PXIE Medium Energy Beam Transport concept

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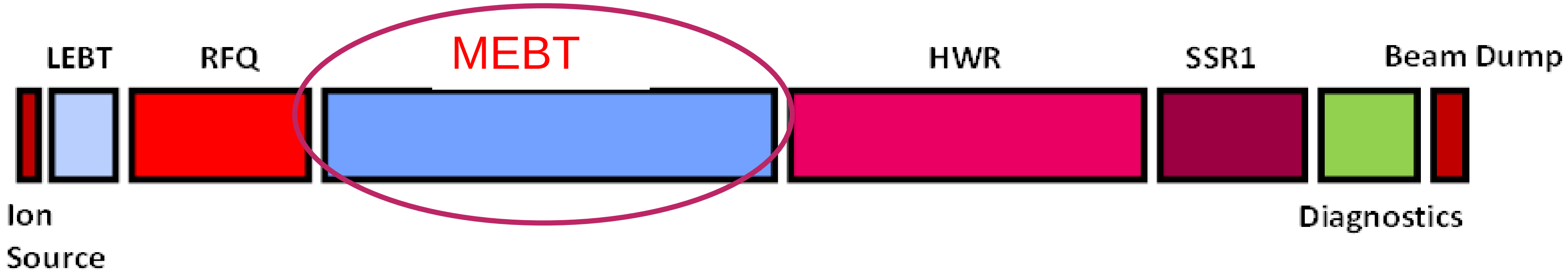
Project X collaboration meeting
April 10, 2012

Outline

- Goals and specifications
- Scheme
- Subsystems
- Summary

Goals



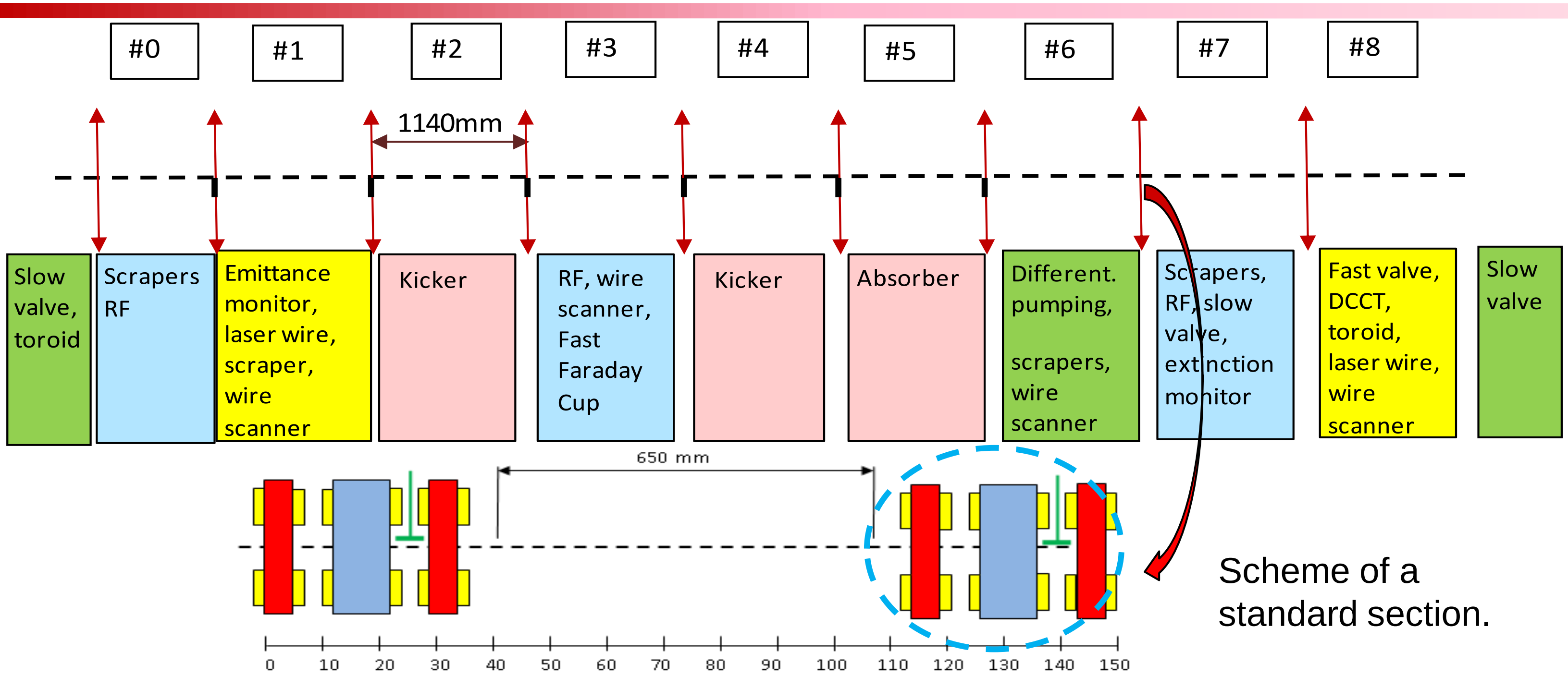
- Medium Energy Beam Transport (MEBT) functions
  - Form the bunch structure required for the linac
    - Bunch-by-bunch selection
  - Match optical functions between RFQ and SRF
  - Include tools to measure the properties of the beam coming out of RFQ and sent to SRF
  - Clean transverse halo particles

