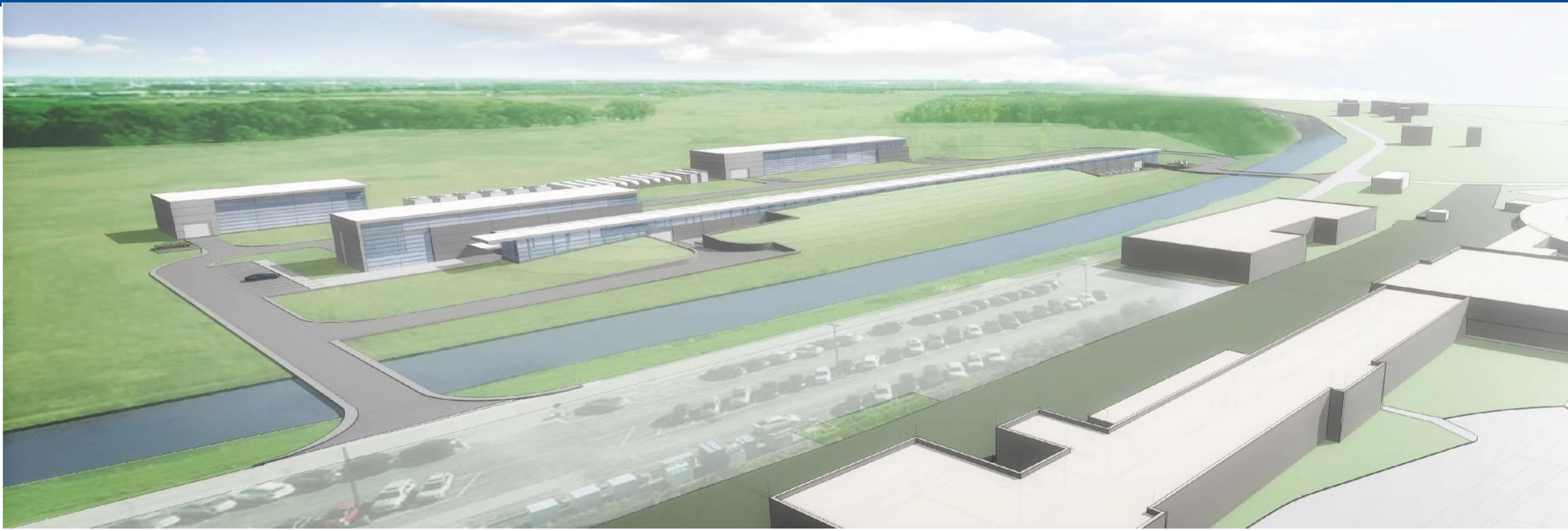


PIP2IT Plans and Accomplishments

Accelerator Support Systems

Alexander “Sasha” Shemyakin

PIP-II DOE Independent Project Review

12-14 December 2017

In partnership with:
India/DAE
Italy/INFN
UK/STFC
France/CEA/Irfu, CNRS/IN2P3

Outline

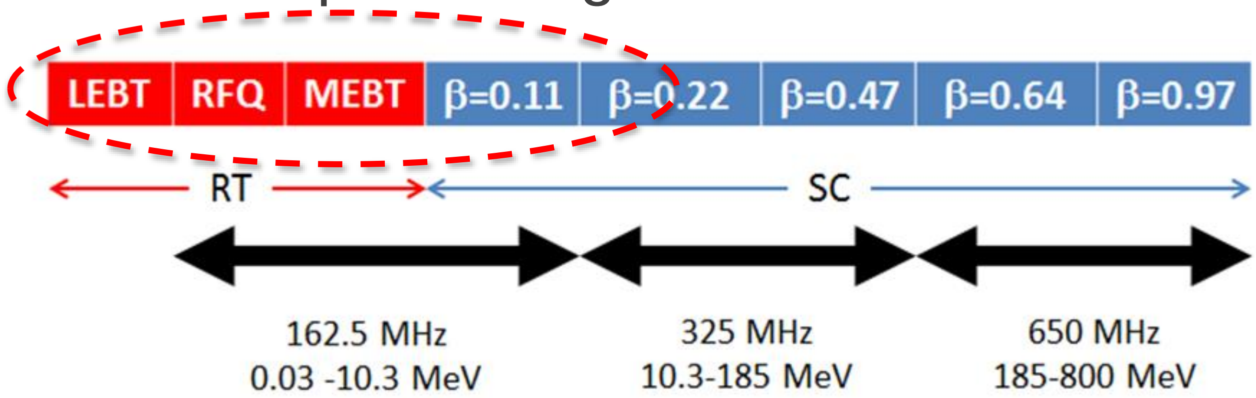
- Introduction to PIP2IT
- PIP2IT warm front end
- Achievements
- Plans
- Summary

About Me:

- Role in PIP-II: PIP2IT group leader
  - With PIP-II project since 2011, working with the Warm Front End
- Relevant Experience
  - Worked with accelerators for 35 years
  - 20 years at Fermilab. Development and operation of 4 MeV Electron Cooler

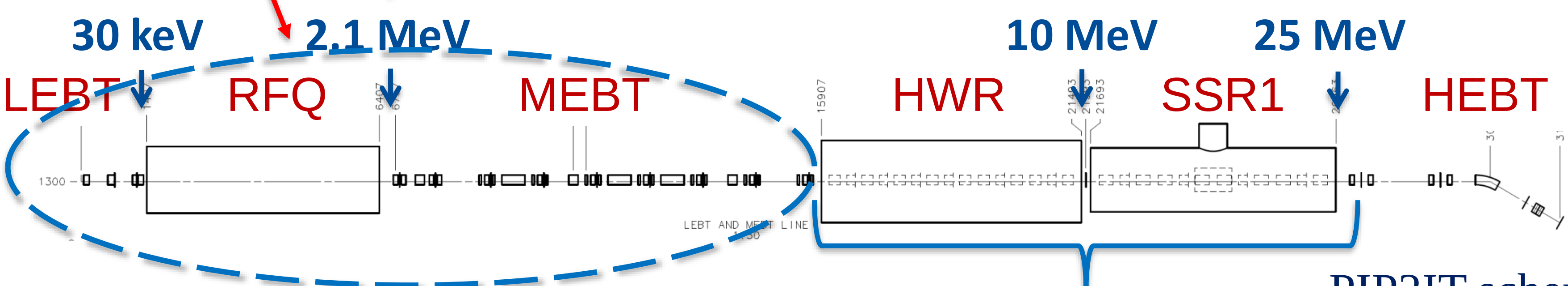
PIP-II and PIP-II Injector Test (PIP2IT)

- PIP2IT: a test accelerator representing the PIP-II front end



PIP-II Linac scheme

Warm Front End (WFE) has been assembled and tested



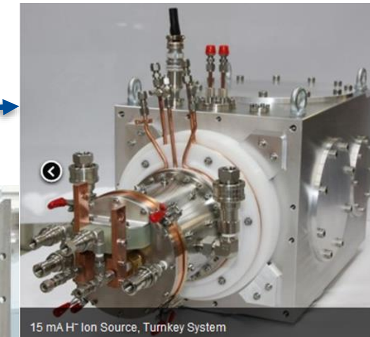
To be installed and tested in FY19/20

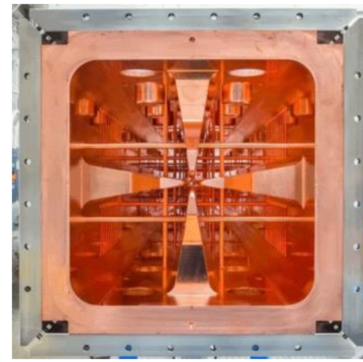
PIP2IT scheme

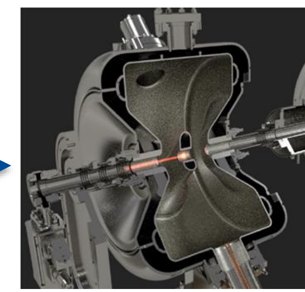
LEBT = Low Energy Beam Transport; RFQ= Radio Frequency Quadrupole; MEBT= Medium Energy Beam Transport; HWR = Half-Wave Resonator; SSR1=Single Spoke Resonator; HEBT = High Energy Beam Transport

PIP2IT: Testing one-of-a-kind elements of PIP-II

- Variety of different accelerator structures
  - Ion source (30 keV),
  - RFQ (2.1 MeV),
  - HWR (10 MeV),
  - SSR1 (25 MeV)







- Bunch-by-bunch selection scheme (next slide)

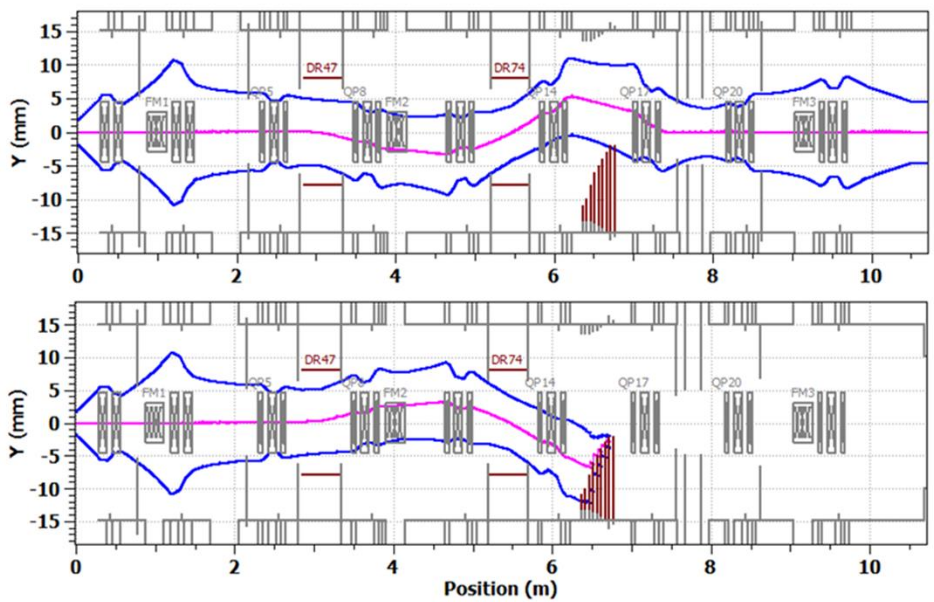
Mission Statement (see P. Derwent's presentation)**:**

