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MEBT Status and Commissioning Plan

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PIP-II Machine Advisory Committee Meeting

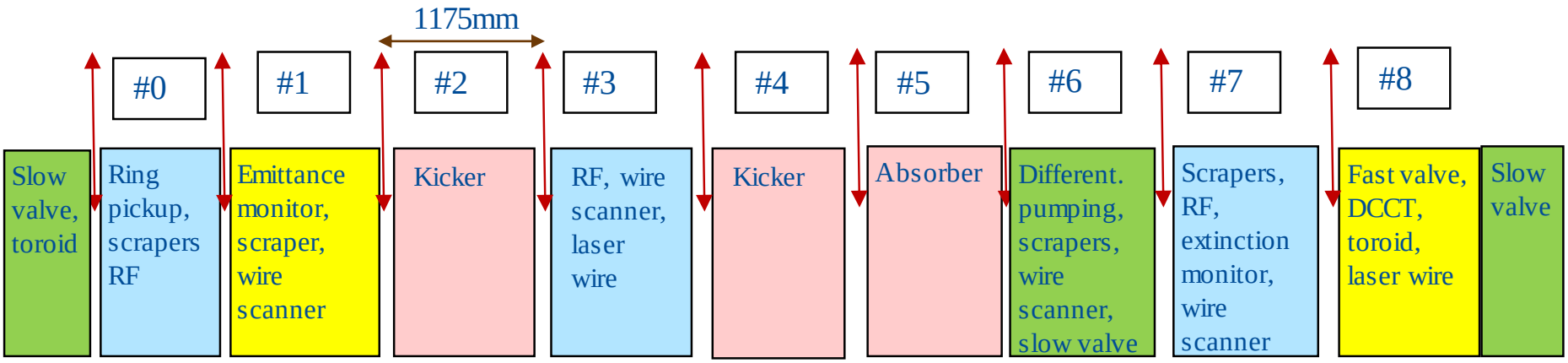
15-17 March 2016

Outline

- MEBT functions and challenges
- MEBT elements and their status
  - Magnets, bunching cavities, scrapers, chopping system
  - Diagnostics and RF will be covered in separate talks
- MEBT stages
- MEBT at PXIE vs PIP-II MEBT

MEBT functions

2.1 MeV; 5/10 mA (nom./max) CW; emittance 0.23/0.31 μm rms n (transv./long.)

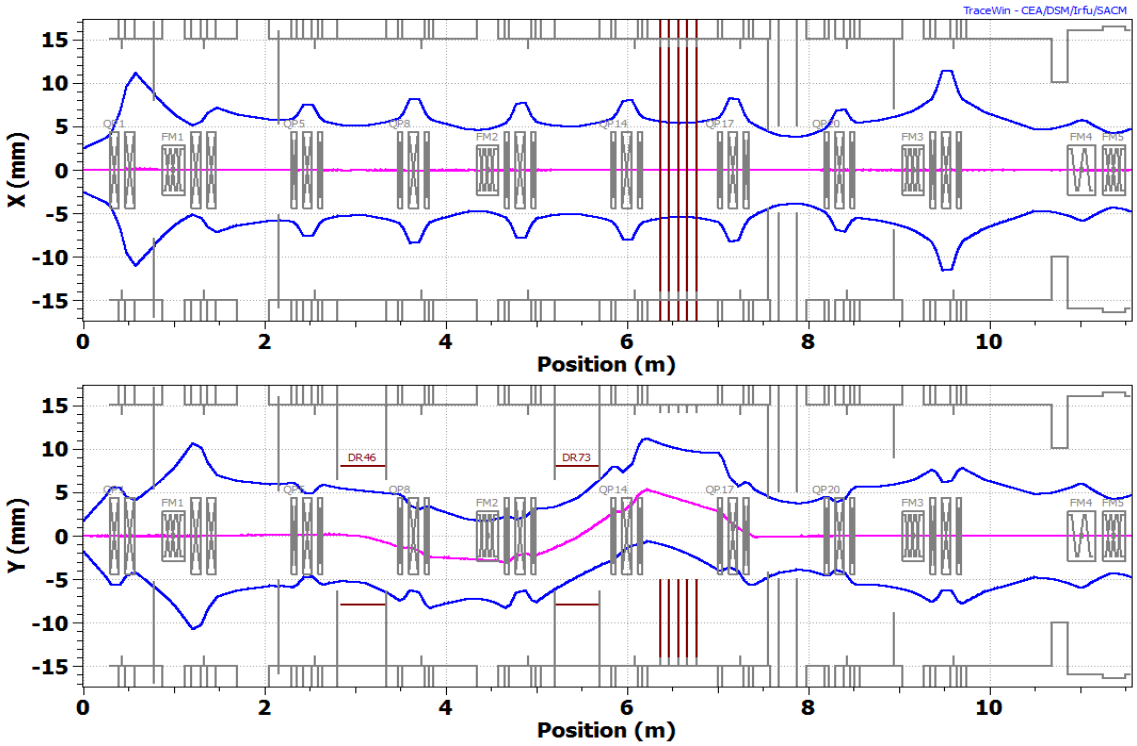


- Optical matching from RFQ and to HWR
- Chopping
  - Any bunch from initial CW train can be removed
- Scraping
- Transition from HV to particle-free, UHV part upstream of HWR
- Measuring beam parameters; MPS

PIP-II MEBT challenges to address

- The main challenges are related to the goal of bunch-by-bunch selection
- Beam chopping
  - Fast kickers; beam loss and extinction
  - High-power beam absorber in vicinity of passing bunches
- Vacuum management near SRF
  - Absorber gas load, dust, accident scenarios
- Measuring beam optics; stability of operation
  - Passing the beam through 3 tight apertures (kickers and differential pumping insert)
  - Interaction with the scraping system
  - Emittance growth
- All will be studied at PXIE

PXIE MEBT configuration



3σ envelopes of passing bunches.
2.1 MeV, 5 mA. TraceWin.
A. Saini.

