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PIP-II R&D Program

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PIP-II Machine Advisory Committee

9-11 March 2015

R&D Program

- The purpose of the R&D program is to mitigate technical and cost risks, by validating the choices made in the PIP-II facility design and by establishing fabrication methods for major sub-systems and components, including the qualification of suppliers
  – Technical risk: impair the ability to meet fundamental performance goals
  – Cost/Schedule risk: compromise the ability to meet currently understood cost or schedule goals
    - CD-2: Approve performance baseline (2017)
    - CD-3: Approve start of construction (2019)

PIP/PIP-II Performance Goals

Performance Parameter	PIP	PIP-II	
Linac Beam Energy	400	800	MeV
Linac Beam Current	25	2	mA
Linac Beam Pulse Length	0.03	0.5	msec
Linac Pulse Repetition Rate	15	20	Hz
Linac Beam Power to Booster	4	13	kW
Linac Beam Power Capability (@>10% Duty Factor)	4	~200	kW
Mu2e Upgrade Potential (800 MeV)	NA	>100	kW
Booster Protons per Pulse	4.2×10^{12}	6.5×10^{12}	
Booster Pulse Repetition Rate	15	20	Hz
Booster Beam Power @ 8 GeV	80	160	kW
Beam Power to 8 GeV Program (max)	32	80	kW
Main Injector Protons per Pulse	4.9×10^{13}	7.6×10^{13}	
Main Injector Cycle Time @ 60-120 GeV	1.33*	0.7-1.2	sec
LBNF Beam Power @ 60-120 GeV	0.7*	1.0-1.2	MW
LBNF Upgrade Potential @ 60-120 GeV	NA	>2	MW

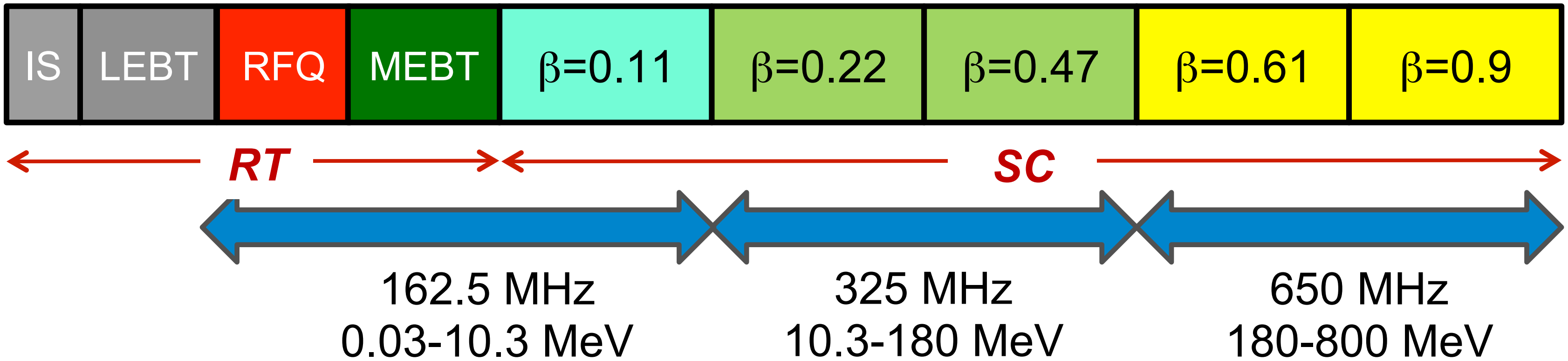
*NOvA operates exclusively at 120 GeV

5 primary areas to address risk

1. Development and integrated systems testing of PIP-II Front End components (PXIE);
2. Development of a Booster injection system design capable of accepting extended beam pulses from the PIP-II linac ;
3. Development and demonstration of cost effective superconducting radio frequency acceleration systems at four different frequencies and with rf duty factors ranging from 10% to 100%;
4. Development of systems designs capable of supporting a 50% increase in the proton beam intensity accelerated and extracted from the Booster/Recycler/Main Injector complex;
5. Development of requisite capabilities at international partner institutions to successfully contribute to PIP-II construction.

2 and 4 addressed in presentations by B. Pellico and I. Kourbanis

PIP-II Linac Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_{opt}=0.65)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_{opt}=0.97)	650	500-800	24/8/4	5-cell elliptical, doublet*