The PIP-II Injector Test (PIP2IT) facility replicates the front end of the PIP-II linac through the first SSR1 cryomodule. PIP2IT is intended to serve as a complete systems test that will reduce technical risks associated with the PIP-II linac in both pulsed and CW operating modes.

PIP2IT FRS - ED0001223

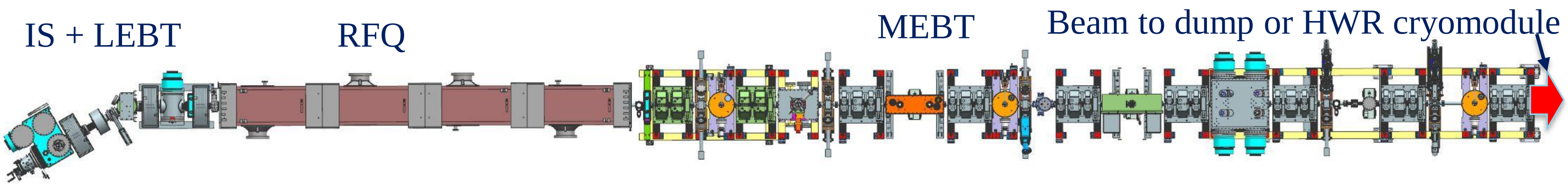
Unique feature of PIP-II: flexible bunch structure

- “Bunch-by-bunch selection” in MEBT allows removing un-needed bunches
  - Effective injection into the Booster
  - With an RF separator at the end of the linac, possibility to deliver quasi-simultaneously to different users the beam with very different time structure
- The selection scheme is being tested at PIP2IT
  - Chopping system: Two kickers working in sync and absorber.
  - 6σ separation at absorber



Simulated 3σ envelopes of passed (top) and removed (bottom) bunches.

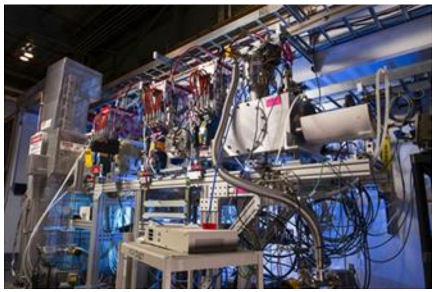
Presently assembled: PIP2IT WFE



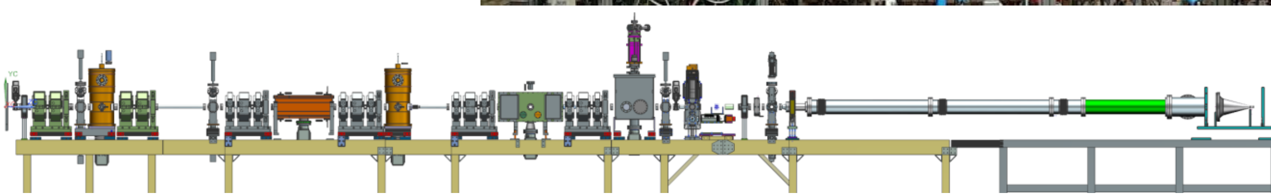
- 30 keV, 15 mA H^- Ion Source (from 5 µs to DC)
- LEBT (3 – solenoids; 30º bend to accommodate 2 ion sources in PIP-II)
  - Chopper to form macro-pulses
- CW-compatible 2.1 MeV RFQ (produced by LBNL)
- 10-m long MEBT with fast chopper
  - 2 quadrupole doublets and 7 triplets (produced by BARC, India)
  - 3 bunching cavities
  - Collimation system (4 sets x 4 scraper plates)
  - Differential pumping system