- Two doublets and 7 triplets; three bunching cavities
  - No dramatic changes in the optical design since 2011
- Chopping system: two kickers and absorber
- Smaller beam size after absorber for differential pumping

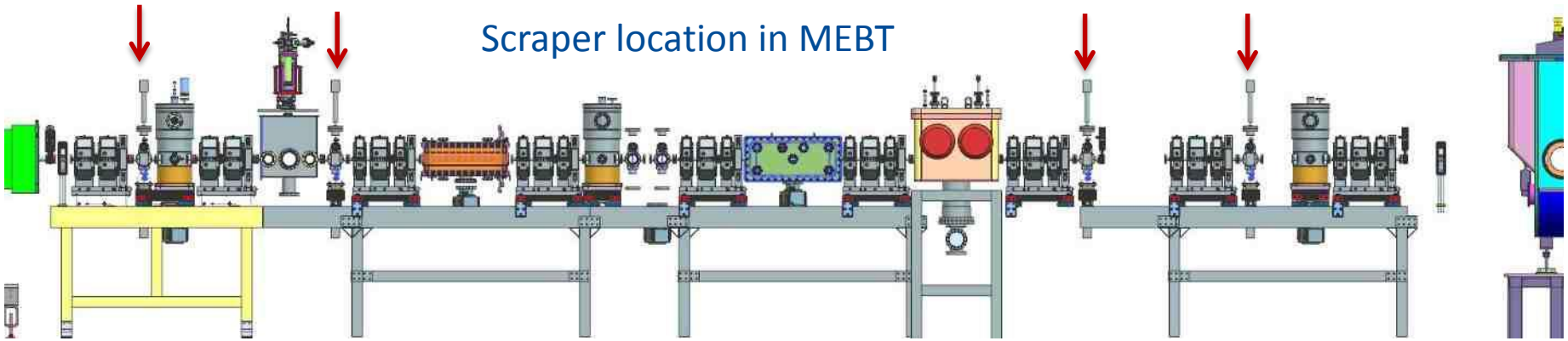
Focusing elements

- Magnets: 25 quadrupoles, 9 x 2 dipole correctors + spares
  - Produced by BARC, India and delivered in batches
    - First two doublets with dipole correctors are installed on girder
      - Considered prototypes, but quality within specs
    - Four triplets are coming in August 2016
    - The rest in FY17
  - Power supplies are inherited from Ecool
- Bunching cavities: procured at HiTech
  - A prototype was fully tested and is used in MEBT-1
  - 3 production cavities have been ordered (May'16 delivery)
  - bunching cavity amplifiers are being commissioned (see R. Pasquinelli's report)

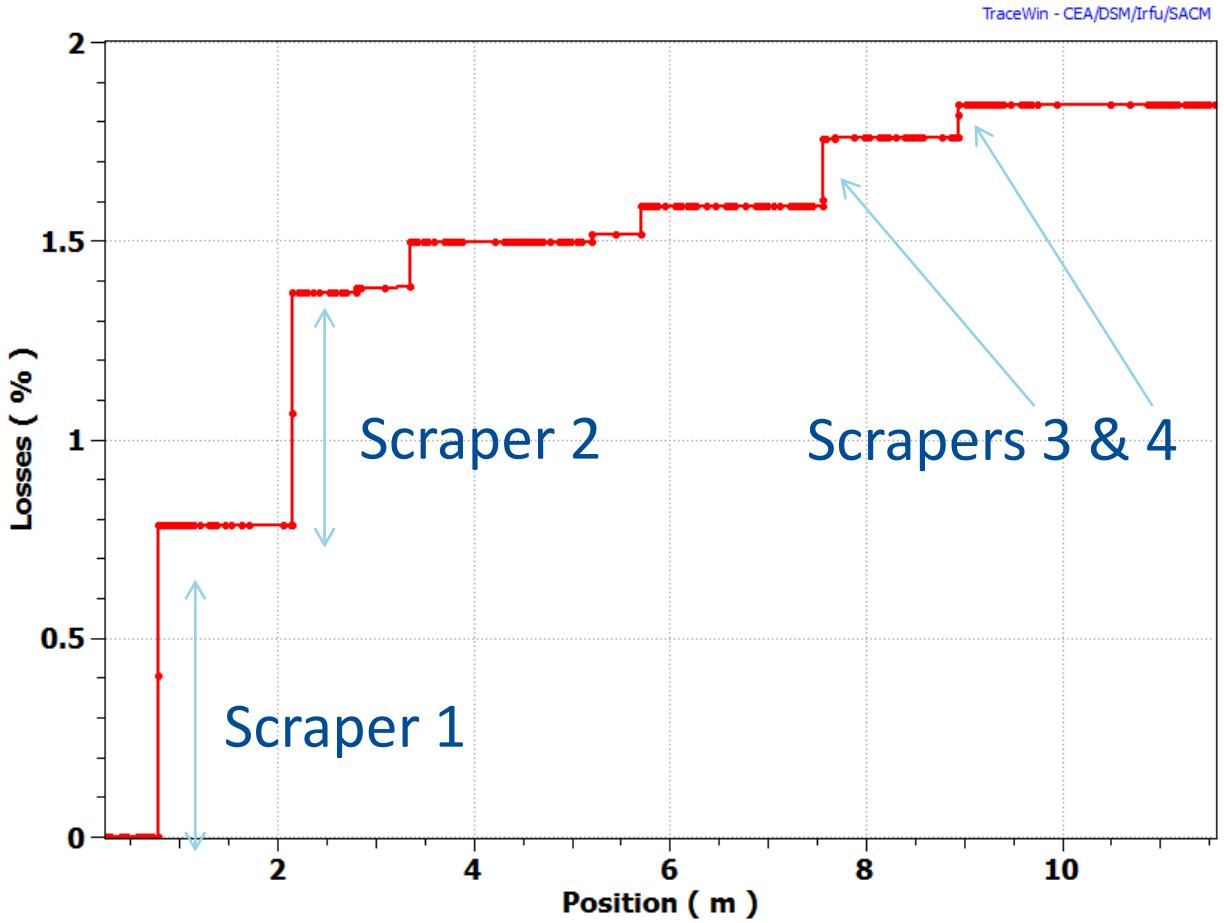
Two doublets and bunching cavity installed on a girder in the PXIE cave

