The Project-X Injector Experiment (PXIE)

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NA-PAC'13, Oct 1, 2013

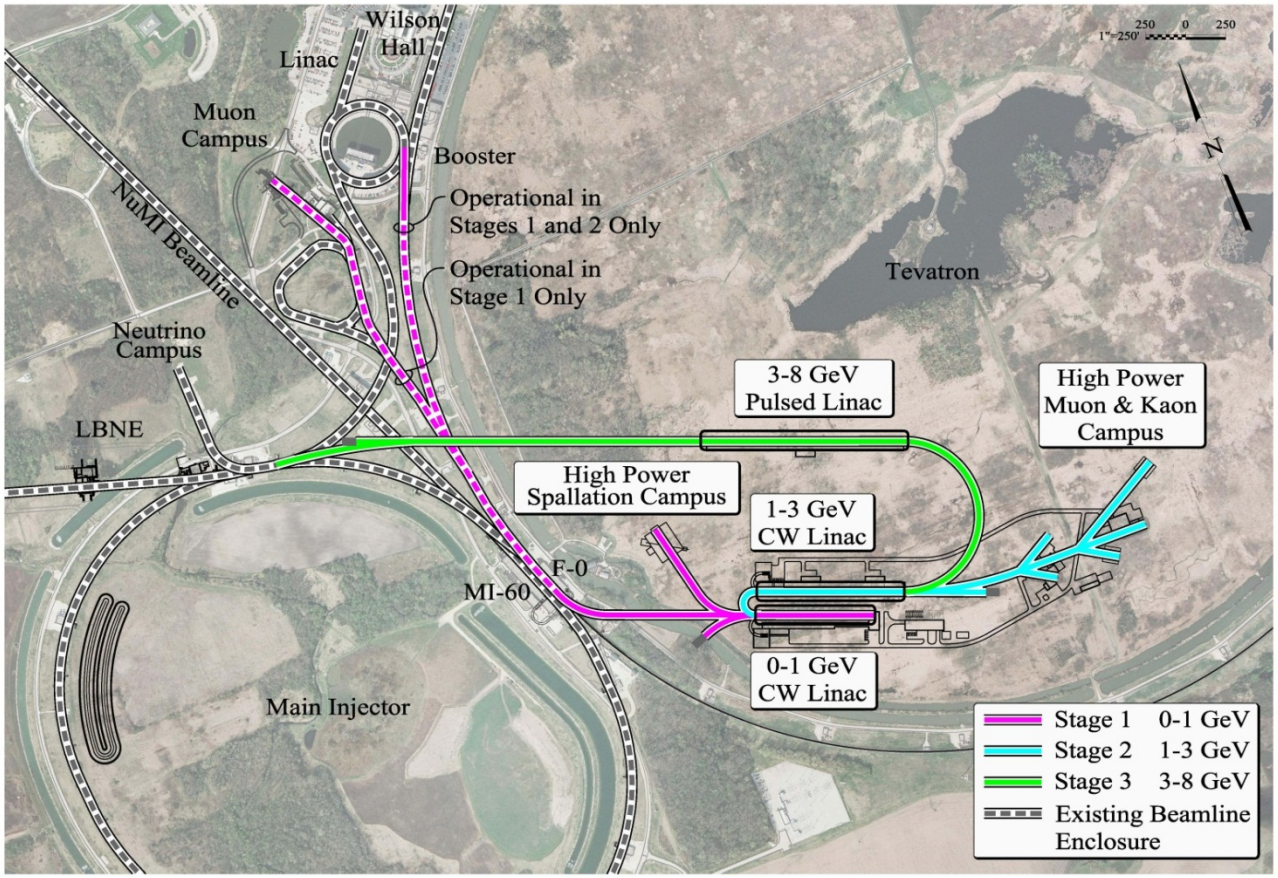
Outline

- Project X and PXIE
- Goals
- Status of subsystems
- Plans

Project X

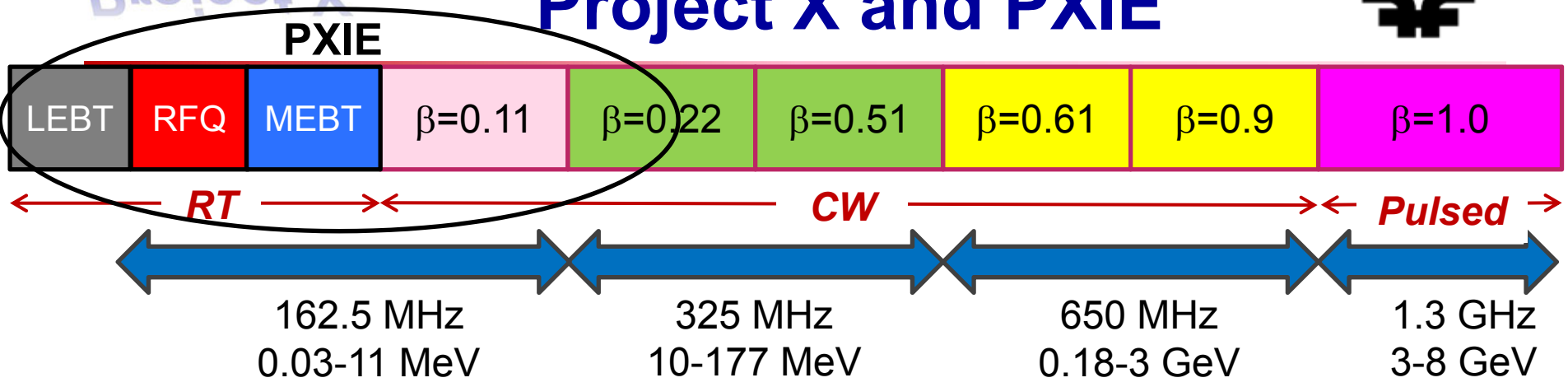
- Project X is an Intensity Frontier accelerator providing MW-scale proton beam to many users quasi- simultaneously