Several stages

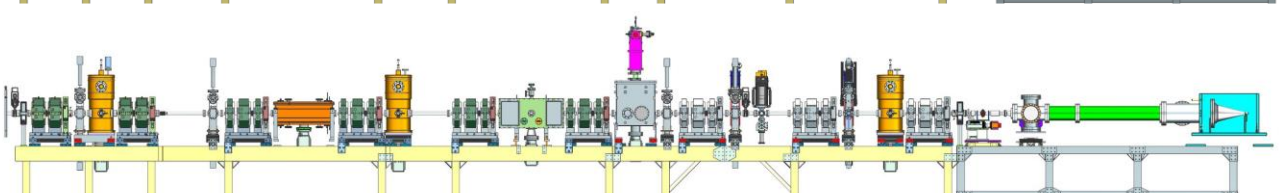
- Adding equipment in pace with delivery and budget



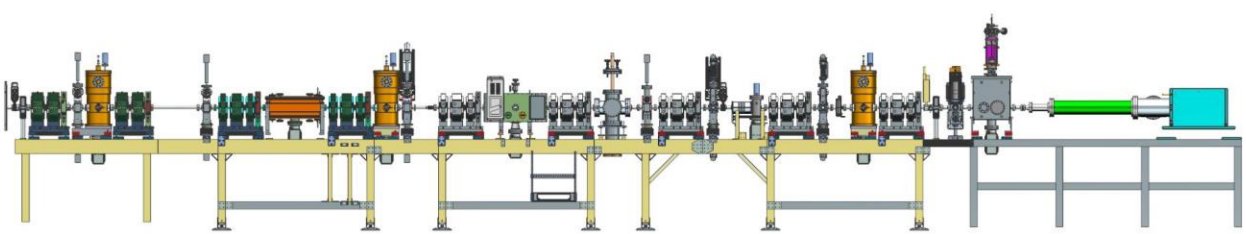
  - Ion Source + LEBT in several versions
  - Addition of RFQ + two-doublets MEBT



  - +4 triplets and kickers



  - + 3 triplets and both kickers



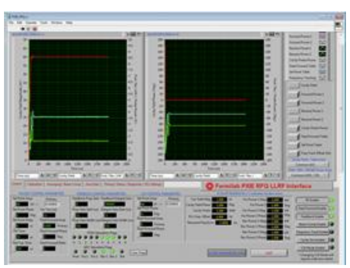
  - + differential pumping insert (present assembly)

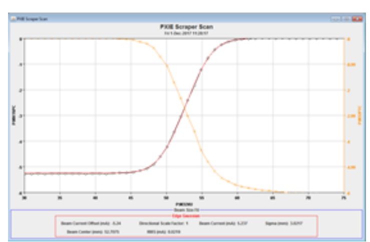
“CDR parameters” and high duty factor operation

- PIP-II: “CW-compatible linac working initially in a pulse mode”
- Philosophy for PIP2IT
  - Design all elements intended to be used at PIP-II as CW-compatible but focus on operation at “CDR parameters”
    - “CDR parameters” = parameters required for future injection into the Booster: 0.54 ms x 20 Hz at 5 mA from the RFQ with about half of all bunches removed in MEBT to create a non-periodic pattern optimized for filling the Booster RF buckets
  - Test at higher duty factors, up to CW, when it is compatible with pursuing the main goal
    - address discovered issues

Achievements

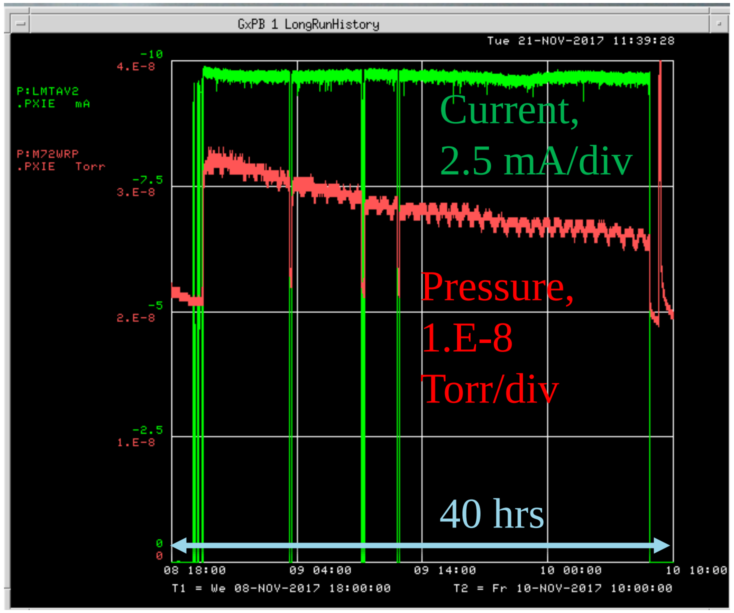
- Beam at “CDR parameters” through a full-length MEBT
- LEBT with un-neutralized section
- RFQ reliably operating at CDR parameters
- CW – compatible MEBT
- Prototype elements of the fast chopping system
- CW-compatible Machine Protection System
- Diagnostics
- And other development that will not be presented here, e.g.
  - LLRF, control programs, 20 Hz operation …