MEBT Functional Requirement Specification

Beamline height from the floor	1.3m
Ion type	H-
Input beam energy	2.1 (+/-1%) MeV
Nominal output energy (kinetic)	2.1 (+/- 1%) MeV
Maximum frequency of bunches	162.5 MHz
Nominal Input Beam Current	5 mA
Beam Current Operating Range	1- 10 mA
Nominal Output Beam Current	1 mA
Nominal Charge per Bunch	30 pC
Residual Charge of Removed Bunches	< 10-4
Beam Loss of pass through bunches	< 5%
Nominal Transverse Emittance	0.27 mm mrad
Nominal Longitudinal Emittance	0.8 eV-µs
Longitudinal Emittance Tolerance	<10% increase over input
Transverse Emittance Tolerance	<10% increase over input
Beam Displacement at exit	< +/- 0.5mm
Beam angle at exit	< 0.5 mrad
Scraping to transverse emittance (n, rms, pulsed mode for 10W avg beam power)	<0.05 mm mrad

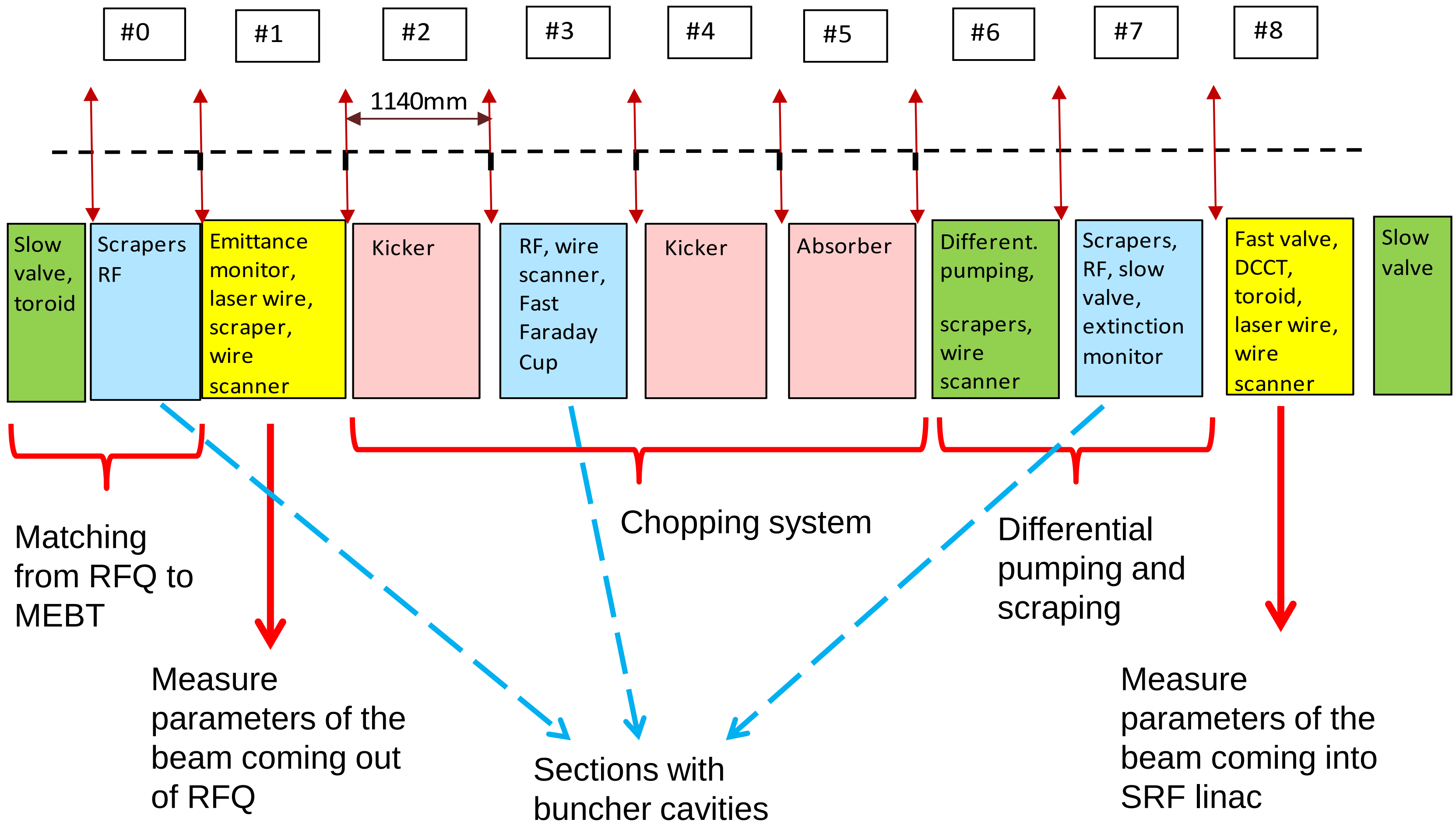
- The MEBT creates the final time structure of the PXIE beam, chopping ~80% of the beam with a wideband chopper. The MEBT allows for **bunch by bunch selection**, using a programmable cyclical buffer.
- Specifications are stable since Oct 2011