MEBT scraping system

- 4 scraper sets, 4 blades in each set. Will be used for
  - Diagnostic
    - Beam size and profile measurements; beam halo
  - Part of active protection system
    - Increased scraper current generates alarm signal for MPS
  - Scraping (the main function)
    - Scrape the beam halo or intercept the beam in case of incidents
- One set was successfully tested at LEBT (200W/set rating)

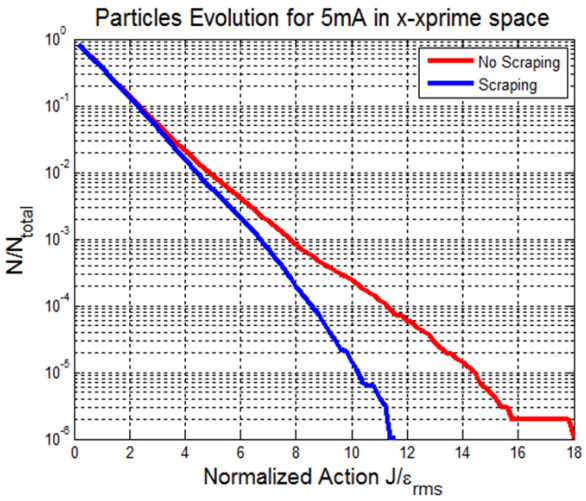


Nominal scraping scenario



Scraper 1	Scraper 2	Scraper 3	Scraper 4
0.8 %	0.6%	0.16 %	0.08 %

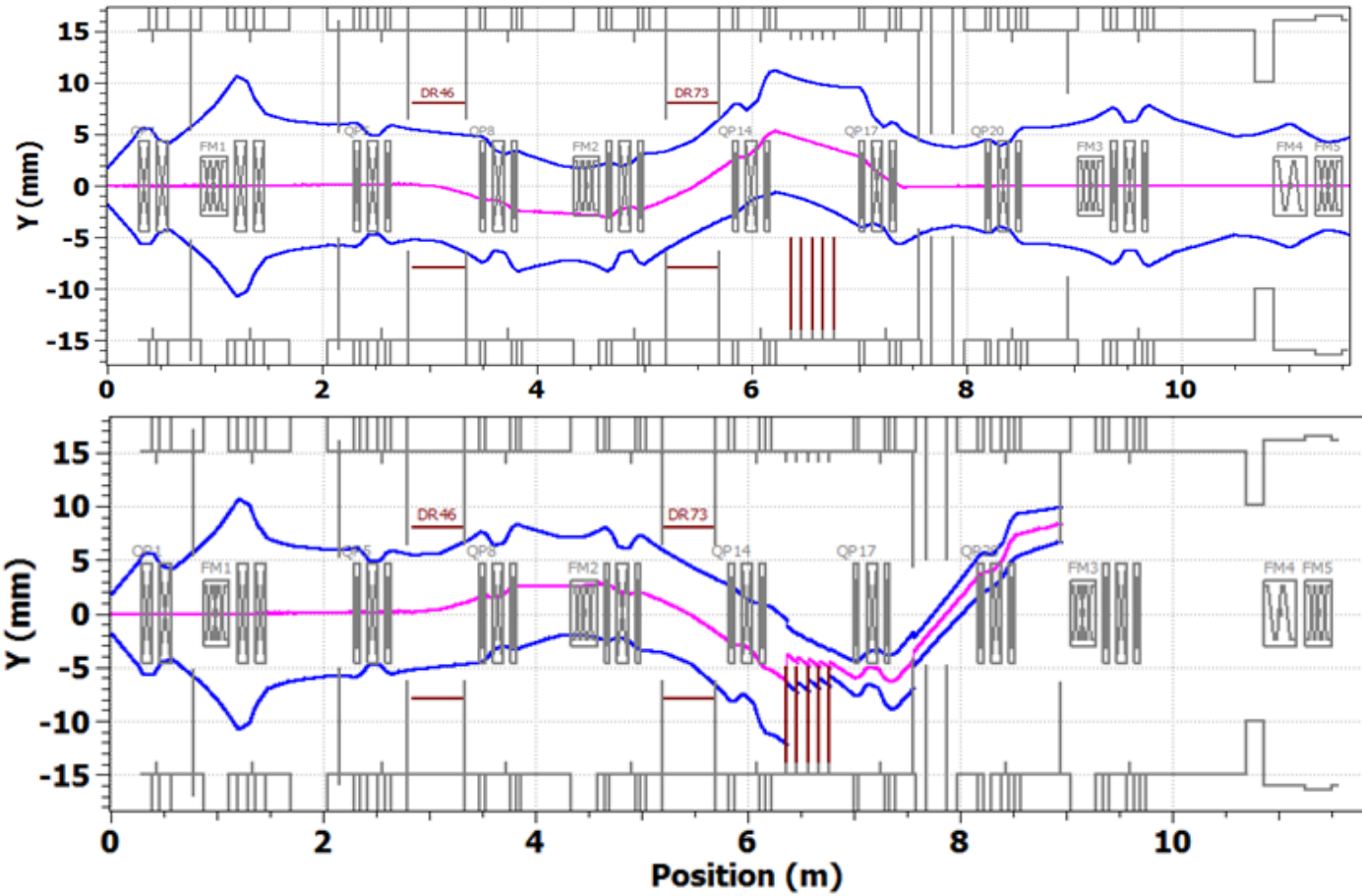
- Scraper positions are adjusted to be close to 90º of transverse phase advance
- Protect SRF from trajectory or envelope errors



