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Warm Front End and PXIE Status

Alexander Shemyakin

DOE Independent Project Review of PIP-II

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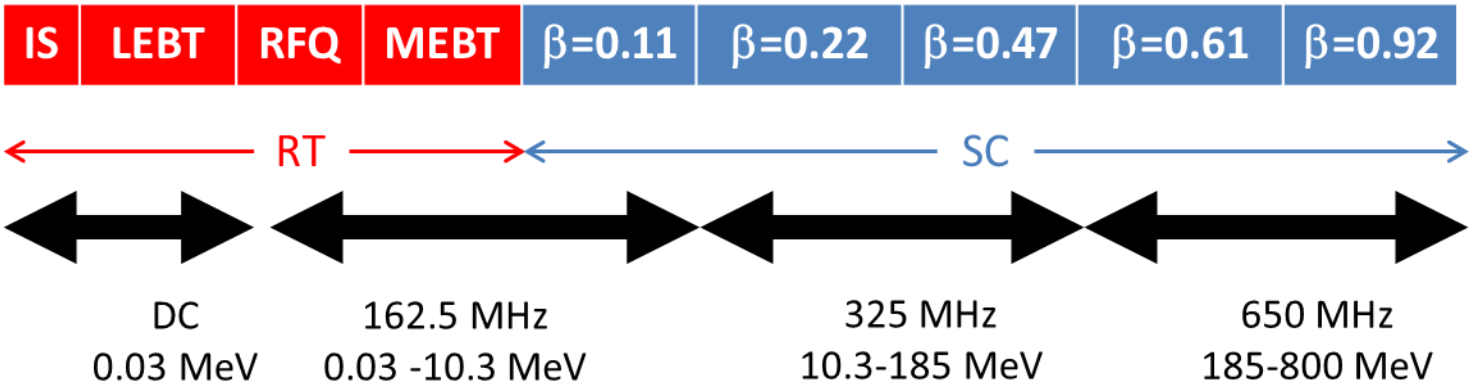
Outline

- PIP-II warm front end
- PXIE status
- Plans

PIP-II warm front end

- PIP-II: 800 MeV SRF linac constructed of CW-capable accelerating structures and operated initially at 1% duty factor
- The warm front end prepares H- beam optimized for Booster injection and provides capabilities for future CW operation
  - Ion Source (IS) and Low Energy Beam Transport (LEBT)
  - Radio Frequency Quadrupole (RFQ)
  - Medium Energy Transport (MEBT)

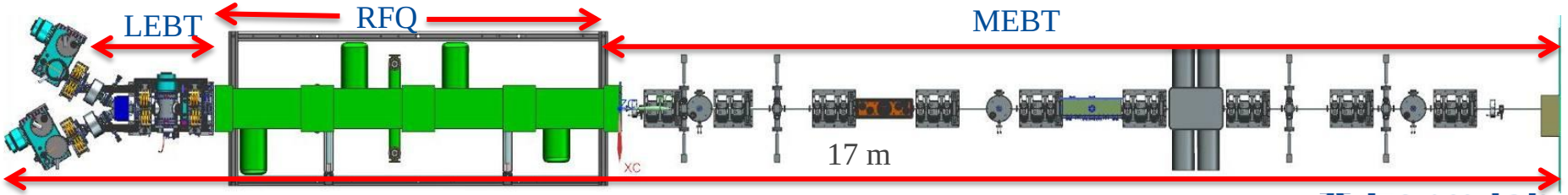


PIP-II warm front end parameters

- Parameters
  - Output energy 2.1 MeV
    - Below neutron production and high enough to mitigate space charge effects up to 10mA
  - Peak beam current up to 10 mA (from μs to CW)
    - 5 mA nominal; 4 mA in macropulse for Booster injection
  - Bunch-by-bunch selection capability
    - For bucket injection to Booster and for future CW multi-user operation
  - Output rms emittances: $\varepsilon_{\perp}$<0.23 μm, ε_{L}<0.31 μm
  - Proper vacuum, tails, and bunch extinction management
- While the combination of parameters is unique, most of elements exist in other machines
  - Exception: bunch-by-bunch selection