MEBT scheme

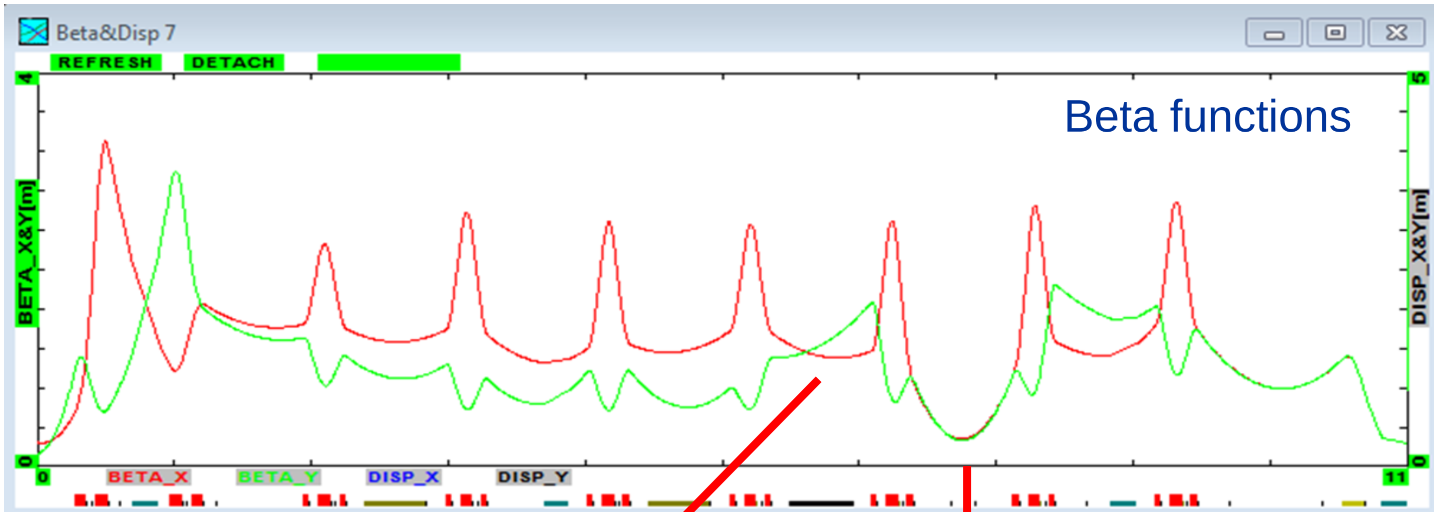


- MEBT consists of 9 sections with the total length of ~10m.
  - 8 sections have the identical length (1140 mm between centers of triplets)
  - The section #0 is shorter and is bounded by two doublets
  - ~ 90 deg phase advance between sections
  - Two kickers working in sync