Our website: projectx.fnal.gov/



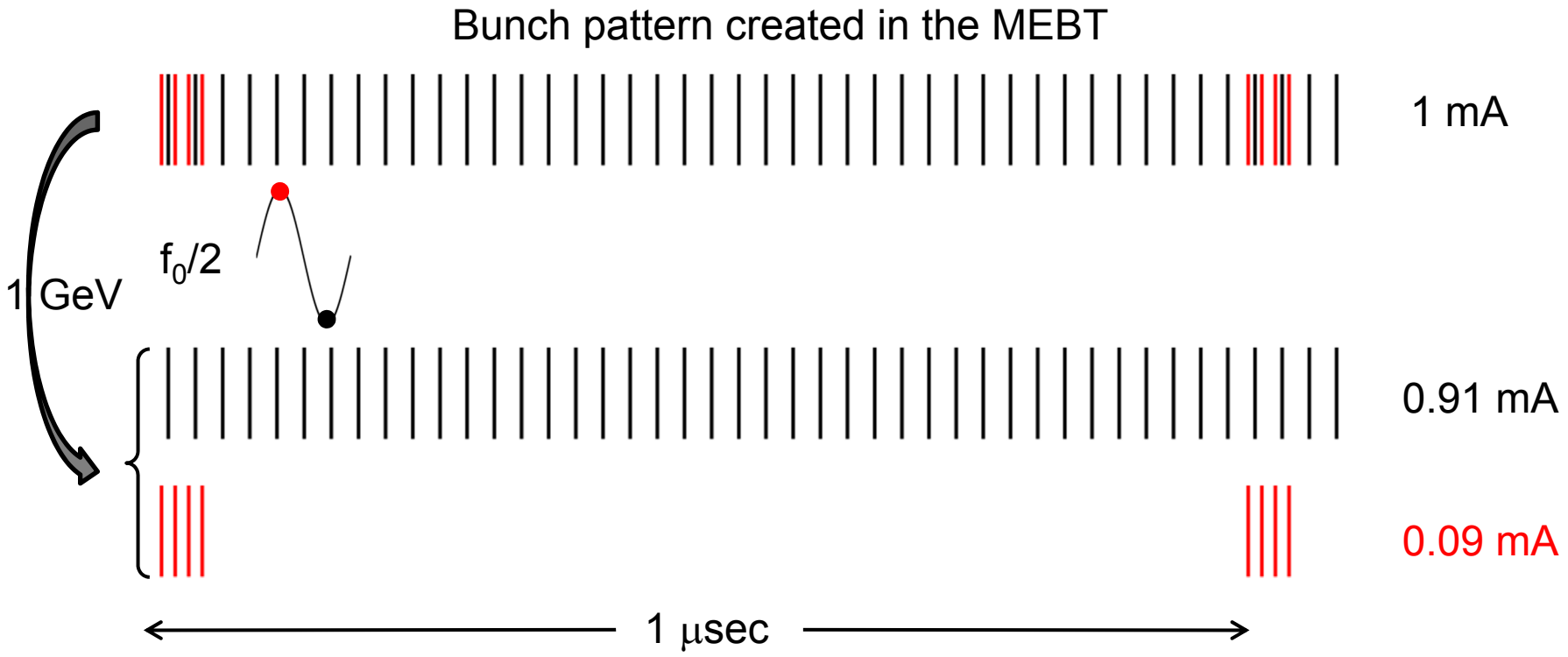
Project X

Project X and PXIE



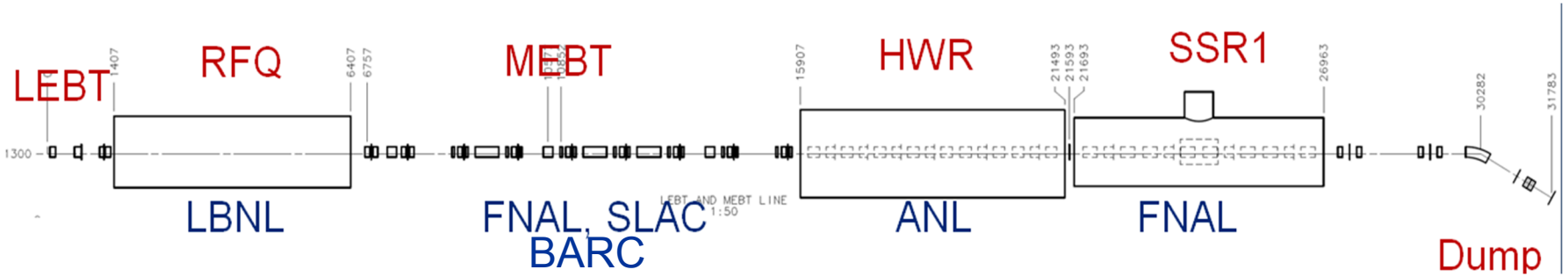
Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-11	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	11-38	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.51)	325	38-177	35/21/7	SSR, solenoid
LB 650 (β_G=0.61)	650	177-467	30/20/5	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	467-1000	42/16/7	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	1000-3000	120/30/15	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

Flexible Beam Structures (Example/Stage 1)



RFQ beam current: 3.64 mA

PXIE structure



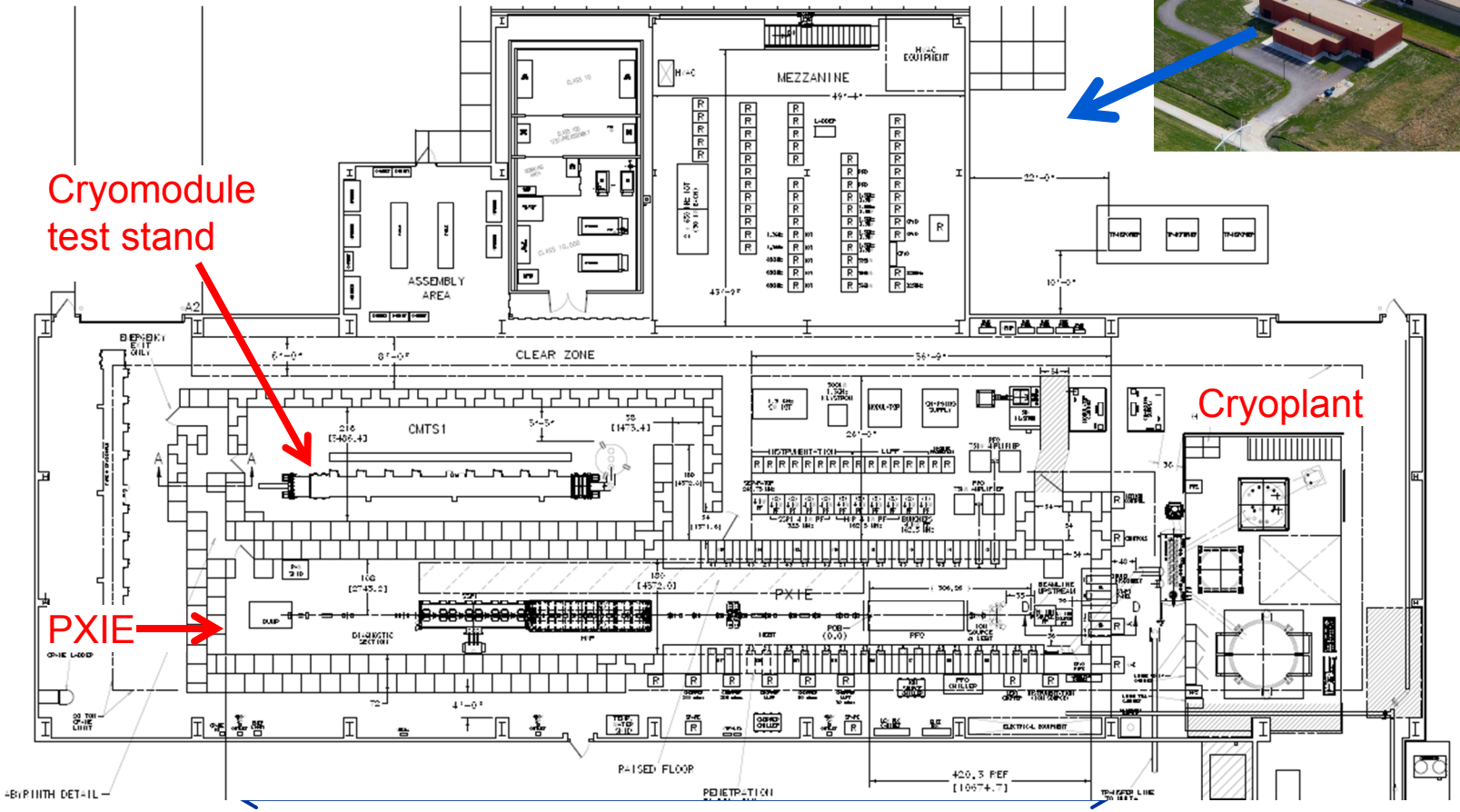
- Standard scheme for the proton (H-) acceleration
  - Ion source and LEBT (30 keV, 5 mA nominal/ 10 mA max DC)
    - Beam pre-chopping for machine tuning
  - 162.5 MHz RFQ (2.1 MeV, 5/10 mA CW)
  - MEBT (chopping, 5mA CW->1mA Repetitive Structure)
  - 2 SC cryomodules accelerating the beam to 20-30 MeV
  - HEBT (beam diagnostics)
  - 50 kW beam dump
- Total length ~ 40 m
- Collaboration between Fermilab, ANL, LBNL, SNS, SLAC, and Indian institutions

Goals

- PXIE is a program to validate the concept for the Project X front end, thereby minimizing primary technical risks
- The main specific goals
  - Demonstrate the bunch-by-bunch chopping
    - Kicker and absorber
  - Efficient acceleration of 1mA beam in SRF to at least 15 MeV
    - Emittance dilution; halo generation and management
- Also, address
  - Emittance issues and pre-chopping in LEBT
  - Reliable CW RFQ
  - MEBT/SRF interface (vacuum, microparticle migration)
  - Diagnostics for testing the extinction of the removed bunches to ~10^{-9}
  - Gain experience in design and operation of SC cryomodules
    - SSR1 cryomodule is being designed and built by Fermilab