Beam losses for passing bunches. Nominal beam (5 mA, $\varepsilon_{tr/z}$=0.21/0.28 µm). A. Saini.

Chopping system

- Two travelling-wave kickers working in synch and absorber
  - Two kicker versions, 50 Ohm and 200 Ohm



Passing bunch. -250V, +250V on upper plates.

Removed bunch. +250V, -250V on upper plates. Case with 0.05% of beam leaking to scrapers is shown.

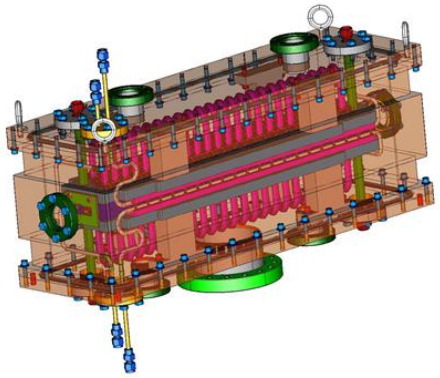
3σ envelopes. 2.1 MeV, 5 mA. A. Saini. Bipolar kicker version.

Chopping system - development

- Absorber: 21 kW CW; 0.5m; 29 mrad grazing angle
  - Separate TZM plates pressed against a water-cooled aluminum base; ¼ prototype tested
  - No new development for the absorber since last P2MAC
- Kickers: 2 versions distinguished by characteristic impedance
  - Main version – 50 Ohm; bipolar kick; AC-coupled
    - Driver: linear amplifier with pre-distortion; commercially available
  - Second version – 200 Ohm
    - Higher impedance allows considering a fast switch as a driver
    - Potentially simpler and cheaper solution; DC-coupled

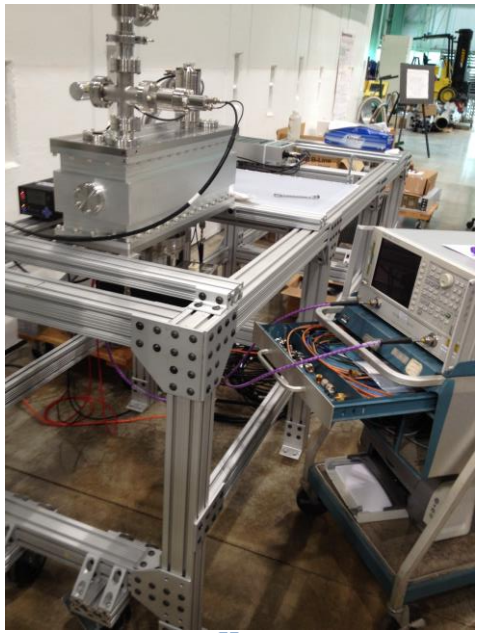
50 Ohm kicker

- Features
  - Bipolar signal; bunches to be removed or passed are kicked in opposite directions
  - Plates connected in vacuum with 50 Ohm cables
- Status
  - One plate was successfully tested in vacuum
    - Full-power and RF measurements
  - Final prototype is fully assembled
    - Will be power-tested at MEBT



3D model. A.Chen, M. Jones

Half of the kicker (one plate) assembled. D.Sun



Kicker under testing. D.Sun, D. Peterson

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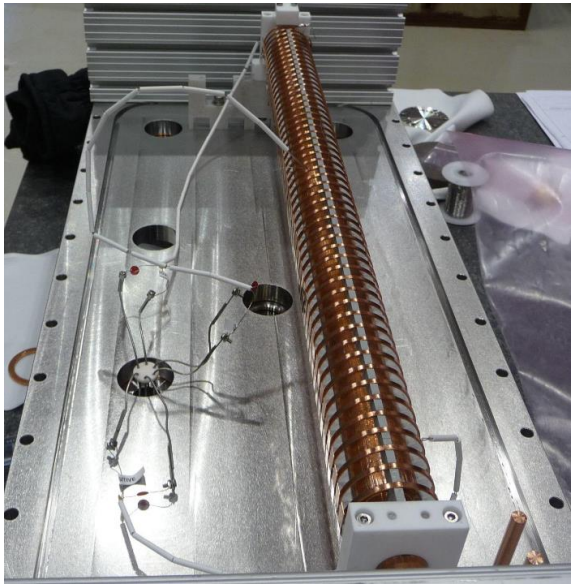
200 Ohm kicker