MEBT scheme components



MEBT optics

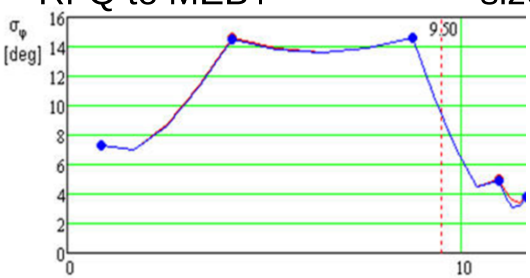


Matching from RFQ to MEBT

Increased beam size at absorber

Small orifice for differential pumping

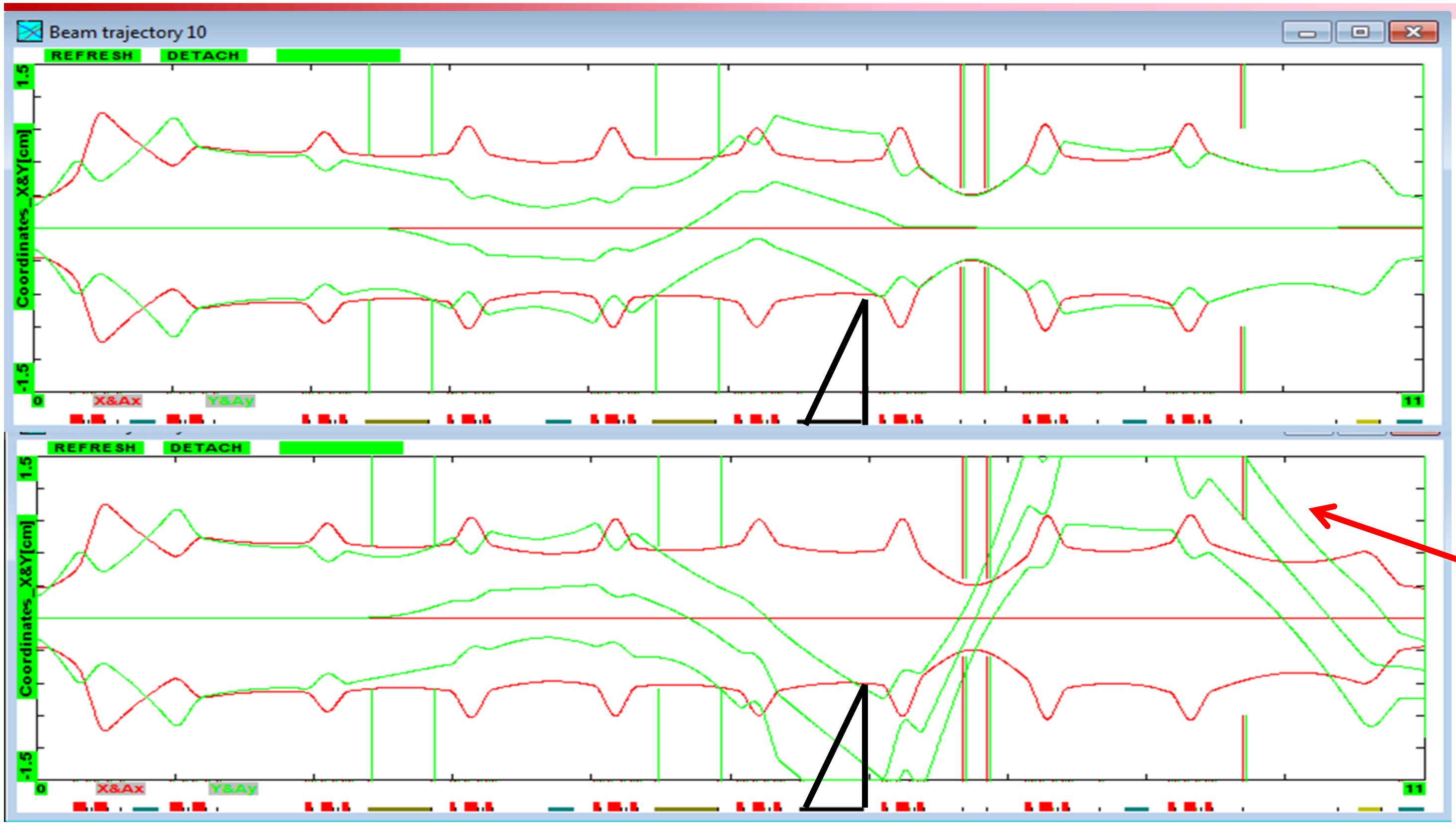
Matching from MEBT to HWR



1-sigma longitudinal size of the beam in MEBT, degree of 162.5 MHz

V. Lebedev

Beam chopping



Trajectory of the removed bunches downstream the absorber is an artifact

- Beam trajectory and 3σ envelope at for passing (top) and removed (bottom) bunches