PXIE layout

- PXIE will be assembled in the existing Cryo Module Test Facility building



Shielding enclosure


PXIE Cave

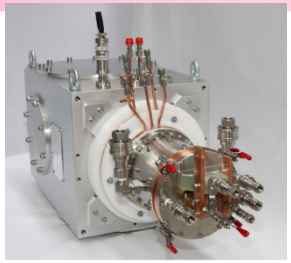

Racks on North Wall


Racks/Chillers on East Wall


Elec. Distribution

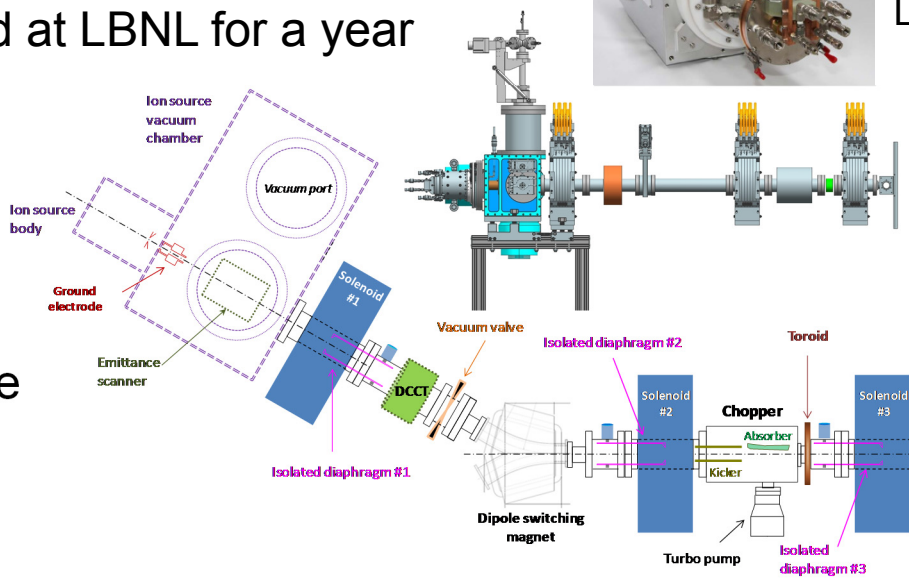
Ion source and LEBT

- H- ion source
  - Purchased from D-Pace Inc
  - Was tested and used at LBNL for a year

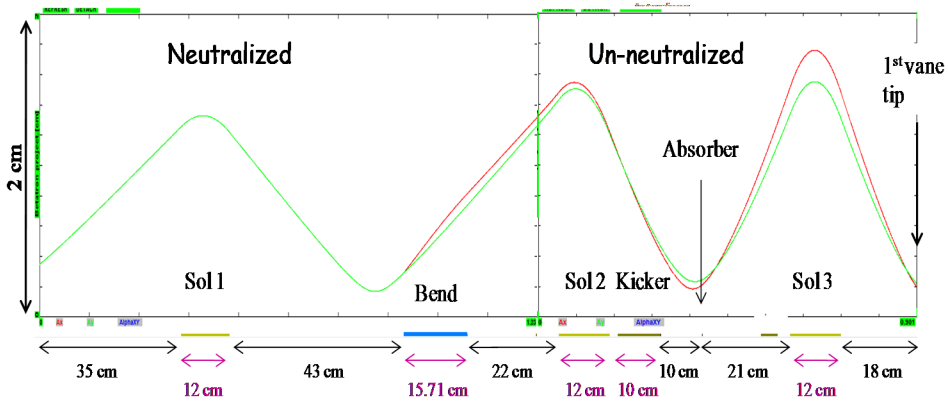


30 kV;
15 mA DC;
$\varepsilon_{rms,n\_x} \approx 0.12\mu m$;
Life time 300 hrs

- LEBT
  - 3 solenoids
  - Dipole to accommodate two IS for PX
    - Only one at PXIE
  - Chopper
    - Pre-chopping, MPS, pulse mode
  - Possibility of partially un-neutralized transport
  - Beam halo scraping



3D model of the first, straight stage of LEBT

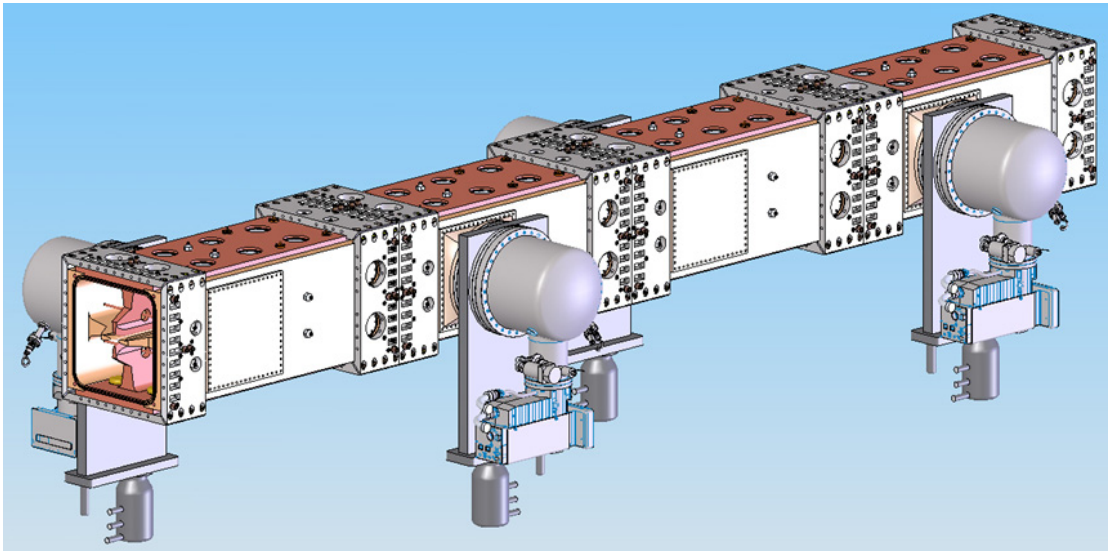


Ion source installation

First beam expected – Nov. 2013

RFQ

- Design (LBNL): 4 vanes CW RFQ
  - 162.5 MHz frequency to make bunch-by-bunch chopping possible
  - 2.1 MeV energy to exclude residual radiation in the MEBT

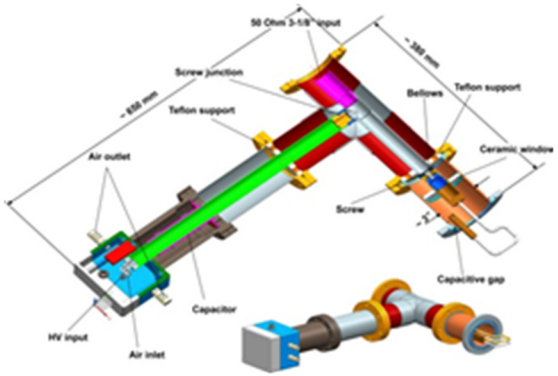


Beam current: 1 – 10 mA;

$\varepsilon_{\perp n,rms}$ < 0.25 μm

$\varepsilon_{||n,rms}$ ≤ 1.0 keV-ns

Length: ~4.4 m

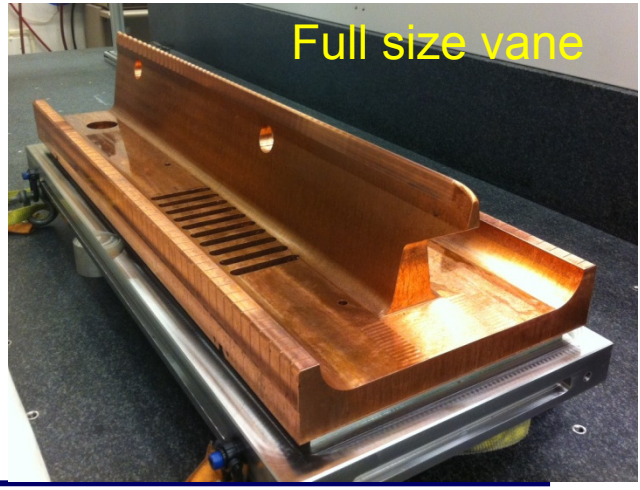


RF coupler has been designed.