Front end design concept

- Standard scheme: Ion sources, LEBT, RFQ, MEBT
  - Long MEBT to accommodate the chopping scheme
- Attention to factors that may determine reliability and uptime
  - Two ion sources
  - Low gas flow to RFQ with a long LEBT
  - Proven-design RFQ with low particle loss
  - System of scrapers in LEBT and MEBT
    - Passive and active parts of Machine Protection System
  - Suppression of gas flow to SRF with a differential pumping section downstream of the MEBT absorber



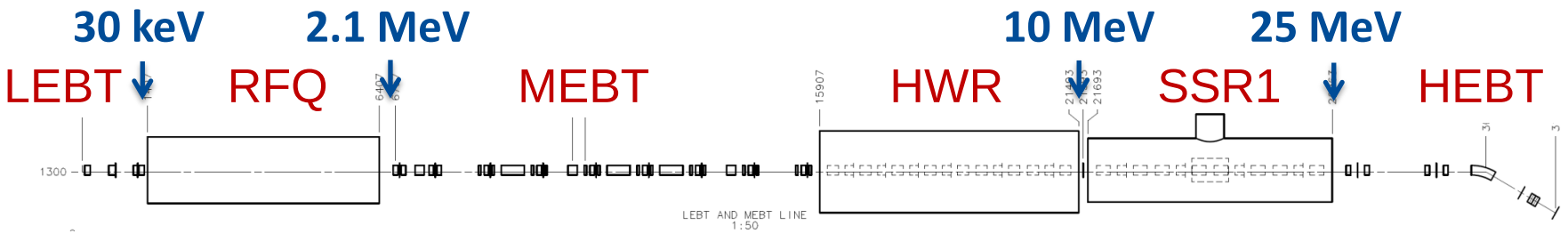
R&D topics

- Many ion machines have had problems with front ends
  - R&D can mitigate risks for PIP-II and speed up commissioning
- The most important R&D issues
  - LEBT with low emittance growth compatible with chopping
  - Reliable CW RFQ
  - Bunch-by-bunch selection in MEBT
  - Compatibility of high-power deposition in MEBT absorber with SRF downstream

- Will be addressed by PXIE

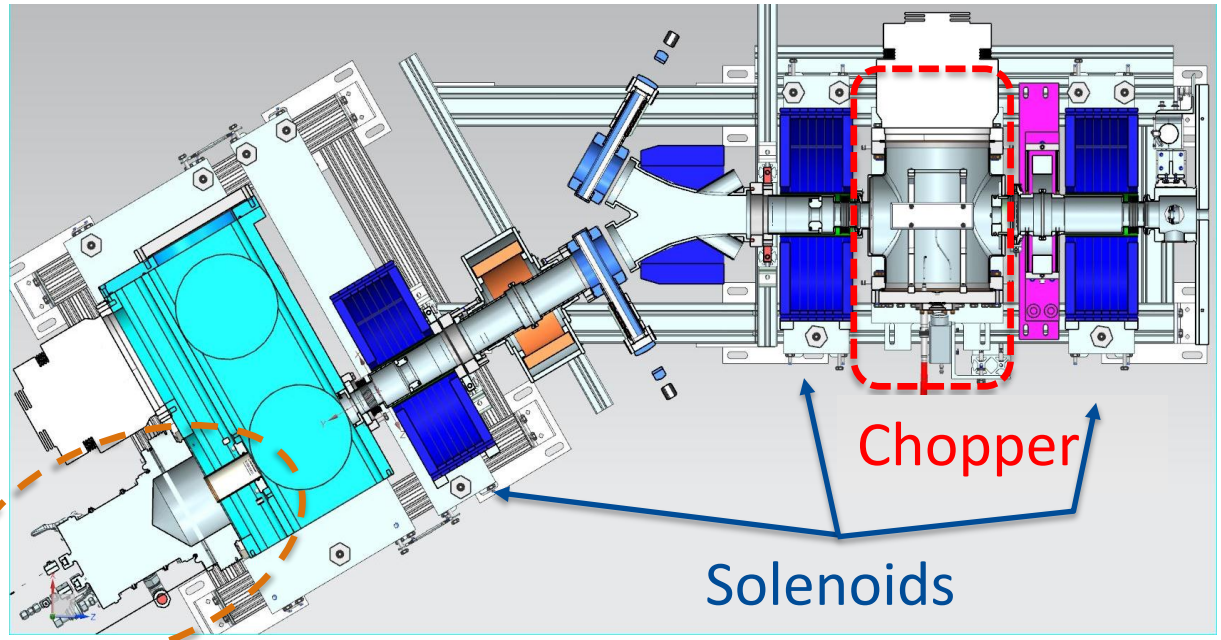
PIP-II Injector Experiment (PXIE)