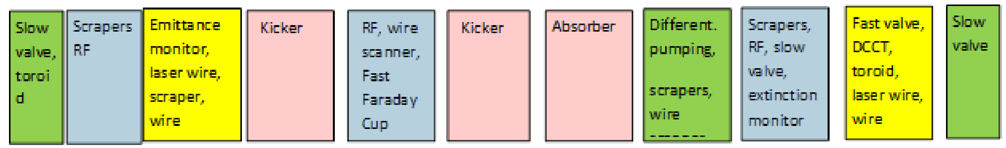
V. Lebedev

Subsystems

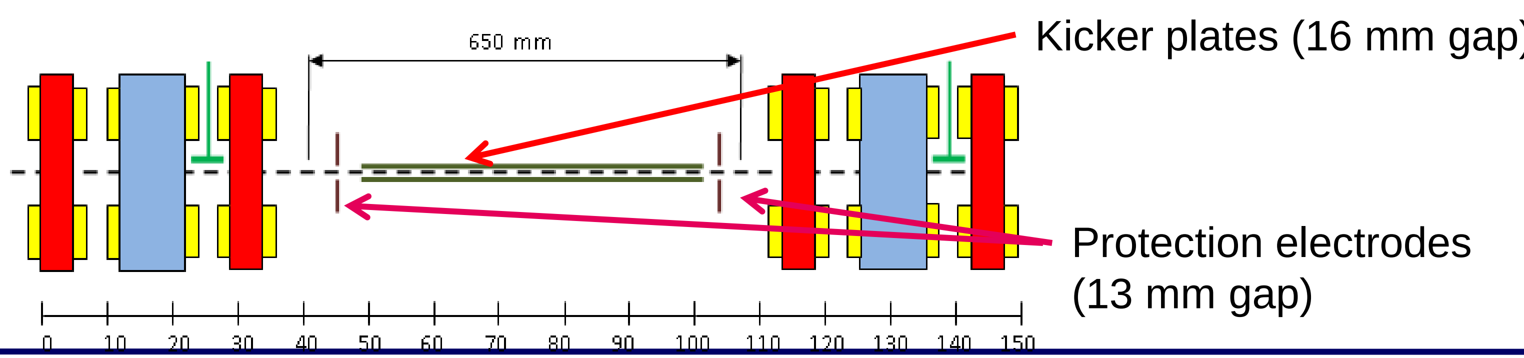
- Kickers
  - See reports of V. Lebedev, G. Saewert, and T. Tang.
- Absorber
  - See C. Baffes' report
- Quadrupoles
  - Conceptual design stage
- Buncher cavities
  - See G. Romanov's report
- Vacuum
  - See A. Chen's report
- Protection system; scrapers
  - Pre-conceptual design stage
- Diagnostics
  - See M. Wendt's report

The largest risk items. Require significant R&D.

Kickers: scheme

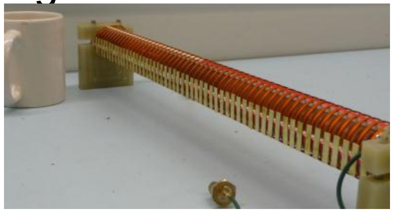


- Two kicker sections working in sync
  - –~180 deg phase advance between
  - –Kicker length in one section ~ 50 cm
  - –Vertical deflection (up at the absorber)
- Bunch dimensions (6-sigma) at kicker locations are:
  - ~12 mm vertical (Y), ~16mm horizontal (X) , and ~1.3 ns in time.

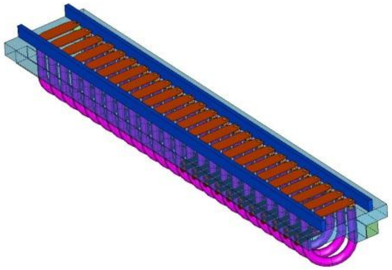


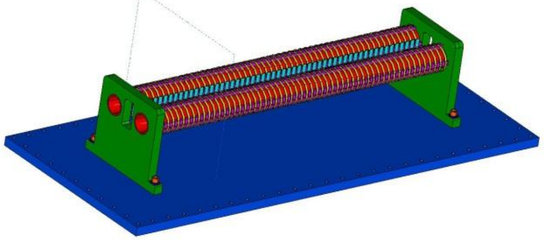
Kickers: requirements

- Any bunch of the 162.5 MHz CW train can either pass or be removed.
- The kicker electric field is generated by applying equal and opposite polarity voltage to the two opposing electrodes of each kicker assembly.
  - "Bipolar scheme": The voltage is applied to kick the beam out, and the opposite polarity is applied to allow the beam to pass through.
  - 250 V in each polarity
  - For passing bunches, the flat top tolerance is ±25 V
  - Flat top duration is 1.3 ns
  - the maximum average frequency of switching cycles is 33 MHz