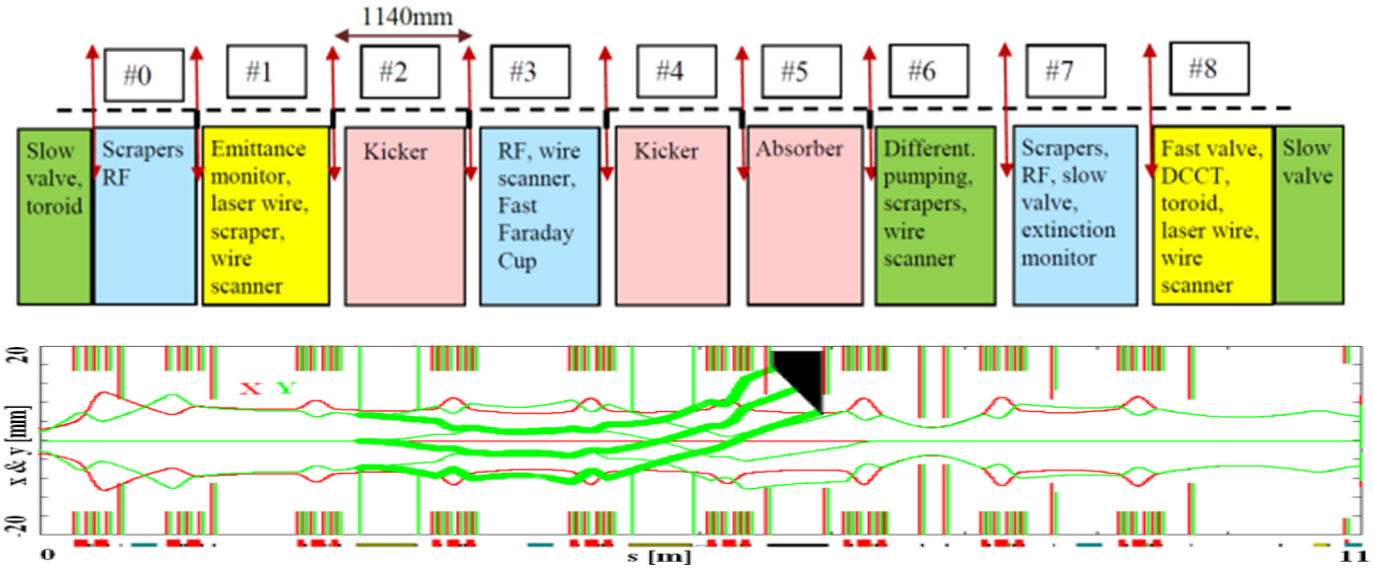
RFQ fabrication

- Tests that required to validate fabrication techniques are complete at LBNL
  - Braze, profile cutters, full size vane machining, etc.

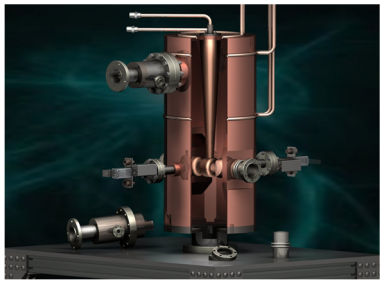
- Production RFQ started August 2013
  - Rough machining of 16 vanes complete
  - Gun-drill of water cooling channels of the first four vanes (module-2) complete
- Preparation for bead-pull apparatus in progress
- Schedule
  - First low power RF measurement (bead-pull) of module-2 in early 2014
  - Completed RFQ assembly to arrive at FNAL by the end of 2014



MEBT



MEBT sections and optics. 3σ envelopes of passing bunches – thin lines, removed bunches- thick lines. Red squares- quads, blue – bunching cavities.

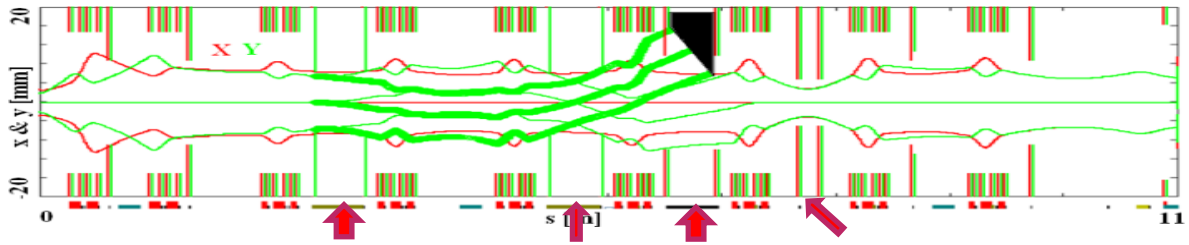


Design: I. Terechkine et al.

- Transverse focusing by 9 quadrupole doublets/triplets; small β-function variation
  - Quads/dipole correctors have been designed by BARC, India; manufacturing prototypes
- Longitudinal focusing – 3 bunching cavities
  - Prototype is in bidding process

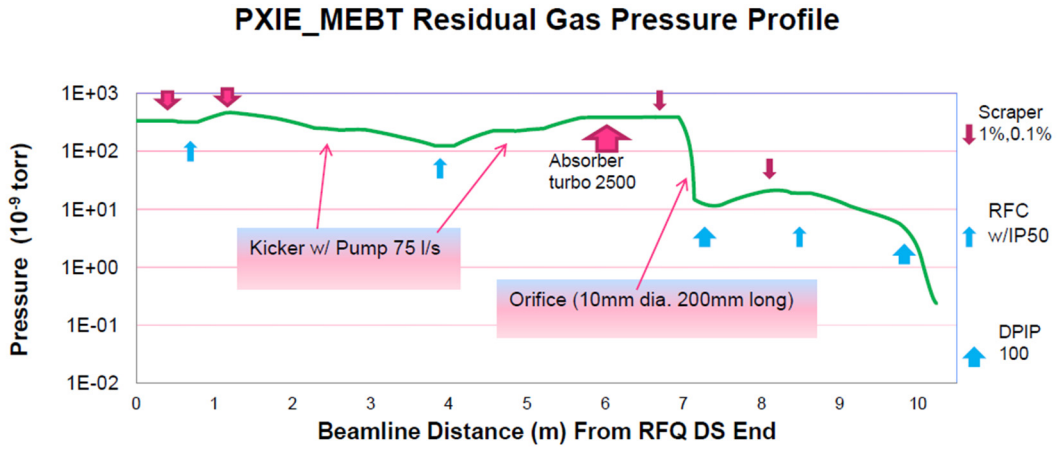
Frequency	162.5 MHz
Max voltage	100 kV
Gap	2x23 mm
Max power loss	1.5 kW

Chopping system



Two kickers separated by 180º Absorber Differential pumping

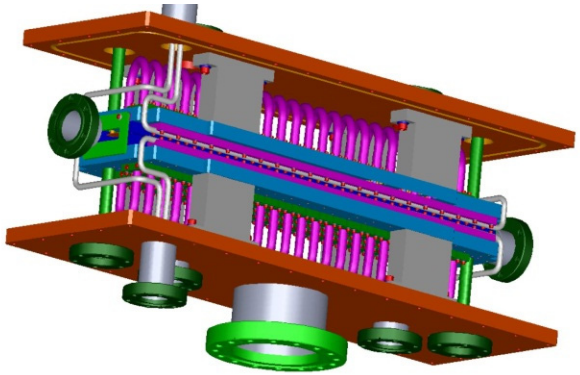
- Undesired bunches are removed by the MEBT chopper
  - Two kickers separated by 180º and working in sync (next slide)
  - Removed and passing bunches are separated at the absorber by $6\sigma_y$
  - Large gas load from absorber, ~1 mTorr·l/s
    - 2500 l/s turbo pumping at the absorber and differential pumping



Kicker

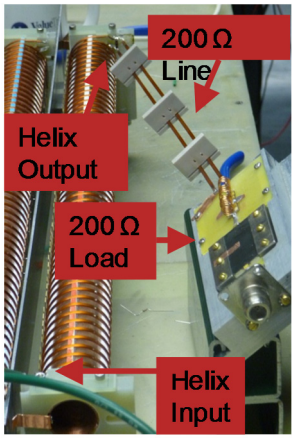
- Travelling – wave, broadband kickers: 50 and 200 Ohm versions
  - 0.5m, ±250V on each plate, 16mm gap; 6σ beam length is 1.3 ns

- 50 Ohm
  - 25 electrodes per plate connected in vacuum by cables
    - Assembling a full-size prototype
  - Commercial linear amplifier and pre-distortion
    - Lower-power driver was successfully tested



3D model
A.Chen, D.Sun

- 200 Ohm
  - Helix as travelling-wave structure
    - Mechanical design of a prototype
      - Driver: broadband, DC coupled switches in push-pull configuration
        - Fermilab development
        - Single switch: tested to 0-500V
        - Complete driver: tested to 0-100 V