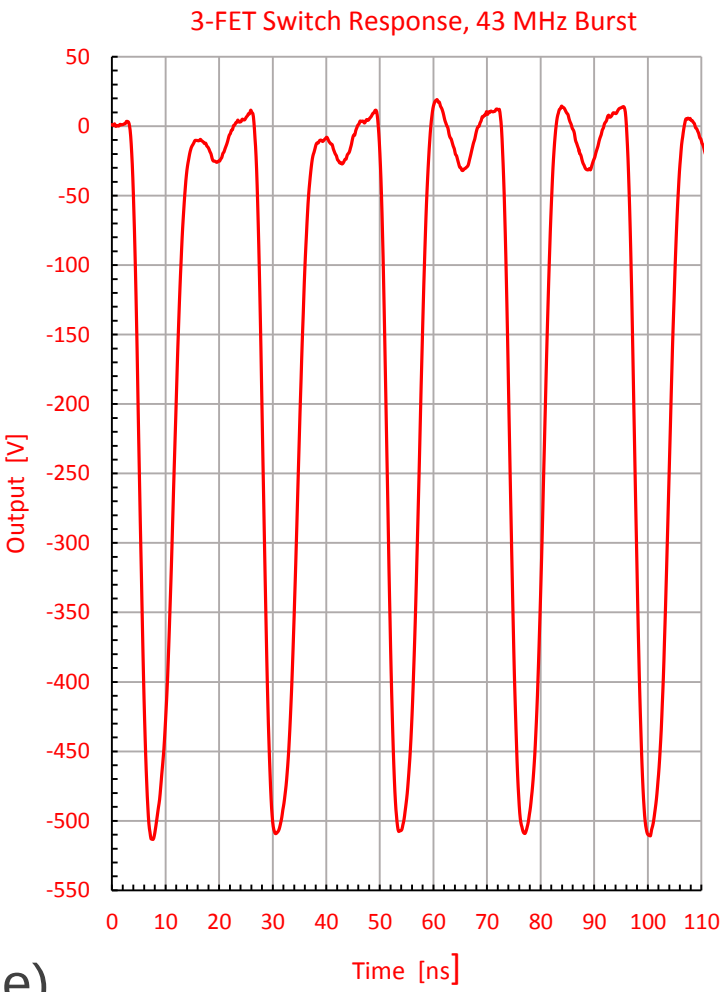
- TW structure is a helix with welded plates
- A vacuum-compatible helix was tested
  - Power testing in vacuum is successful
  - The phase velocity was found off by 5%; redesigned
- A complete kicker with modified helixes is being assembled
  - Planned to be fully tested before end of summer 2016
- Each helix will be driven by a switch
  - From 0- to- +500 V and from 0- to- -500V, correspondingly
  - Switch scheme: 3-4 FETs in series triggered simultaneously



Kicker prepared for power testing in vacuum.
A.Chen, G.Saewert

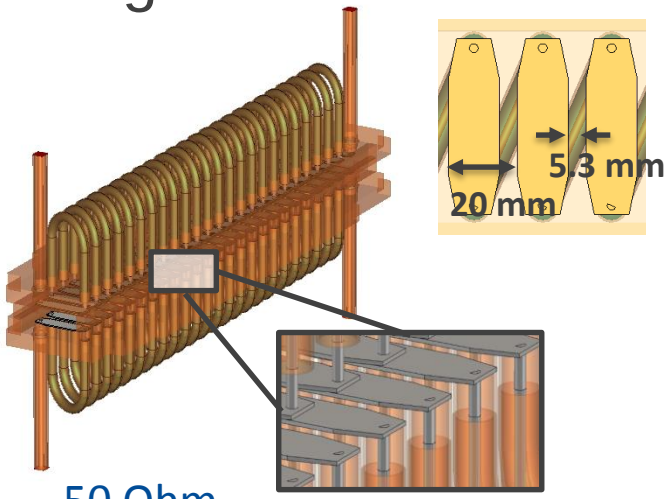
200 Ohm Helix Driver status (G. Saewert)

- Evaluation results of 3- GaN FET “-500V” switch
  - Load used: 185 Ohm
  - 3.0 ns turn-on, 4.0 ns turn-off (5-95%)
  - Operated at 630 V
  - Timing match of 3 boards is <0.2 ns
  - Flattop pulse width adjustable range: 2.5 ns to infinity
  - Tested 9 MHz CW, and >40 MHz bursts
  - Better cooling is required for higher rep rates
- Results of thermal modelling of a scheme with water cooling
  - 4 FETs mounted on BeO ceramic
  - ~20 W per FET (extrapolated from data)
  - Junction temperature: ~120 ºC (acceptable)