- At this stage, two versions of a traveling-wave kicker are being developed
  - "50 Ohm version"
  - "200 Ohm version"





Kicker schemes

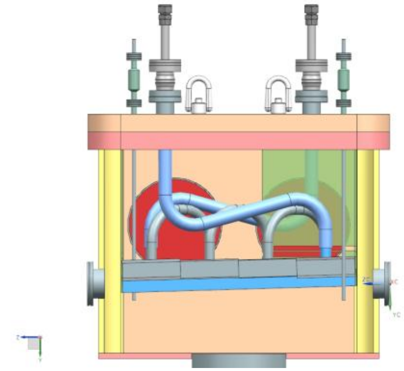
Impedance	50 Ohm	~200 Ohm
Kicker structure	Plates connected with coaxial cables	Helix with attached plates
Driver	Commercial linear amplifier fed by a pre-distorted signal	A fast switch (being developed at FNAL and SLAC)
Advantages	Commercial amplifier, feedthroughs, loads, cables	DC coupling; possibly lower cost
Kicker status	Mechanical design	EM and mechanical design
Driver status	Tested at 240 V ptp. Full-power amplifier can be purchased.	Switch tested at 500 V ptp.

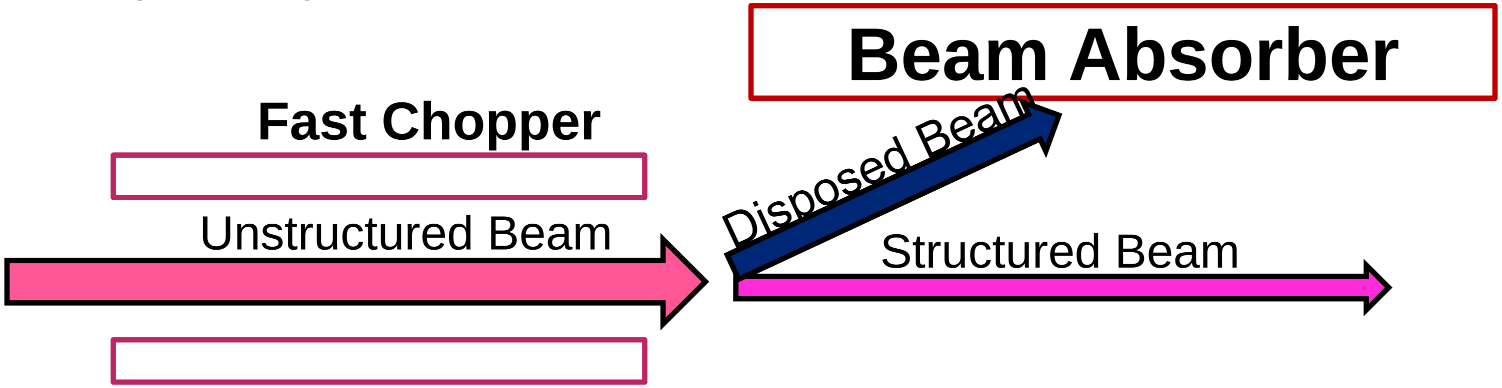
See reports of V. Lebedev, G. Saewert, and T. Tang.