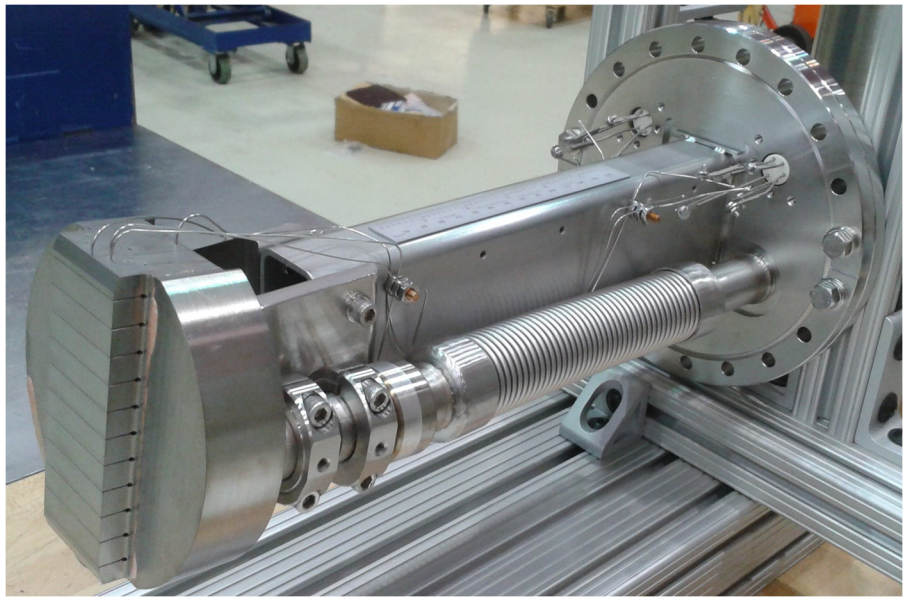


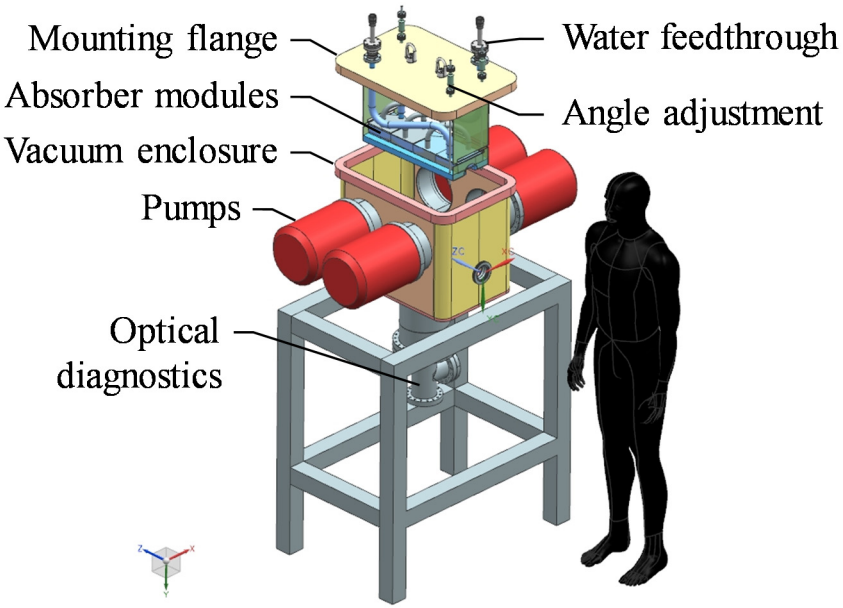
RF model G. Saewert

Absorber

21 kW absorber (x2 full nominal power)

- 29 mrad incident angle; Mo alloy TZM
- ¼ size prototype was tested with e-beam at expected power density, 17 W/mm^2
- Second prototype is being designed

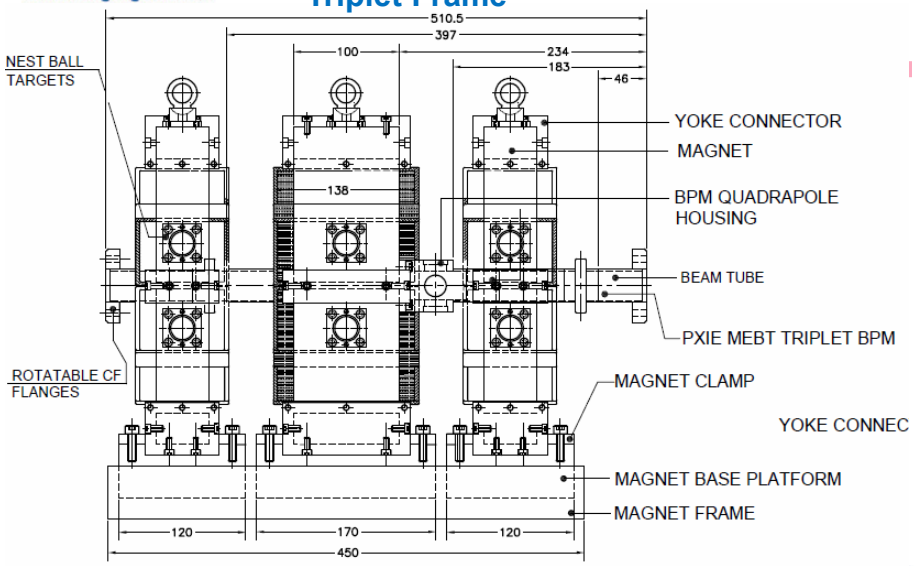




Design and Development of PXIE MEBT Magnets at Bhabha Atomic Research Centre, DAE, India

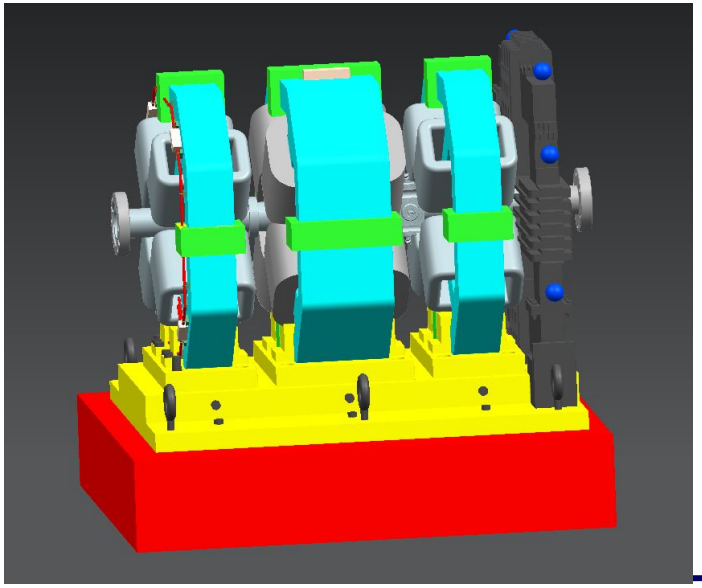
भाभा परमाणु अनुसंधान केंद्र

Triplet Frame

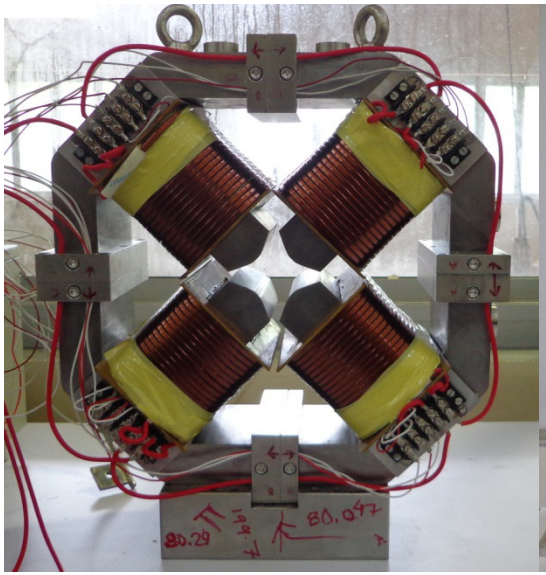


Development work at BARC

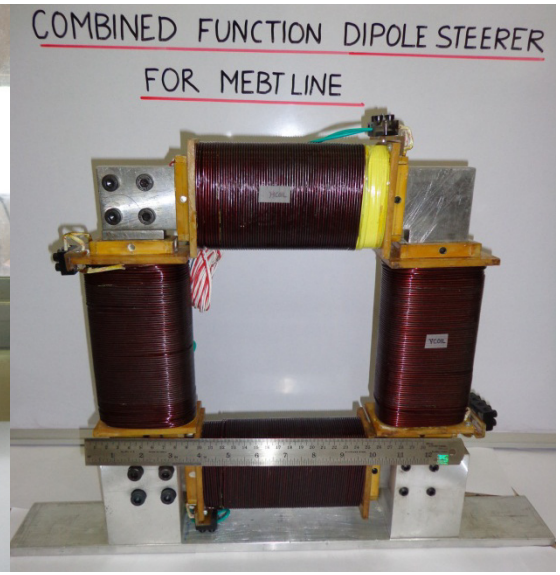
1. Electromagnetic design of Magnets- Quadrupole Focussing Magnets and dipole correctors (9 triplets/doublets with correctors)
2. Engineering design
3. Development drawings
4. Fabrication and Geometrical inspection
5. Magnetic measurements(integral fields)
5. Quality checks and traveller
6. Qualification tests with H^+ beam at 2.5 MeV