- PXIE is part of the R&D program that addresses the risks associated with the front end of PIP-II
  - Warm front end + 2 cryomodules + HEBT + beam dump
  - Nominal regime is CW; pulsed mode for commissioning and modelling the Booster injection
  - Goal PXIE parameters replicate those for the corresponding section of PIP-II
    - 2mA from μs to CW; arbitrary 162.5 MHz bunch structure



Ion source and LEBT - concept

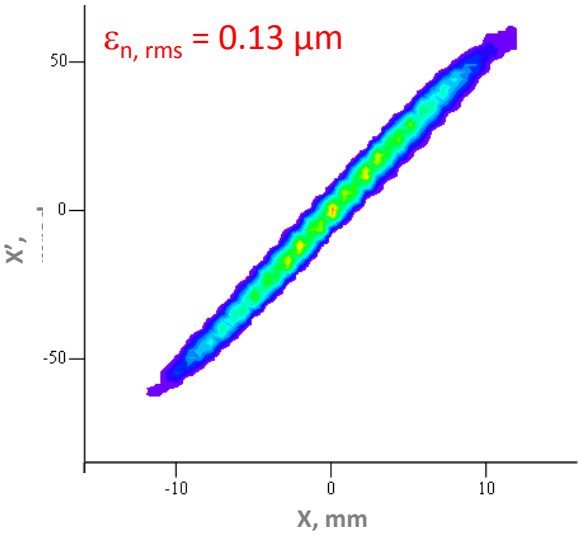
- Commercial 15mA DC ion source
  - D-Pace, Inc.
  - Modulator at extraction electrode
- 3 Solenoids with dipole correctors
- Bending dipole
  - Accommodate 2 ISs for PIP-II
  - Part of Personnel Protection System
  - Clearing secondary particles
- Diagnostics
  - Beam current monitors
  - Emittance scanner
  - Isolated diaphragms
- Chopper
  - Pre-chopping, MPS, pulse mode
  - 60 Hz, 1μs to DC
- Possibility of partially un-neutralized transport
- Possibility of scraping the beam at various locations
  - Tail particles management