Absorber

- The absorber should withstand 2.1 MeV X 10 mA = 21 kW focused into a spot with 2 mm rms radius
- Difficulties:
  - Thermal load
  - Mechanical stress
  - Outgassing
  - Blistering
  - Sputtering

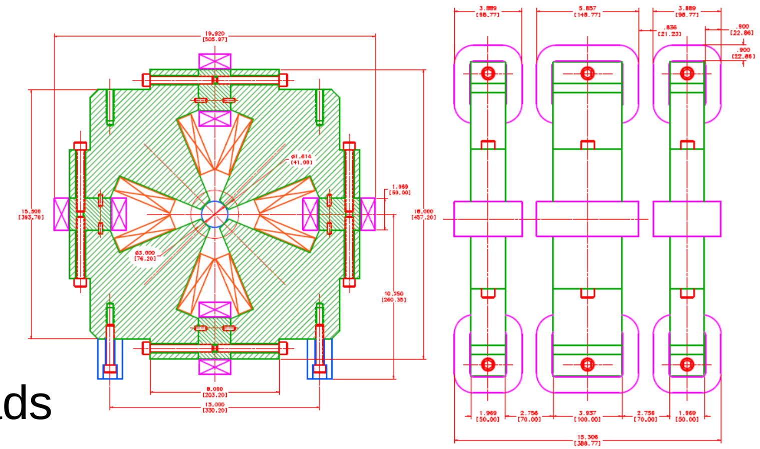
See C. Baffes' report for details





Quadrupoles

- Two types of quads, F (10 cm magnetic length) and D (5 cm)
  - Maximum integrated gradient- 1.5T/0.85T (F/D)
  - Tip separation – 34 mm (diam.)
  - Good field region- 23 mm (diam.)
  - Field quality- 1%
  - Integrated dipole coils (F)
    - 2.1 mT*m
- BPMs between quads
  - Installed before final assembly of quads
- Stage of conceptual design
  - Quad prototype in 2012



Vl.Kashikhin, A.Makarov

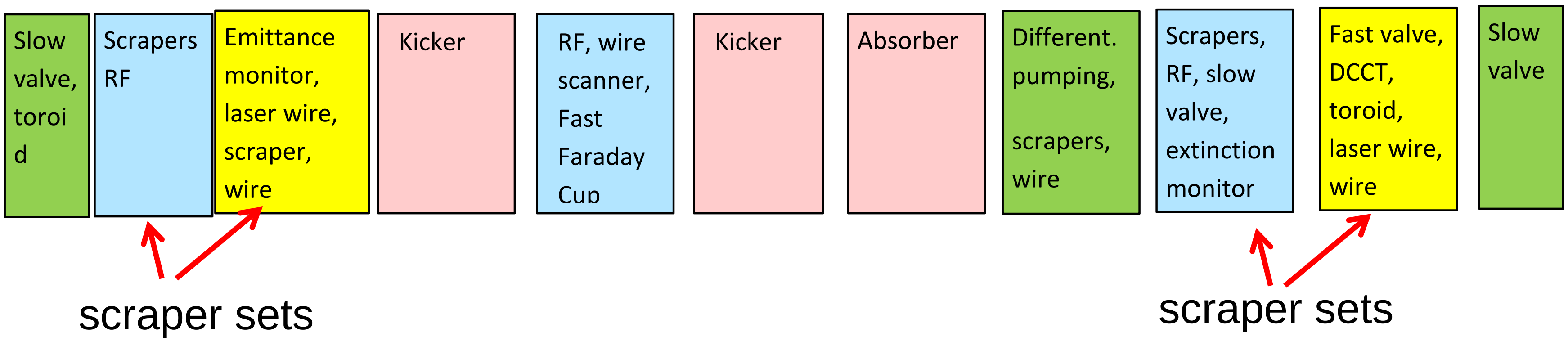
Vacuum: requirements

- H- stripping
  - Minor effect for the intensity decrease, but neutrals might flight all the way to SRF and deteriorate the cavity performance
  - Decided to limit the integral of (pressure)*(length) by $1 \cdot 10^{-6}$ Torr·m
    - Corresponds to the stripping probability in MEBT of $1.4 \cdot 10^{-4}$.
  - The flux of neutrals will be collimated in several locations of MEBT
- Gas load to SRF (Half Wave Resonator)
  - Hydrogen deposition on cavity walls should be << monolayer
  - Main gas load is H2 produced from H- at absorber (and scrapers)
    - 5mA of H- gives $4.4 \cdot 10^{-4}$ l·torr/s of H2
  - ANL operates SRF with $\sim 5 \cdot 10^{-8}$ Torr in the adjacent warm part
    - Decided to require $P < 5 \cdot 10^{-9}$ Torr at the end of MEBT
  - Solution: strong pumping of the absorber; differential pumping section
- See A. Chen's report