Triplet 3-D model



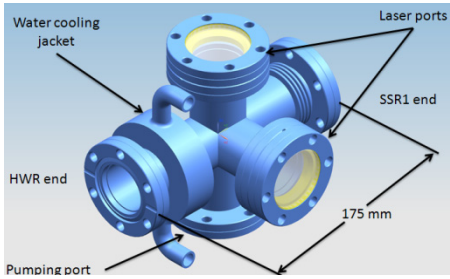
Quadrupole F



Dipole Steerer

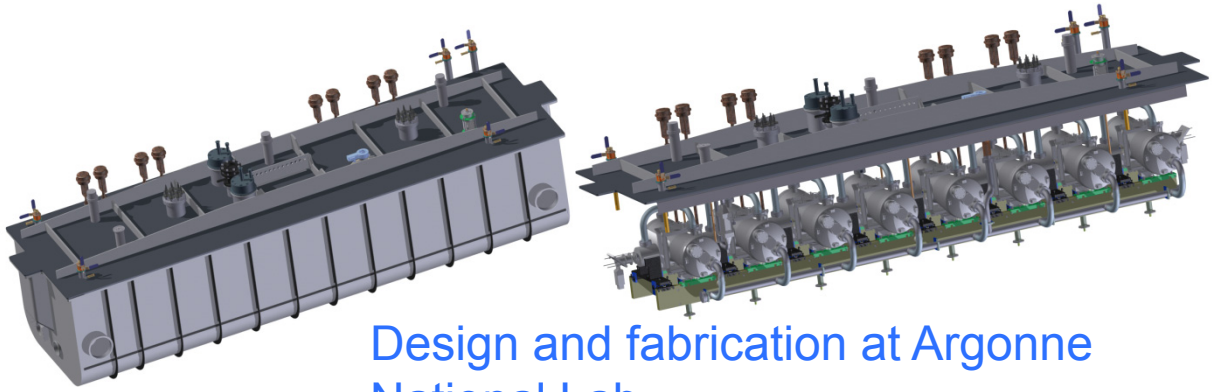
SRF cryomodules

- Two cryomodules operating at 2K, HWR and SSR1
  - Half Wave Resonators (HWR) and Single Spoke Resonators (SSR1)
  - Warm gap between cryomodules; fast vacuum valves on both sides
- In both cryomodules
  - Solenoidal focusing
    - No magnetic steel; bucking coil to reduce fringe field
  - BPM and dipole correctors in each solenoid
- Structure of HWR cryomodule
  - 8 cavities, 8 solenoids arranged as 8x (S C)
  - Starts with a solenoid to mitigate H_2 influx from MEBT
- Structure of SSR1 cryomodule
  - 8 cavities, 4 solenoids arranged as 4x (C S C)
  - Separated coils of dipole correctors allow creating of skew-quads
  - The first upstream element is a cavity to improve longitudinal dynamics



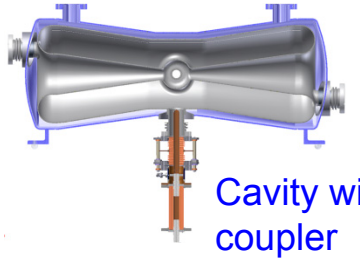
Warm transition box between CMs

HWR



Design and fabrication at Argonne National Lab

Beam energy: 2.1-11MeV
Frequency 162.5 MHz
CM length (flange-to-flange): 5.9 m
β_g 0.11
Cavity voltage 1.7 MV

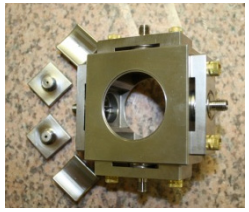


Cavity with coupler

- Cavity and cryomodule design is complete
- Prototypes of 10-kW RF coupler and SC solenoid with steering coils have been built and successfully tested
- BPM prototype has been built and tested with beam in FY13
- Nb parts for all cavities fabricated in FY13
- Two prototype SC cavities will be tested in FY14

Solenoid installed in He vessel

Cavity parts



BPM parts

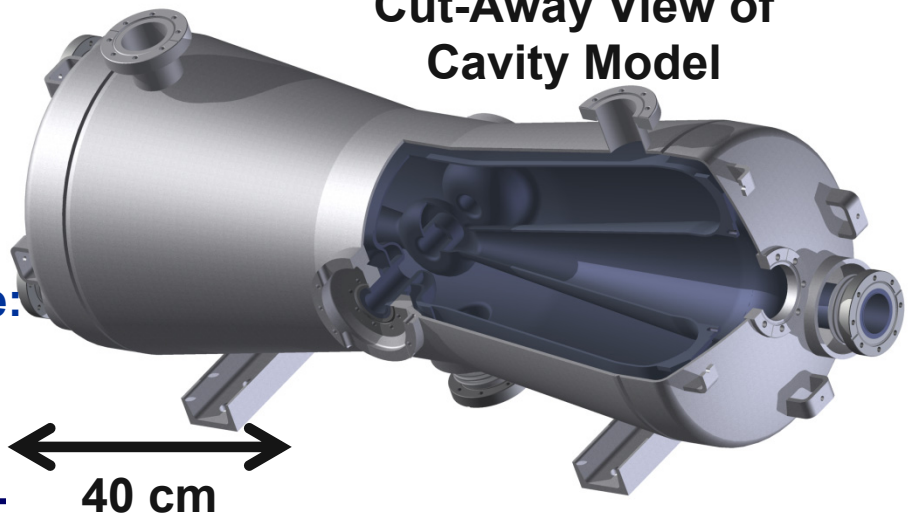
Project-X Halfwave Resonator Development @ ANL

Cavity Type	HWR
Frequency	162.5 MHz
Optimal β	0.112
Effective Length	20.7 cm
Aperture	33 mm
E_{peak}/E_{acc}	4.7
B_{peak}/E_{acc}	5.0 mT/(MV/m)
G	48 Ω
R_{sh}/Q	272 Ω

Niobium Production Cavity Parts

Prototype Cavity Parts

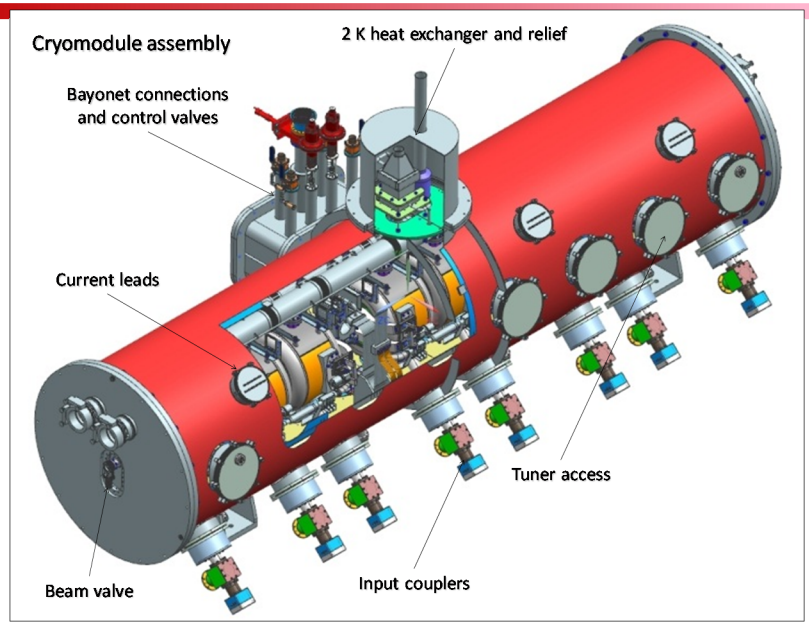
Cut-Away View of Cavity Model



- **Highly optimized conical-halfwave resonators:**
  - B. Mustapha et al, IPAC12, Pg. 2289.
  - Z. Conway et al, LINAC12, Pg. 624.
- **Compact lattice layout and 2 K cryomodule:**
  - P. Ostroumov et al, LINAC12, Pg. 461.
- **Prototyping 2 resonators now.**
- **Production cavity Nb parts are ready.**