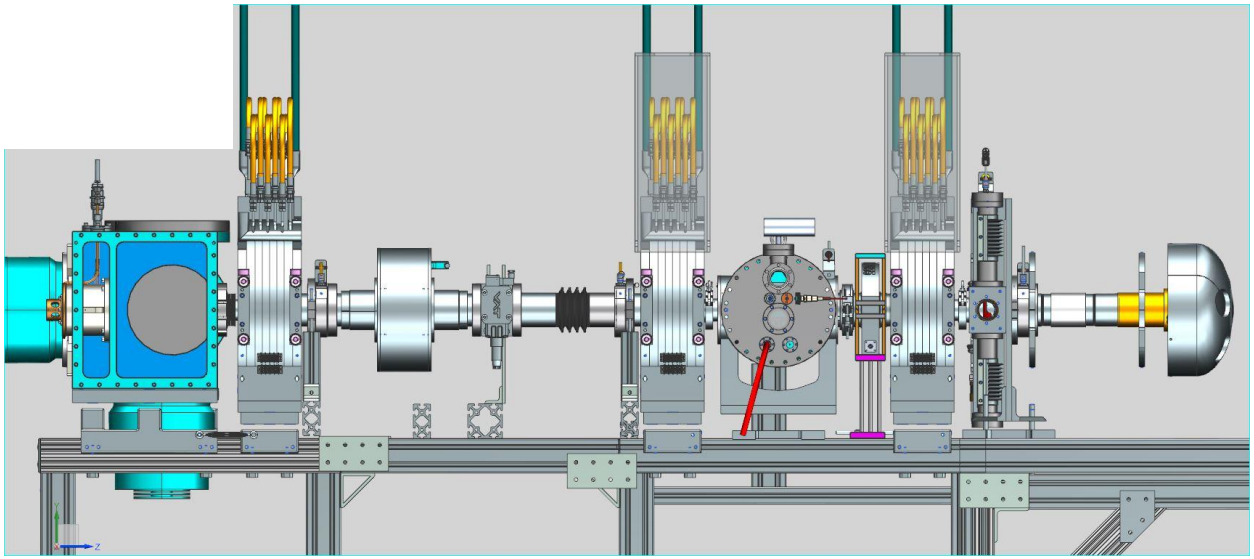


Scheme of PXIE IS and LEBT in final configuration

Ion source and LEBT - status

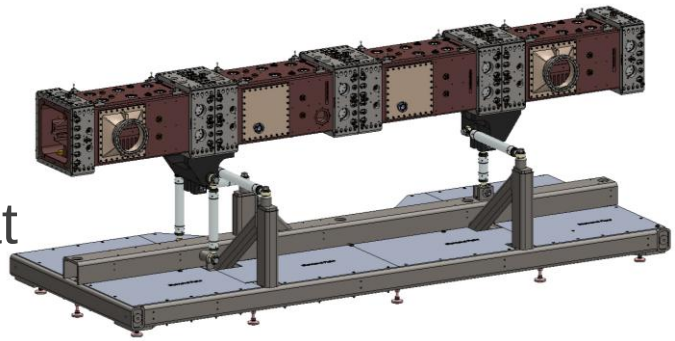
- IS and LEBT are assembled, fully commissioned, and ready for RFQ arrival
  - Straight configuration; dipole will be installed in FY16
  - Beam current up to 10 mA in pulse and DC modes
    - 24 and 72 hrs runs at 5 mA; current stabilization loops
  - At 5 mA, Twiss parameters reconstructed to the RFQ entrance are on target

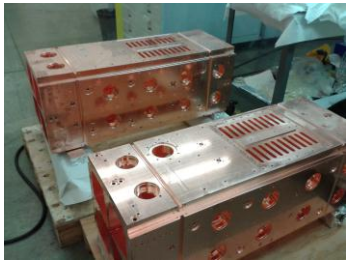




RFQ

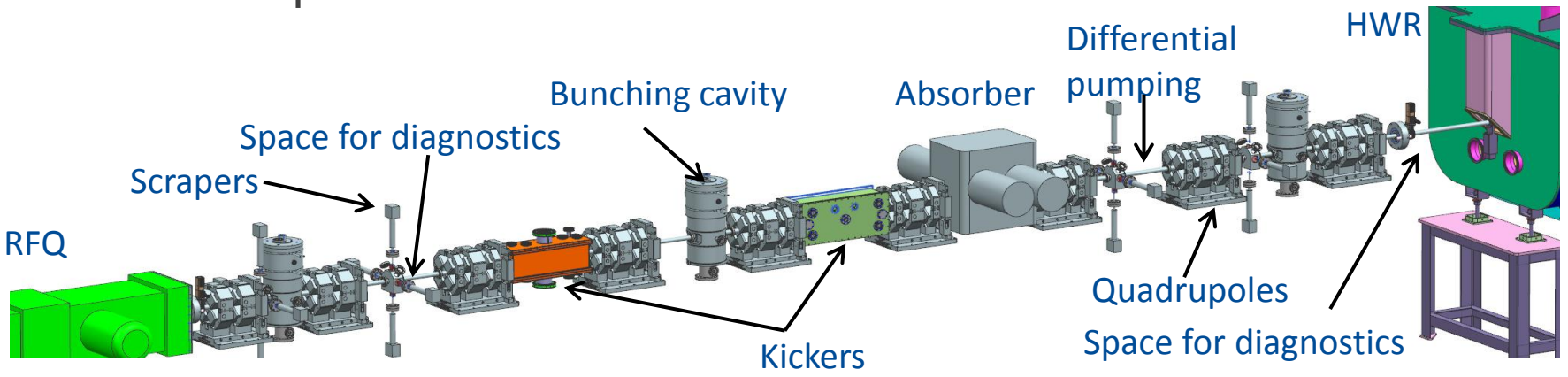
- Designed and constructed at LBNL
  - 4 vane, 4 module brazed copper body
  - Similar RFQ has been commissioned at IMP (Lanzhou, China) with 10 mA CW
- All body machining and brazing is done
  - All other parts are either on hand or will be delivered in coming weeks
- Expected delivery in July 2015
- Two 75 kW 162.5 MHz solid-state amplifiers are installed and commissioned
- Water cooling system and LLRF are being prepared