Beam through a full-length MEBT

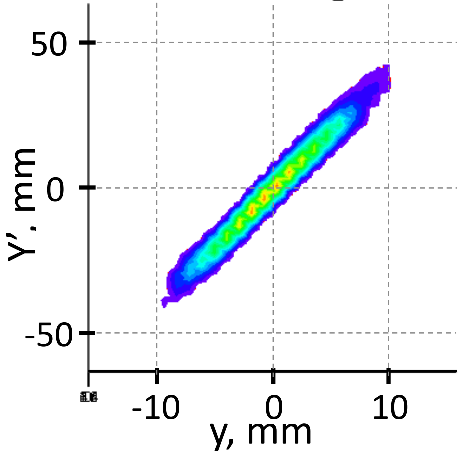
- Operation of most WFE components at CDR parameters have been demonstrated
  - Beam was passed through the full-length MEBT with one kicker producing a required deflection pattern
    - 0.54 ms x 20 Hz x 5 mA; about half of all bunches are deflected
    - 24 hours continuous run with both passed and deflected bunches transported to the beam dump
  - Beam with a higher duty factor was passed through the full-length MEBT and deposited to the absorber prototype for 35 hours
    - 1.75 ms x 20 Hz x 10 mA; with kickers off



Beam current and MEBT pressure during the 35-hrs long run of the beam to the absorber prototype.

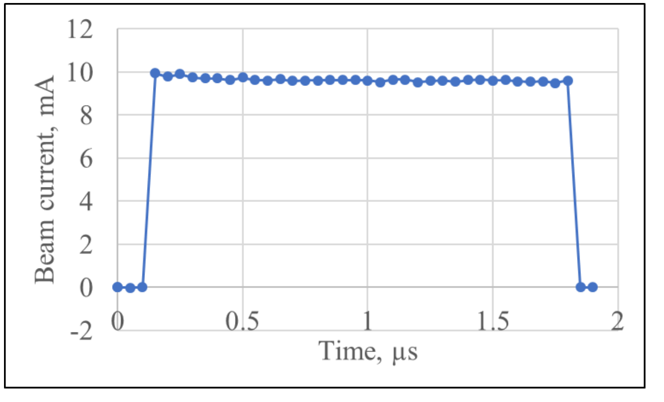
LEBT with un-neutralized section

- Downstream portion of the LEBT is not neutralized
  - With scraping near the ion source and proper focusing, the beam emittance remains low, and beam parameters at the RFQ entrance are optimal
  - Vacuum at the RFQ entrance stays below $2 \cdot 10^{-7}$ Torr with beam
- Since the LEBT chopper is located in this section, beam parameters stays constant through the MEBT pulse
  - Tuning made with 10 µs pulses work for long-pulse operation



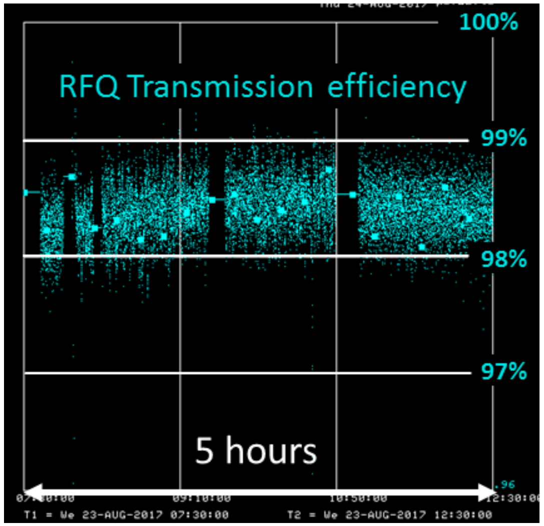
Phase portrait measured at the end of the LEBT at 5 mA. Emittance =0.105 µm (rms, n).

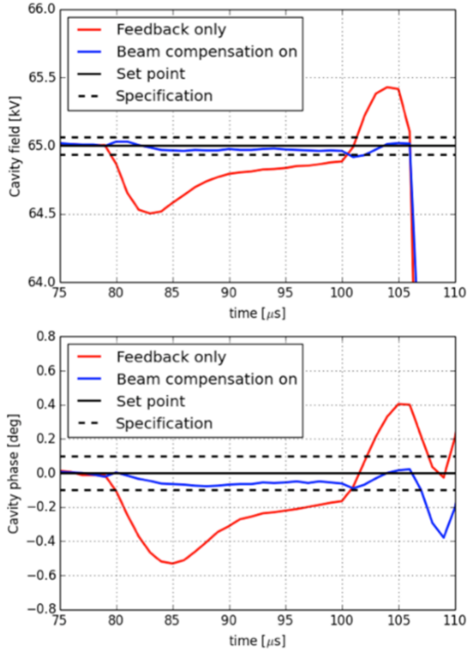
Beam current measured in MEBT through 1.8 ms pulse