See P. Ostroumov et al, SRF'13, MOP064

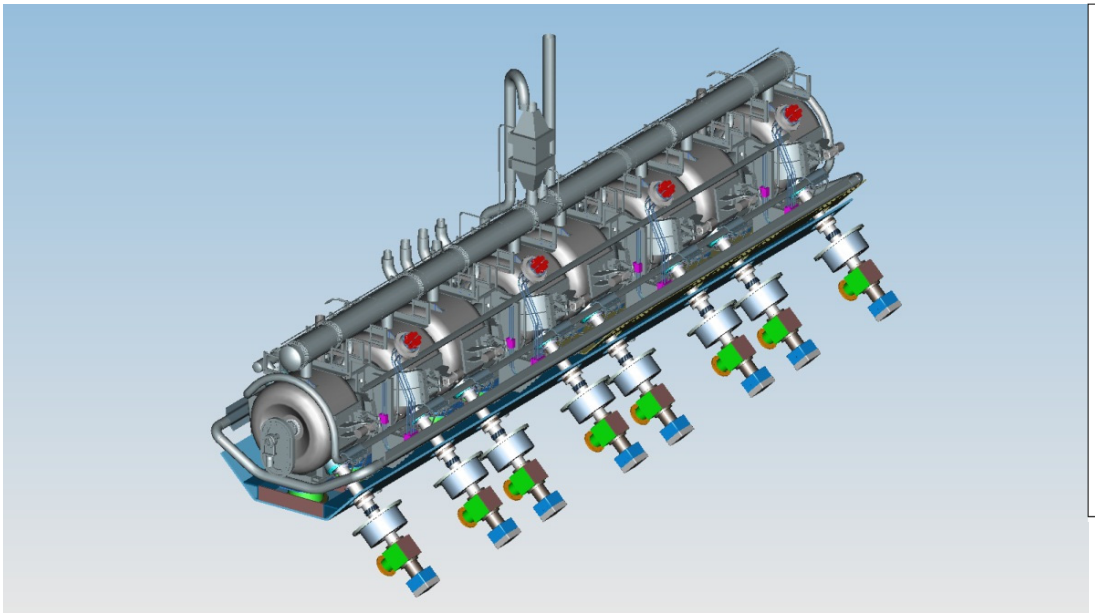
SSR1 development at FNAL

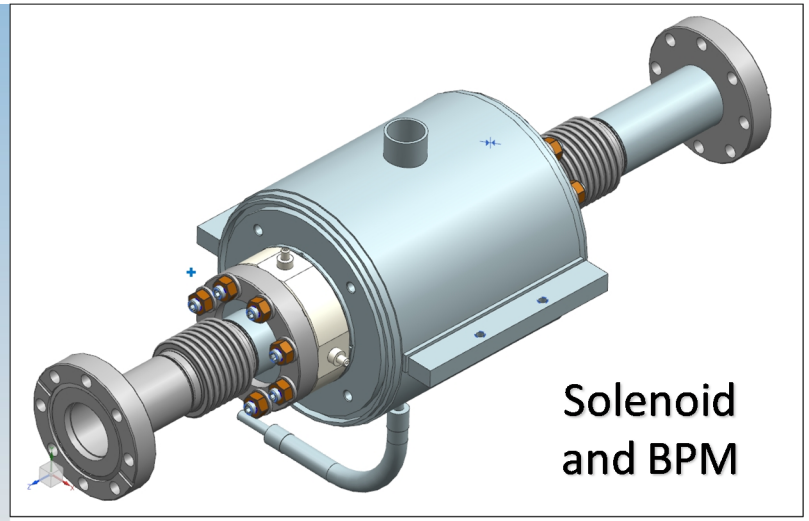


Beam energy: 11-25 MeV
Frequency 325 MHz
CM length (flange-to-flange): 5.4 m
β_g 0.22
Cavity voltage 2 MV

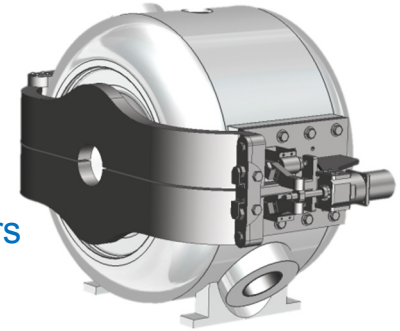
- Design of major components is complete
  - Cavity, tuner, coupler, solenoid, current leads, helium vessel, support
- Detailed drawings for the strongback, supports, and vacuum vessel are ready for procurement.
- First production batch of 10 cavities is complete
  - Tests are proceeding well
  - Prototypes of coupler, solenoid, and helium vessel are close to production

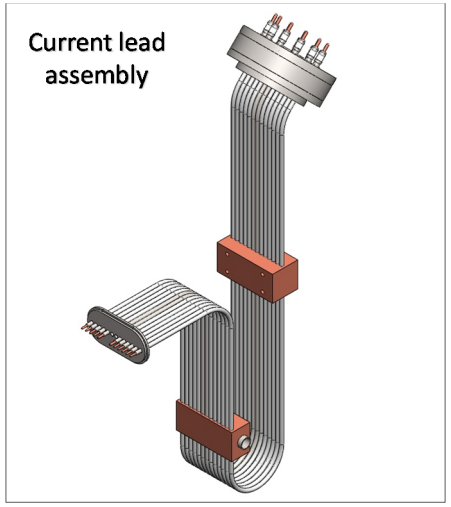
SSR1 development





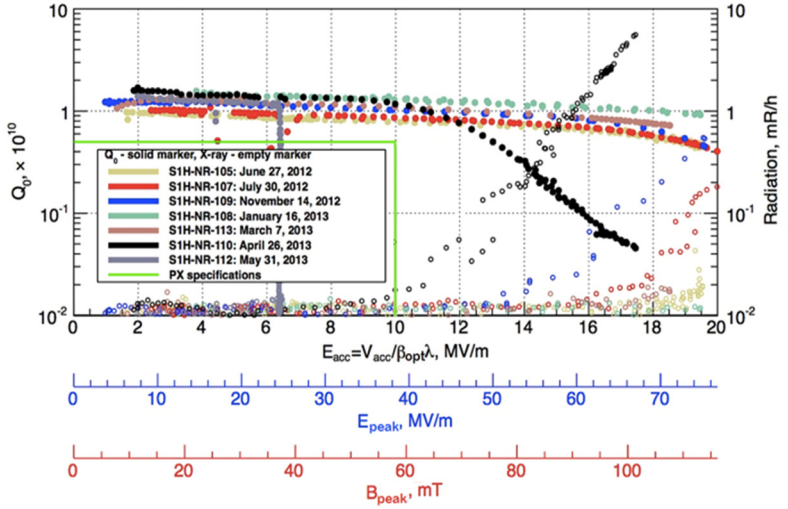
3D model
of cavity
with tuners



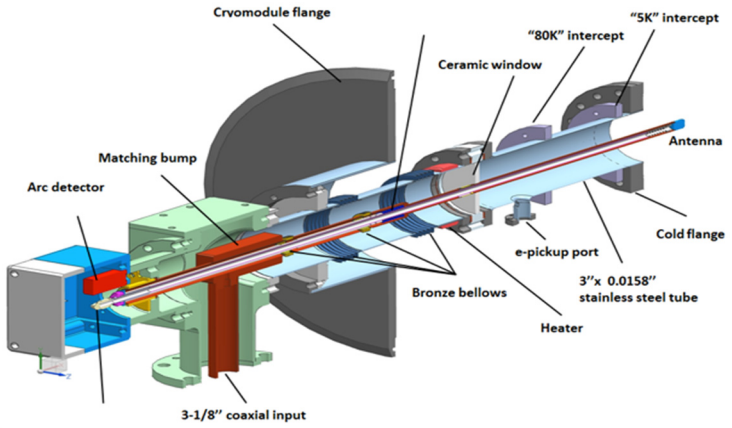


SSR1 cavities and couplers

SSR1 cavity, bare (left) and dressed (right).