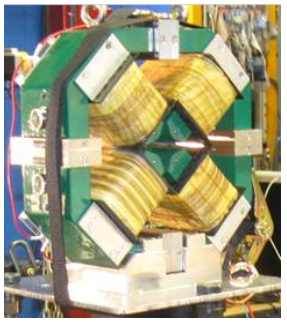
MEBT - concept

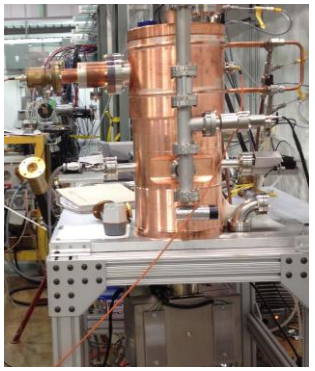
- Transverse focusing with 2 doublets and 7 triplets
  - First short section for beam matching; 1.14 m period after
- Longitudinal focusing with 3 bunching cavities
- Chopping system: Two TW kickers in sync + absorber
- Last ~2 m are particle-free, UHV
- Scrapers: 4 sets by 4 jaws in each
  - Independently moving, electrically isolated, radiation-cooled plates



MEBT – status

- Magnets
  - Quadrupoles and dipole correctors will be supplied by BARC, India
    - Prototypes will be used for RFQ beam commissioning
  - All power supplies are on hand
- Prototype bunching cavity is being tested
  - Ordering of 3 production cavities will follow
  - Five 3 kW 162.5 MHz amplifiers have been ordered
    - One has arrived and is been used in testing the prototype bunching cavity
- A 4-jaws scraper set was tested with LEBT beam
  - Two more sets are in production
- Diagnostics is under development
  - BPMs, toroids, insertion devices





MEBT chopping system – status

- Kicker
  - One half of a 50 Ohm kicker prototype has been tested
    - Excellent RF properties; full-power tested in vacuum
  - Complete kicker prototype is being assembled
    - Will be installed at MEBT in FY16
  - Proof-of-principle operation of a ¼– power driver has been demonstrated
  - If LDRD to develop a fast driver succeeds, the results may be used for a cheaper, 200 Ohm kicker version
    - A prototype kicker is being developed as well
- Absorber
  - A ¼ - size prototype has been tested with an electron beam
    - Will be tested with H^- beam in FY16
    - Design of a full-size absorber will follow