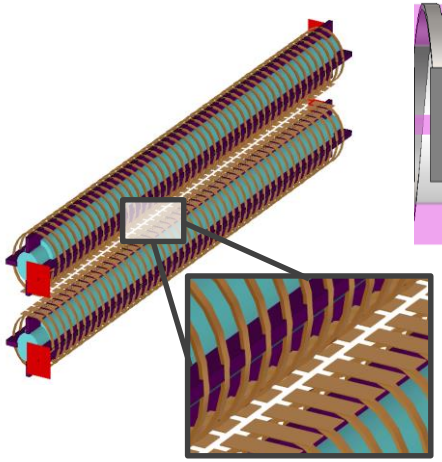


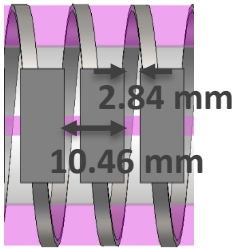
Kickers simulations (M. Hassan)

- Both kickers were simulated with time domain solver of CST
  - With all mechanical details and realistic pulse shapes
- Angles differ from the model of parallel plates by <10%



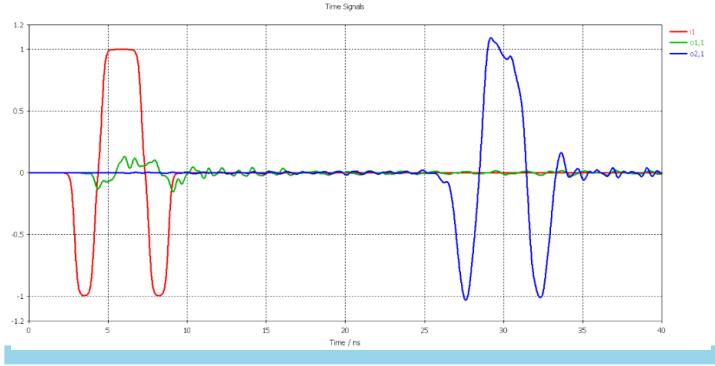
50 Ohm

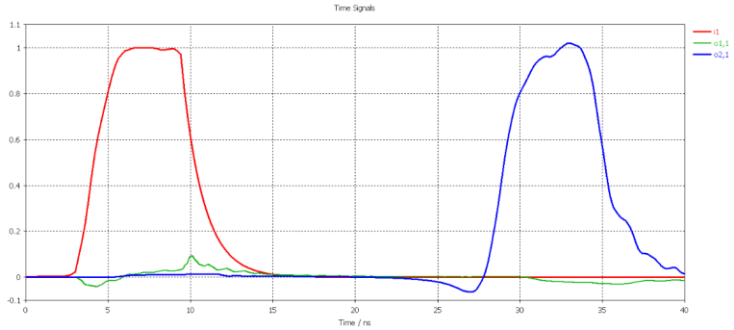




200 Ohm

Simulated geometries and propagated signals for two kickers





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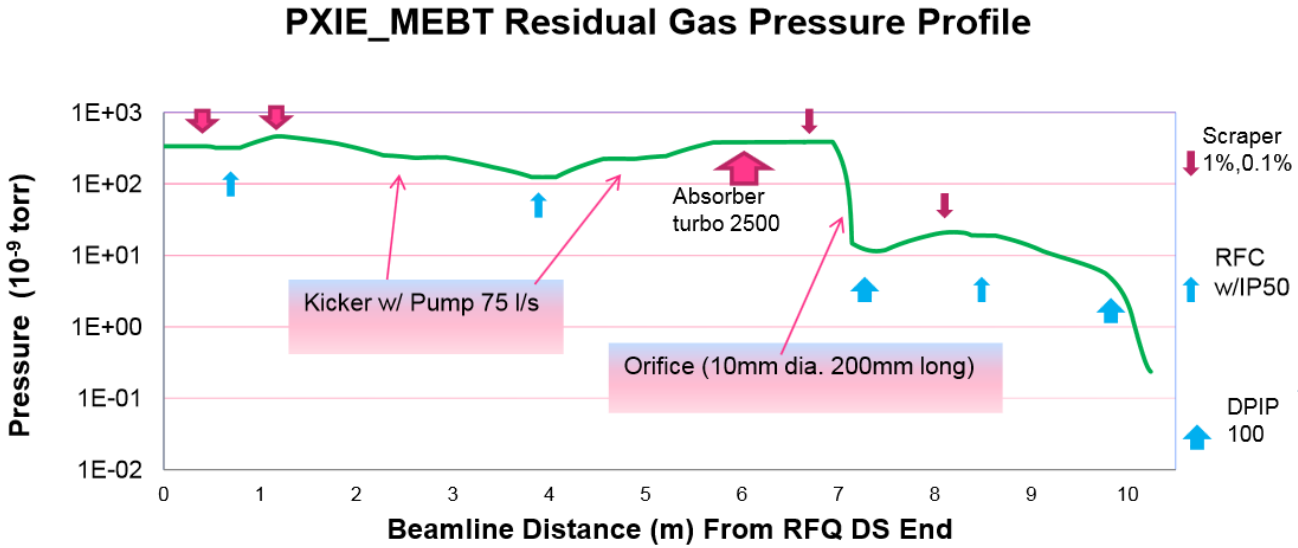
Vacuum components

- HV in most of MEBT and UHV, particle-free in last ~3m
  - MEBT vacuum concept did not change since 2012