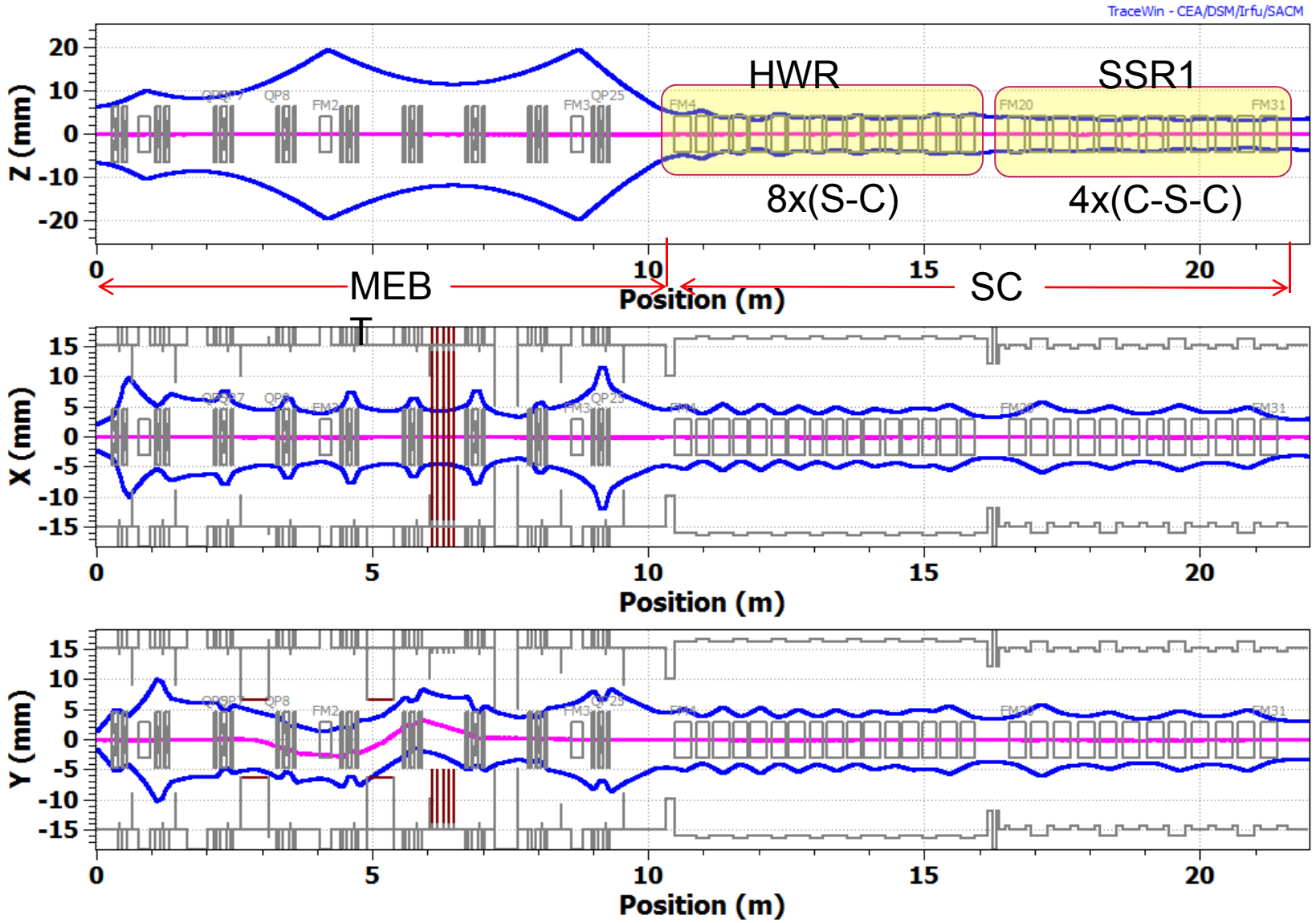


Test results for SSR1 bare cavities at 2 K

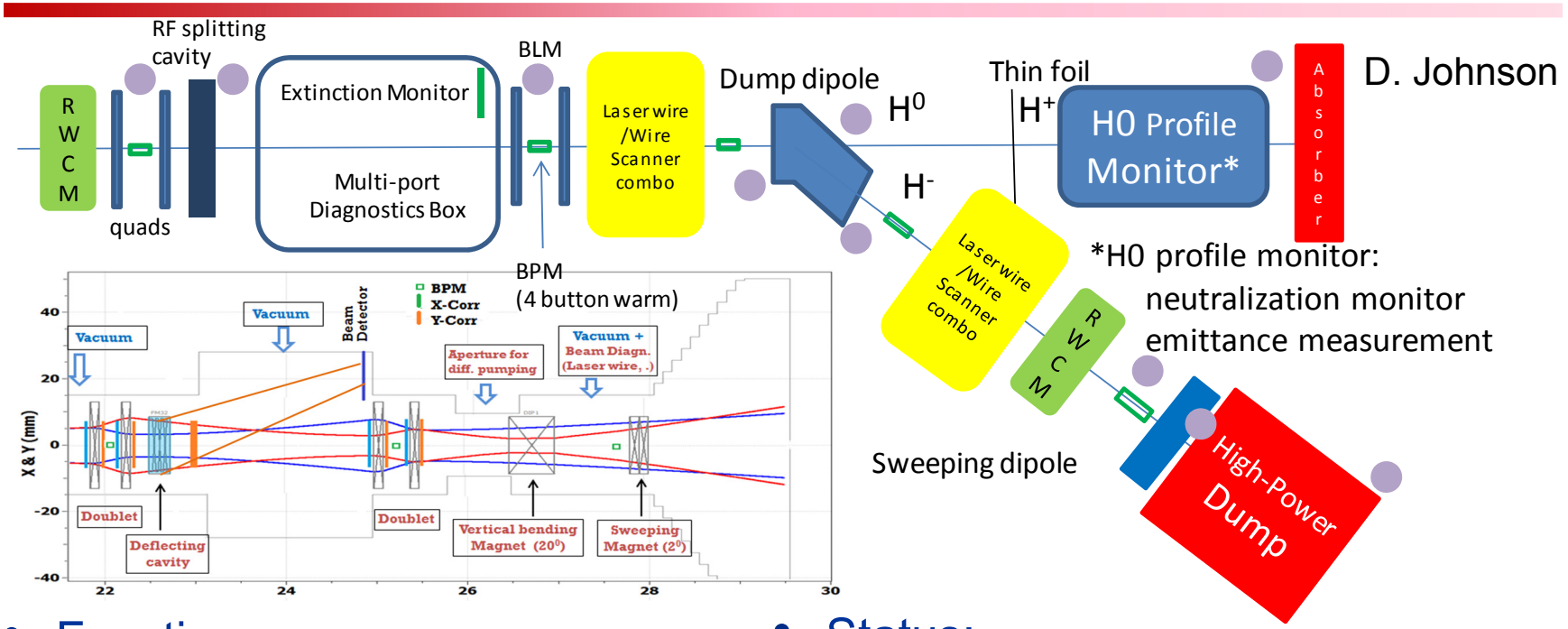


3σ Beam Envelope

- **Kicker polarity in chopper are set for passing beam**



HEBT



- Functions:
  - Primary 50 kW beam dump
  - Instrumentation to characterize beam parameters and measure efficiency of MEBT bunch-by-bunch chopper
- Status:
  - Preliminary design of optics, absorber, and shielding complete
  - deflecting cavity is being designed
  - Instrumentation specifications in progress

Plans

- FY2014 – beam from ion source (at Fermilab)
- FY2015 – beam from RFQ
- FY2017 – Stage 1
  - Ion source, LEBT, RFQ at full power
  - Full MEBT with prototype kickers, prototype absorber, temporary dump, bunchers, some diagnostics
  - Cryo system
  - SSR1 CM – cold and RF powered, no beam
- Aug 2017- Stage 2
  - HWR CM – cold and RF powered, no beam
- Aug 2018- Stage 3
  - HEBT, final MEBT kickers, final 50 kW beam dump, 1-mA beam with required structure delivered to the dump

PXIE- related posters

- MOPMA09: S. Holmes, Status and Opportunities at Project X: A Multi-MW Facility for Intensity Frontier Research
- WEZAA3: A. Grassellino, Advances in SRF Materials Science aimed at High Q Cavities
- TUPSM10: A. Chen, The Conceptual Design of PXIE Vacuum System
- THPBA17: G. Saewert, Status Of PXIE 200 Ohm MEBT Kicker Development
- WEPMA19, WEPMA20, WEPMA21: RFQ development and fabrication at LBNL
- WEPAC05: Tests of Solenoid for HWR CM
- WEPAC21 , THOBA3 , THPMA09: SSR1 cryomodule and cavity development