RFQ

- RFQ works reliably at CDR parameters
  - Includes amplifiers, LLRF, and cooling system
  - > 95% transmission
  - transverse emittance ≤0.2 µm (n rms)
  - Energy is as specified, 2.11±0.5% MeV
- Some of remaining issues
  - Frequency offset (fixed tuners need to be re-machined)
  - Couplers are not compatible with CW

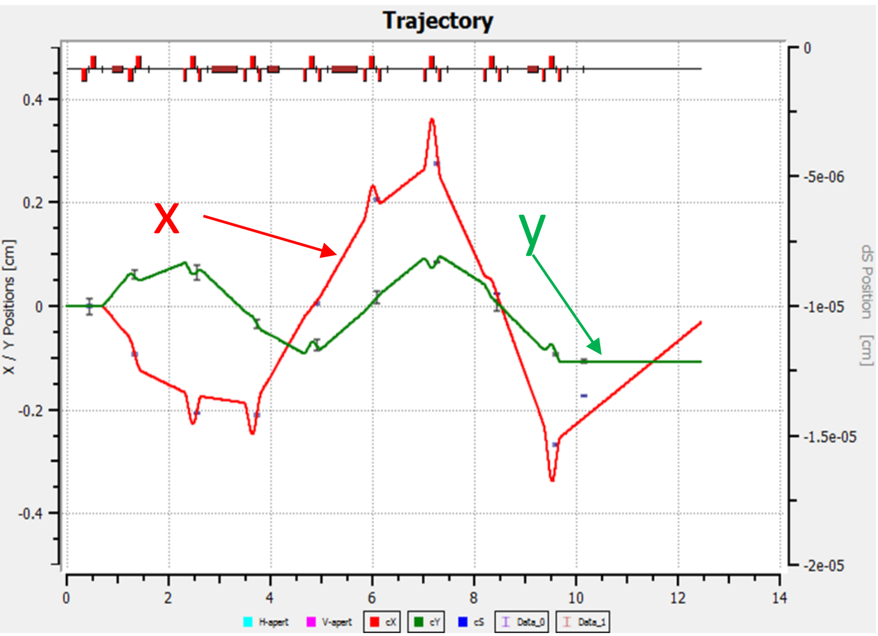




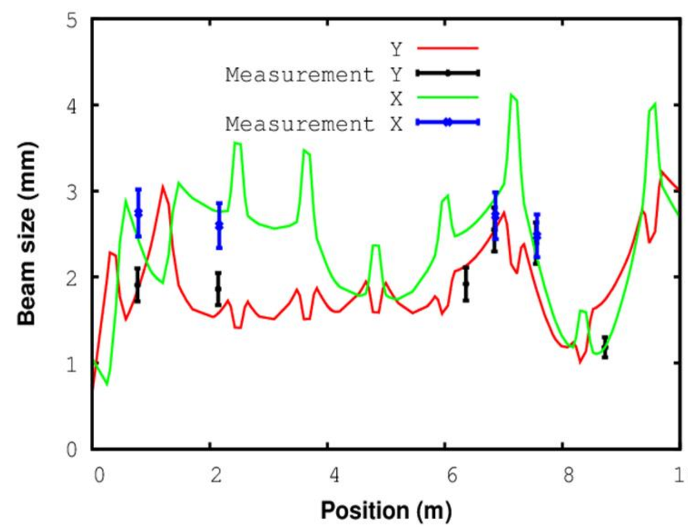
Measured RFQ voltage waveforms with 20 µs, 5 mA beam. With LLRF feed-forward, feedback, and beam compensation loops on, regulation is at 0.1% amplitude and 0.1° level.

MEBT optics

- Transverse optics is measured and in reasonable agreement with simulations
  - Can predict the beam envelope at ~10% level



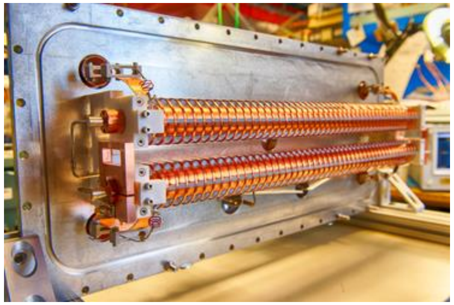
Comparison of simulated and measured beam trajectory responses to deflection with the first dipole corrector.



Comparison of simulated and measured beam envelopes. Beam current is 5 mA.