Protection

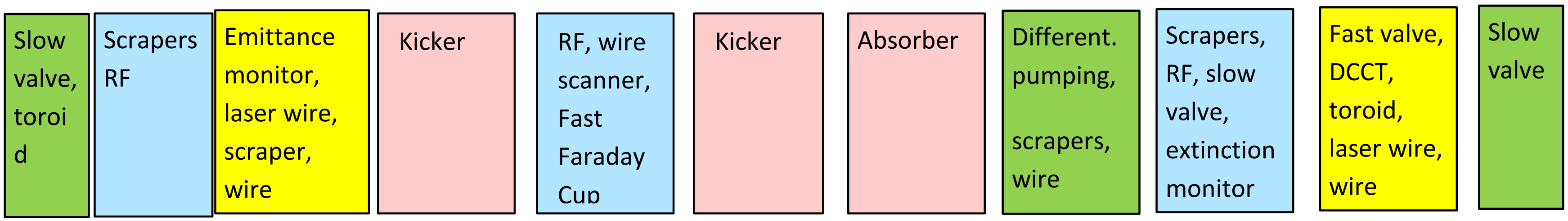
- The beam is turned off in LEBT tripped by various signals from PXIE
- MEBT protection
  - The goal is to have all MEBT beam losses at the controlled locations
  - Beam absorber and scrapers are electrically isolated to measure currents
    - Difficult to calibrate because of secondary emission
  - Comparison of toroid currents at the entrance and exit of MEBT
    - A large misbalance may be used as an indication of losses
- Protection of the kickers
  - Beam tails scraping by the scrapers at the MEBT entrance
  - Electrically isolated plates on both sides of each kicker
    - Current to plates will indicate a loss to kicker plates

Protection and scraping



- We are discussing installation of 4 sets of scrapers
  - Each set may consist of 4 individual scrapers
    - Ideally, each would be movable, electrically isolated, water cooled (50W)
  - ~90º phase advance in each pair
  - The first pair scrapes up to 1% of the CW beam and protects the kickers
  - The second pair scrapes up to 1% of the 1 mA beam and protects SRF
    - Final aperture intercepting neutrals
- Stage: pre-conceptual design

Beam diagnostics



- BPMs in each triplet or doublet
  - Transverse positions, phases, and intensities
  - Capability to gate a single bunch in a periodic sequence
- A set of diagnostics to analyze the RFQ beam
  - Toroid, emittance monitor, wire scanners, fast Faraday cup, laser wires
  - Scrapers as halo diagnostics
- A set of diagnostics to analyze the beam going to HWR
  - Toroid, DCCT, wire scanners, extinction monitor, laser wires
  - Scrapers as halo diagnostics
- During operation: BPMs, laser wires

See M. Wendt's report

Commissioning (1)

- Presently, we are discussing commissioning of RFQ with the assembled MEBT line
  - MEBT diagnostics are used to characterize the beam from RFQ
  - A temporary 2 kW beam dump is installed at the end of MEBT
- Begin commissioning with a pulse beam
  - Formed by the LEBT chopper
  - At start, ~1 µs X 60 Hz X 5mA X 2 MV = 0.6 W
    - to minimize chances to damage but being able to use diagnostics
  - The pulse length is increasing from ~1 µs to milliseconds
    - Most of power directed to the MEBT absorber
- When diagnostics and protection systems are commissioned, start CW operation

Commissioning (2)

- Characterization of the beam from RFQ
  - Current: toroid
  - Energy: time-of-flight reconstruction from BPMs
  - Transverse portrait: emittance monitors
  - Transverse tails: first set of scrapers
  - Longitudinal profile: fast Faraday cup
- MEBT optics characterizations
  - Dipole correctors and BPMs; quads and wire scanners
- Beam at the exit
  - DCCT, toroid, wire scanners, second set of scrapers; extinction monitor

Slow valve, toroid	Scrapers RF	Emittance monitor, laser wire, scraper, wire scanner	Kicker	RF, wire scanner, Fast Faraday Cup	Kicker	Absorber	Different. pumping scrapers, wire	Scrapers, RF, slow valve, extinction monitor	Fast valve, DCCT, toroid, laser wire, wire	Slow valve

Summary

- Specifications for MEBT have been written, and its optics is frozen
- R&D is being actively pursued for the most challenging subsystems, absorber and kickers
  - Technical designs are underway;
  - Plan to manufacture and test a beam absorber prototype with electron beam in FY2012
  - Plan to manufacture and test kicker prototypes in fall of 2012
- Other subsystems are progressing
  - Buncher cavities – technical design
  - Quads, BPMs, vacuum system - conceptual design
  - Other system at the stage of discussions
- In a technically driven schedule, MEBT should be ready by the time of RFQ delivery