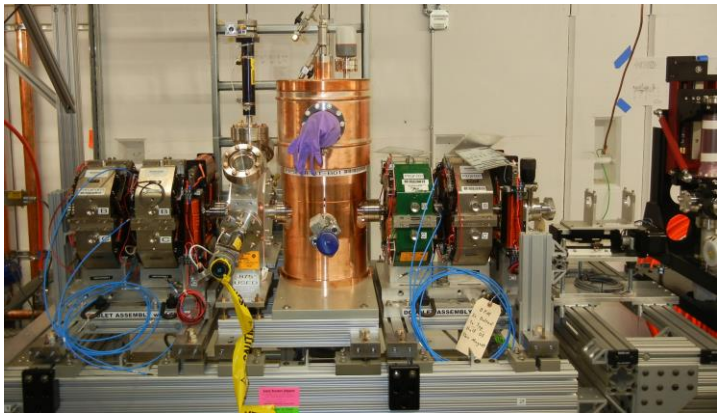
A. Chen

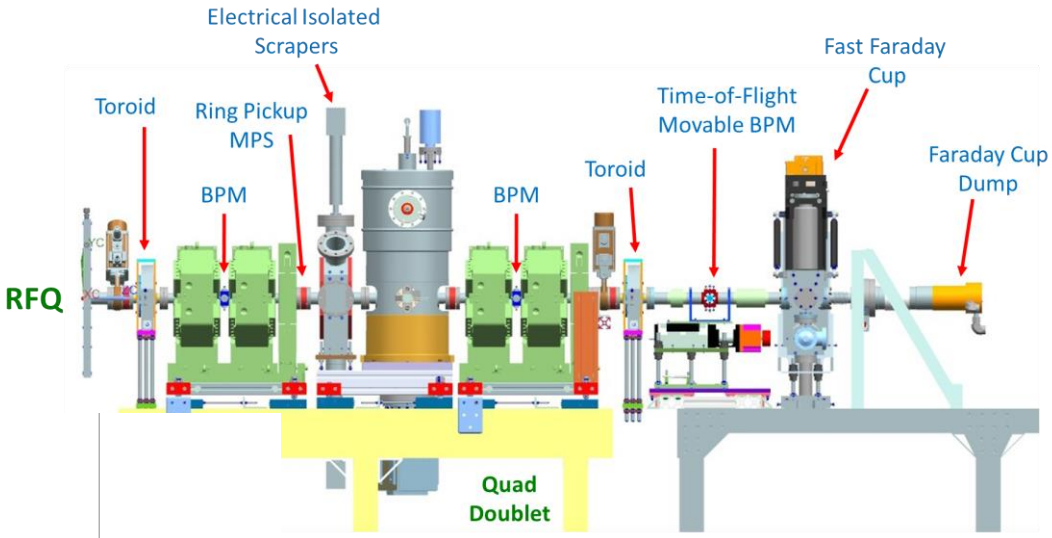
  - All vacuum equipment was identified and most purchased
  - Design of the differential pumping section begins
  - From PXIE experience, need to decide for PIP-II
    - Length of particle-free region
    - Fast acting valve system area

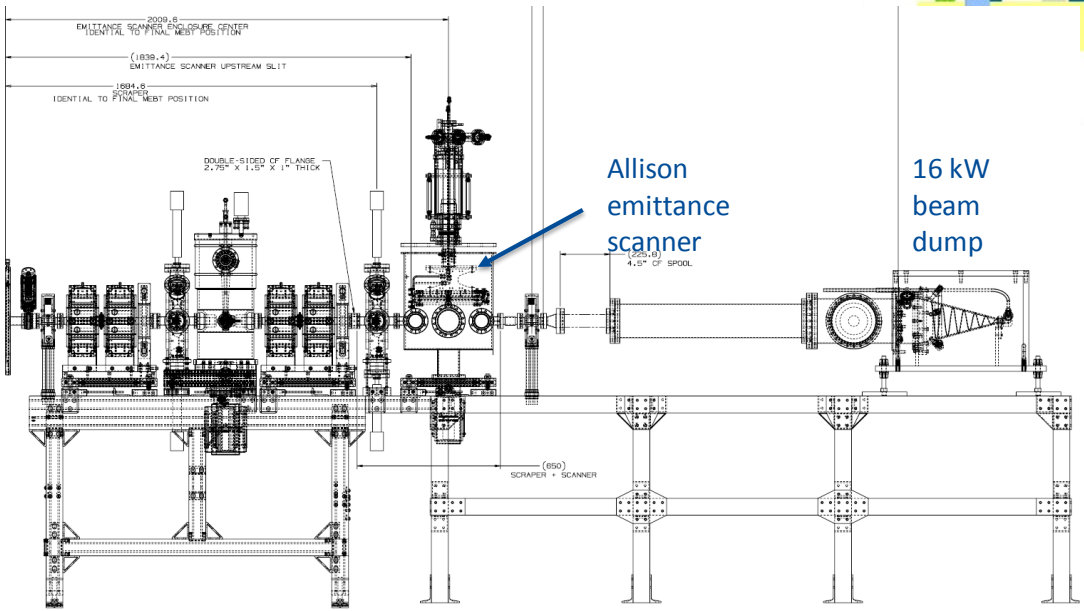
MEBT commissioning plan

- MEBT: 3 intermediate steps
  - determined by magnet delivery schedule
  - MEBT-1 – 2 doublets, 1 bunching cavity (present configuration)
    - To commission the RFQ beam; hopefully 10 kW CW
  - MEBT-2 - + 4 triplets, +1 bunching cavity
    - Install in Fall 2016, run until Spring 2017
  - MEBT-3 - + 3 triplets, +1 bunching cavity
    - Install in Spring 2017, run until shutdown to install SRF
    - Full length, prototype elements
- The final MEBT (install in FY18)
  - Particle-free vacuum chamber in front of HWR
  - Final chopping system (final kickers, drivers, and absorber)
    - Bunch-by-bunch selection