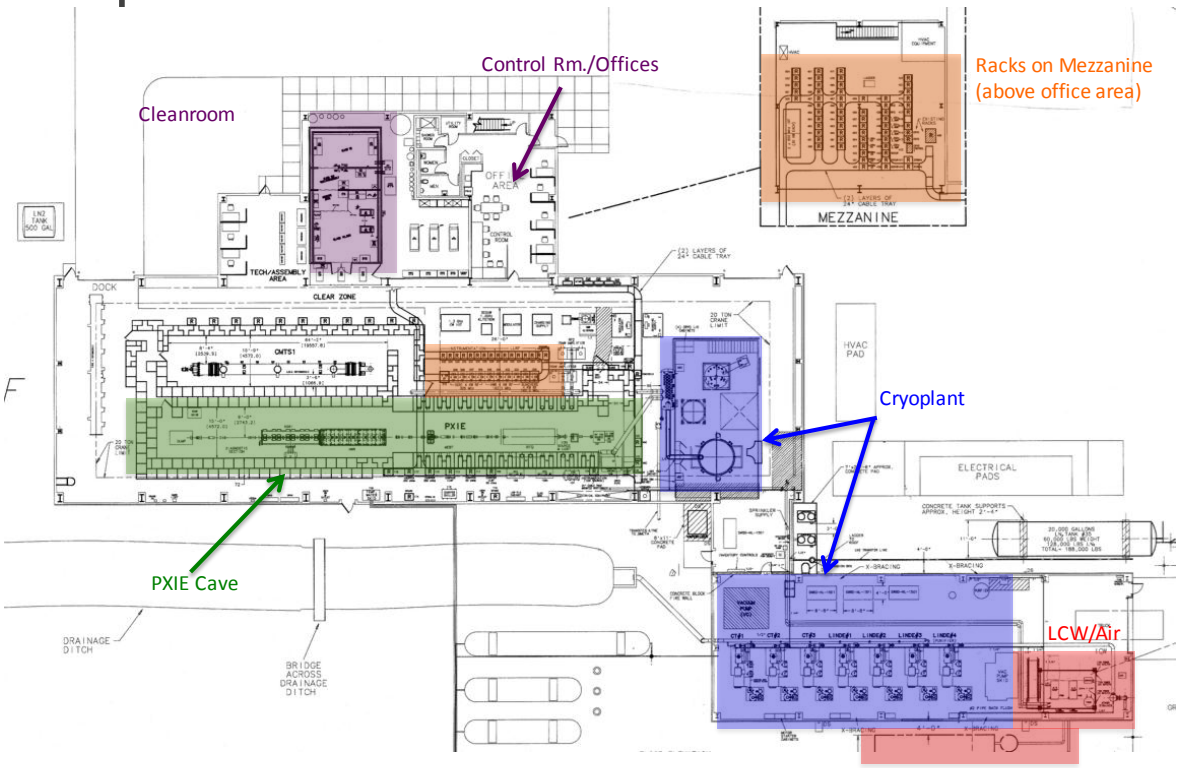
Beyond the warm front end

- Cryomodules: Half-Wave Resonator (HWR) and Single-Spoke Resonator (SSR1) cryomodules
  - HWR: 162.5 MHz, 2-10 MeV; SSR1: 325 MHz, 10-25 MeV
  - Under construction; expected to be delivered in FY17
  - Will be covered in V. Yakovlev's presentation
  - Indian contribution:
    - some of SSR1cavities; 10 kW 325 MHz amplifiers;
    - participation in LLRF and RF protection systems

- High Energy Beam Transport (HEBT) and beam dump
  - To analyze properties of the beam coming out of SRF
    - Emittance, halo, stability, bunch extinction
  - To safely accept 50 kW beam
  - At the stage of conceptual design

PXIE infrastructure

- CMTF building, housing PXIE, has all required capacity
  - Cryo, power, water
  - Distribution systems are being designed and implemented
- All components for the PXIE cave are on hand

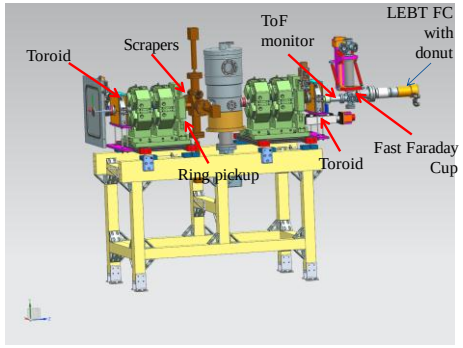


PXIE commissioning plan

- FY15
  - install RFQ; prepare the RFQ beam characterization setup
- FY16
  - Commission RFQ (RF and beam)
  - Install most of the MEBT magnets and kicker prototypes
- FY17
  - Finalize design of all MEBT components
  - Receive both cryomodules
- FY18
  - Install final MEBT; demonstrate bunch-by-bunch selection
  - RF commissioning of both cryomodules; pass a beam through
- FY19: final beam parameters

Warm front end commissioning

- After RFQ RF commissioning, characterize beam (FY16)
  - Using 1st MEBT section, essential diagnostics, and a temporary beam dump; 10 μs pulse first
- Increase the pulse length to 10 kW CW (FY16)
- Install 4 more triplets (FY16)
  - With prototypes of kickers and absorber
  - Test the absorber prototype with H^- beam (FY16)
  - Pass the beam through the kickers
    - Test EM characteristics by applying 162.5 or 81.25 MHz CW RF and observing the bunch shift with BPMs (FY17)
    - Test kicker protection system and their survivability (FY17)
- Install full- length MEBT with final elements (FY18)
  - demonstrate bunch-by-bunch selection (FY18)
  - Test vacuum compatibility of MEBT with SRF (FY19)



Summary

- At the end of the PXIE R&D program, the critical technologies of the PIP-II Linac front end will be validated, accomplishing
  - Acceleration of a 2 mA CW beam in low-beta SRF
  - Demonstration of bunch by bunch selection using state of the art chopping system
  - Specification of conditions for reliable operation of SRF cavities in vicinity of a high power MEBT absorber
  - LFD compensation in pulsed operation of SSR1
  - Detailed characterization of beam parameters, dynamics, and stability