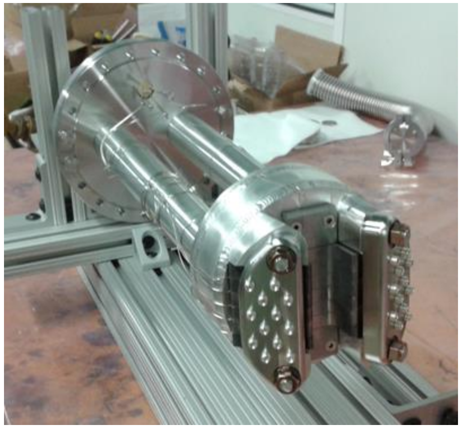
Chopping system

- Two kickers working in sync and absorber
- Since a CW-compatible kicker capable of providing an arbitrary pattern was beyond state-of-the-art, two kicker versions were developed, “200 Ohm” and “50 Ohm”
  - Both are installed; 200 Ohm kicker is fully characterized with beam
- Absorber prototype has been developed and tested at full power density with an electron beam and at 7x CDR parameters at PIP2IT



200 Ohm kicker

50 Ohm kicker

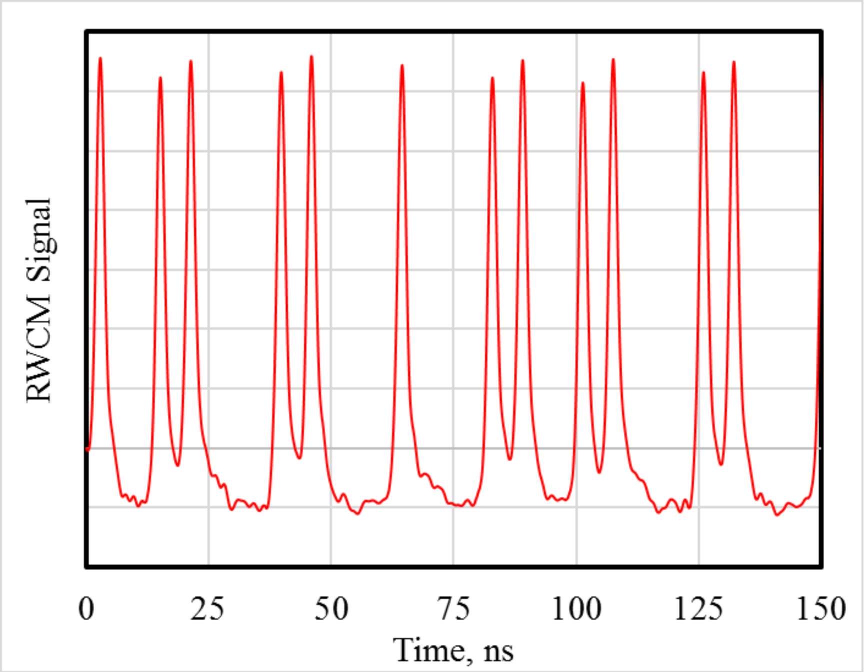


¼ length absorber prototype

200 Ohm kicker performance

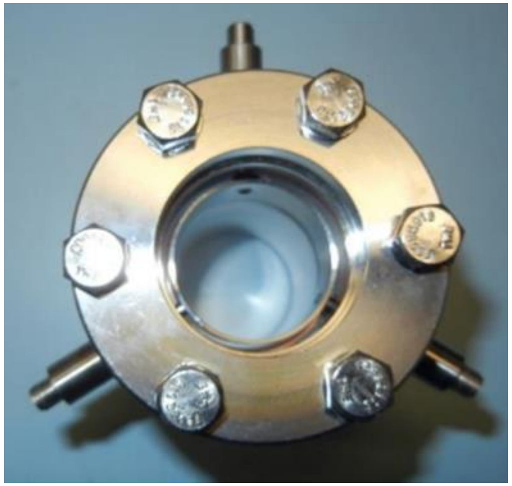
- Completely satisfies CDR requirements
  - 500 V per plate generates 7 mrad deflection
  - Generates non-periodic pattern required for Booster injection
  - Tested with beam in 24-hr run at 0.54 ms x 20 Hz, with switching frequency equal to Booster injection frequency, 44.7 MHz
- The choice for the final kickers

Example of bunch pattern formed by the MEBT chopping system and recorded with Resistive Wall Current Monitor (portion of 10 μs pulse). The 5 mA beam is collimated to 1.5 mA and deflected by 200 Ohm kicker to a scraper. Population left of removed bunches is < 2%. Non-zero signal between neighboring passed bunches is determined by properties of RWCM.



