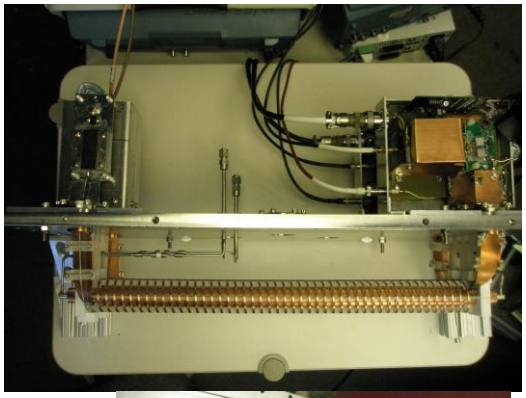


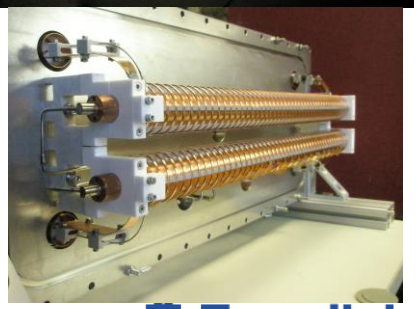
Dipole correctors inspection at Fermilab

Components status (cont.)

- Bunching cavities
  - Manufacturing problems delayed production
  - First cavity has been shipped for final brazing
- 200 Ohm kicker assembly is being finished
  - Two drivers are assembled at the kicker body.
    - Demonstrated capability of generating pulses for arbitrary bunch selection in 40 μs bursts at 50 Hz (limited by cooling scheme).
    - Will be presented at PIP-II meeting on Nov 22, 2016
- 50 Ohm kicker has been ready for installation for a while

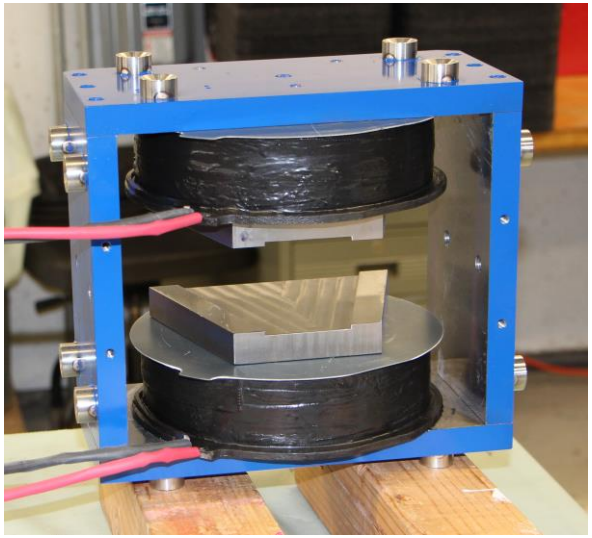
Body of the first “production” cavity after second brazing

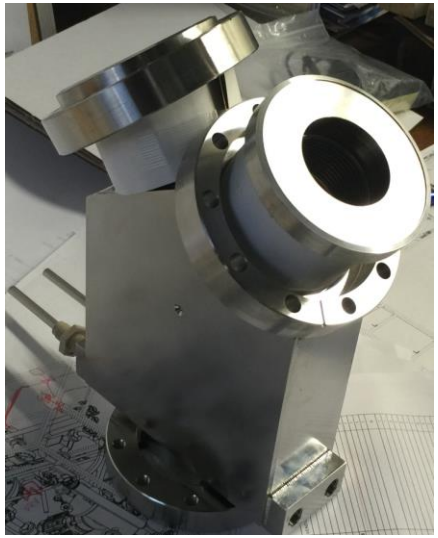




Components status (cont.)

- MEBT emittance scanner – ready for installation
- LEBT bend
  - Magnetic measurements are done
  - Need to install its vacuum chamber





MEBT scanner is being assembled at its vacuum chamber

LEBT bending magnet and its vacuum chamber

Plans for FY17

- Try a high-power beam through RFQ
  - Begin operating with interlocked cave this week
  - Goal: finish by a 24- hrs run with 5 mA CW beam
- Install the MEBT emittance scanner; measure emittance and Twiss functions (Dec 2016)
- Shutdown in Jan 2017 for 2-3 months
  - Install the magnets, bunching cavity(s), kickers, LEBT bend
  - The scope depends on delivery of the magnets
    - May install the full – length MEBT
- Run until Oct 2017
  - determined by cryo distribution installation
  - Goals: beam through full–length MEBT; kickers characterization

Plans – longer term

- If there is a window between cryo distribution work in the cave and installation of HWR, discuss a possibility of an extra run time in FY18 (~several months)
  - Renzhuo Wang will present plans of Cryo on Nov 22
- Shut down until both cryomodules are installed (Q4 FY19 ?)
- Design, manufacture, and install all components for the final PI-Test MEBT
  - Final diagnostics, clean section upstream of HWR, final kicker system, absorber, fast vacuum protection system
  - Also need to design a simple HEBT for a pulsed beam
- Pass a pulsed beam through cryomodules – FY20
- Hopefully, start preparation for a CW beam in PI-Test and full-scope HEBT

Recent contributors (partial list)

- In beam shifts: B. Hanna, J.-P. Carneiro, V. L. S. Sista, L. Prost, A. Saini, J. Steimel, A. Shemyakin
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