MEBT-1: 2 doublets, 1 bunching cavity







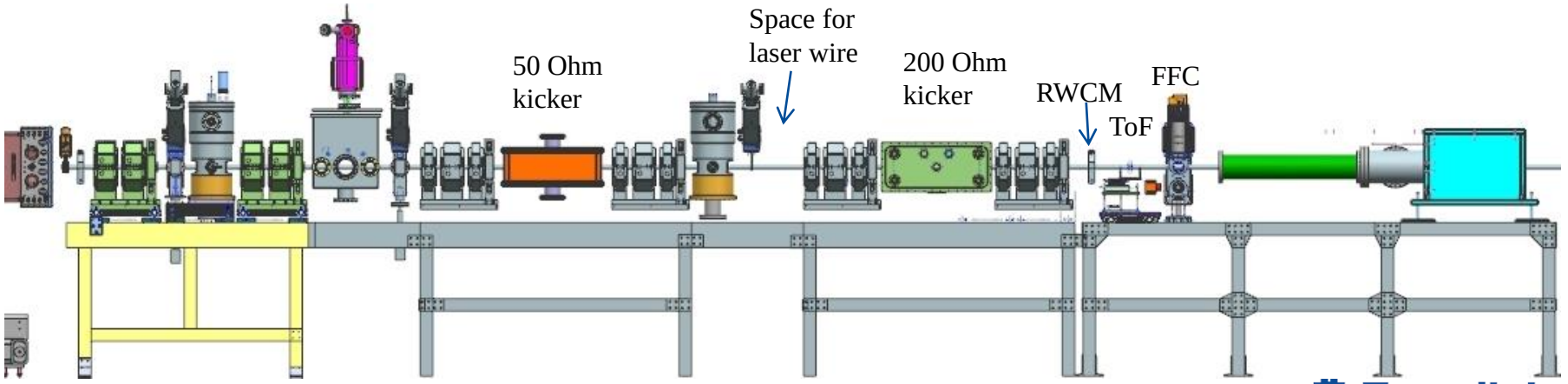
Final MEBT-1 configuration (CW - capable)

Initial MEBT-1 configuration
≤1 ms beam; 20 Hz, ≤5 ms RFQ RF

- Characterization of the beam from RFQ
- Commissioning of sub-systems
  - MPS, LLRF, Instrumentation
- Beam optics
  - Bunching cavity, magnets

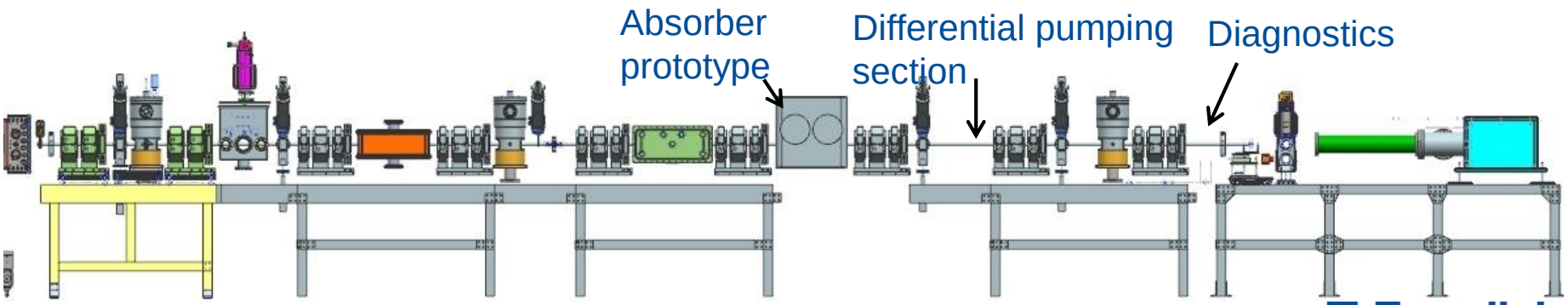
MEBT-2: 2 doublets, 4 triplets, 2 bunching cavities

- The main goal is to test kickers
  - Install both prototypes
  - Test: kickers survival and angle to the beam
    - 50 Ohm: two 81.25 MHz CW drivers
    - 200 Ohm: two 500V switch prototypes
  - Proceed with fabrication of final kickers
- Optics; tests of laser wire and extinction monitor (RWCM)
  - Could be 1-3 versions differing by placement of diagnostics



MEBT-3 : 2 doublets, 7 triplets, 3 bunching cavities

- All magnets, cavities, and scrapers are in final locations
  - The kickers are still 50 Ohm and 200 Ohm prototypes
  - 5kW absorber prototype instead of full absorber
- The last ~2m are “cleanable” but assembled not particle-free
- Main goals
  - Prepare beam for injection into HWR
  - Optics; UHV sections and differential pumping
  - Finalize measurements started in previous versions



PXIE MEBT vs PIP-II MEBT

- While all PXIE MEBT components are designed to PIP-II specs, there may be differences
  - Plan to have the ion sources accessible during linac operation
    - Need a radiation wall (similar to SNS) in MEBT; requires one more section
  - May need a longer particle-free region in MEBT
  - More detailed analysis of risks may require a longer distance from the MEBT chopper absorber to SRF to provide protection by the fast acting valve
  - Longer MEBT would require additional triplets and may need an additional bunching cavity