Machine protection system development

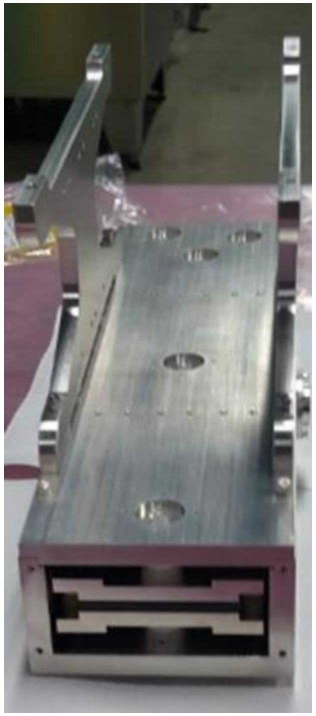
- The beam is interrupted when MPS detects unfavorable conditions
  - Controls pulse width
  - Vacuum, position of valves and insertable devices
  - Beam loss between current detectors
    - MPS employs dedicated capacitive pickups
    - Presently can protect from 3% unexpected beam loss



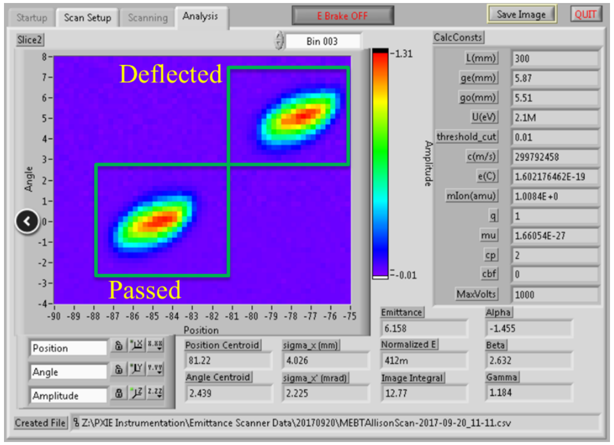
Capacitive pickup for MPS

Diagnostics

- Beam current
  - Toroids (ACCT) measure with 2% accuracy
  - Currents to dump, scrapers, protection electrodes are measurable in 1 μs steps
  - RWCM to measure removal of bunches
- BPMs for position and phase
- Scrapers are used for envelope measurements
- Allison emittance scanners in LEBT and MEBT
  - Successful implementation at 2.1 MeV is unique



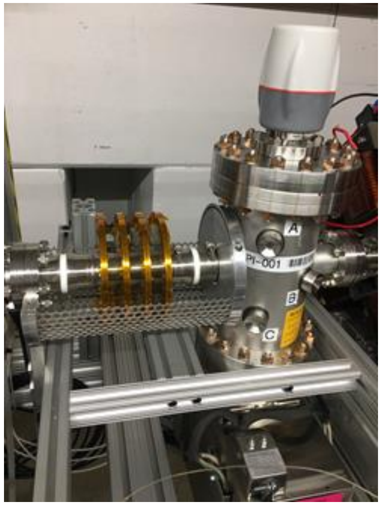
MEBT Allison scanner under assembly



Example of MEBT Allison scanner measurement.
3 μs slice of 10 μs pulse. The 5 mA beam is collimated to 1.5 mA and deflected by 200 Ohm kicker.

Main items remaining for PIP2IT WFE

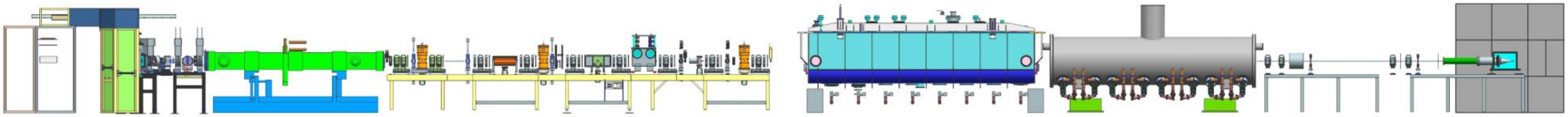
- Test the Differential Pumping System with beam
  - Recently installed
- Manufacture and test the chopping system
  - final kickers and absorber
- Address RFQ issues
  - adjust resonance frequency
  - Address coupler issues
- Assemble and test the vacuum protection system
- Assemble UHV, particle – free portion of the MEBT adjacent to HWR



Differential Pumping Insert installed in MEBT

Plans

- FY18- finish the beam run in WFE–only configuration
  - Start installation of the cryo distribution system in Q3 FY18
- Q3FY19 – start installation of HWR, followed by SSR1
  - Cool down and test all cavities at full gradient – finish in Q1FY20. HWR in CW; SSR1 in both CW and pulse
- FY21/22 – pass the “CDR-parameters” beam through SRF
  - Test all remining items in the Warm Front End
- FY24 WFE is moved to PIP-II
  - Cave is used for testing of SSR1 and SSR2 through FY26



PIP2IT in its final configuration

Summary

- PIP2IT is an important and fruitful test bed for PIP-II front end
  - Solutions for most of WFE components are found and tested
    - Some of them are novel and unique
- Most of CDR WFE parameters are demonstrated
- Plans for the front end to be ready for installation into PIP-II are developed

- Thank you for your attention

END