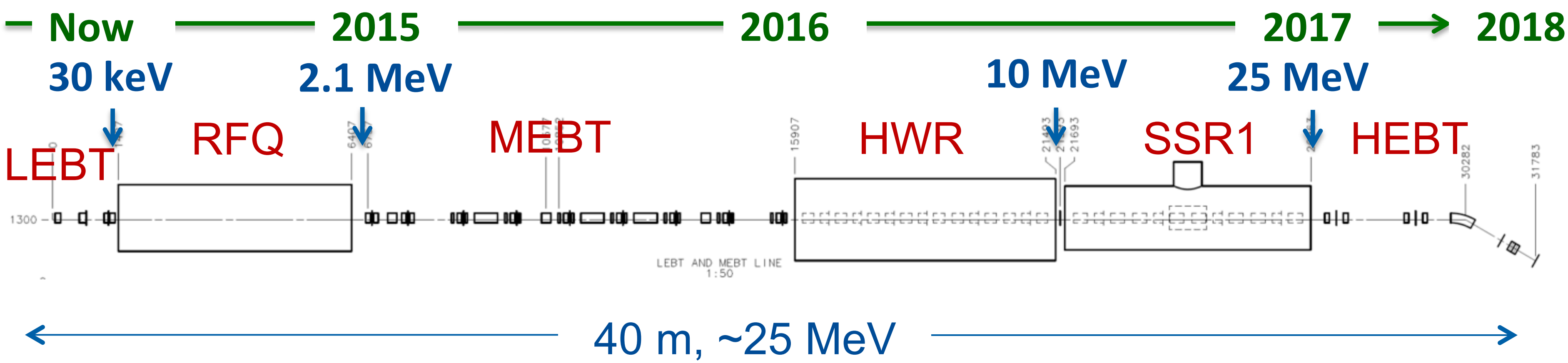
*Warm doublets external to cryomodules

All components CW-capable

Agenda: R&D Program

Presenter	Topic	Information
J. Leibfritz	CMTF infrastructure	Building where we are assembling PXIE
L. Prost	PXIE Warm Status	Ion Source, LEBT, and MEBT
J. Steimel	RFQ Status and Commissioning Plan	Fabrication and preparation for operation
J. Anderson	PXIE Operational Readiness	ES&H requirements, PXIE and PIP-II
H. Padamsee	Superconducting RF: Development Strategy	SRF Overview
P. Ostroumov	Superconducting RF: HWR Status	162.5 MHz Half Wave Resonator
L. Ristori	Superconducting RF: SSR1, SSR2 Status	325 MHz Single Spoke Resonator (IIFC Role)
A. Grasselino	Superconducting RF: LB650, HB650 Status	650 MHz Elliptical Cavities (IIFC Role)
W. Schappert	Superconducting RF: Resonance control	Lorentz Force Detuning and Microphonics
B. Chase	LLRF	Low Level RF control (IIFC Role)
R. Pasquinelli	RF Sources	RF Power amplifiers for 162.5, 325, and 650 MHz (IIFC Role)
V. Scarpine	Instrumentation	Beam Diagnostics and measurements (IIFC Role)
S. Mishra	International Collaborations	India Institutes and Fermilab Collaboration, CERN

PXIE (PIP-II Injector Experiment)



PXIE will address the address/measure the following:

- LEBT pre-chopping
- Vacuum management in the LEBT/RFQ region
- Validation of chopper performance
- Bunch extinction
- MEBT beam absorber
- MEBT vacuum management
- Operation of HWR in close proximity to 10 kW absorber
- Operation of SSR with beam, including resonance control and LFD compensation in pulsed operations
- Emittance preservation and beam halo formation through the front end

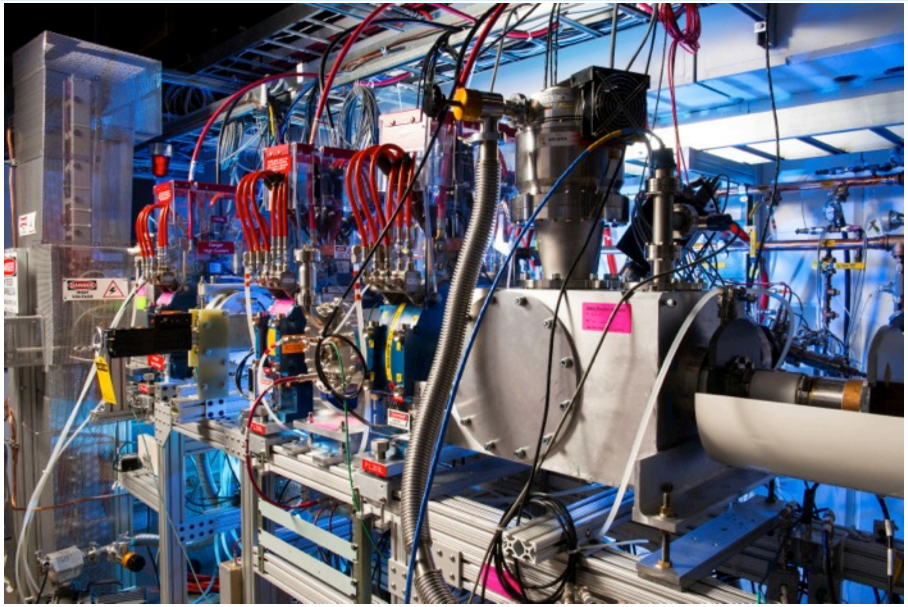
Collaborators
- ANL: HWR
- LBNL:LEBT, RFQ
- SNS: LEBT
- BARC: MEBT, SSR1

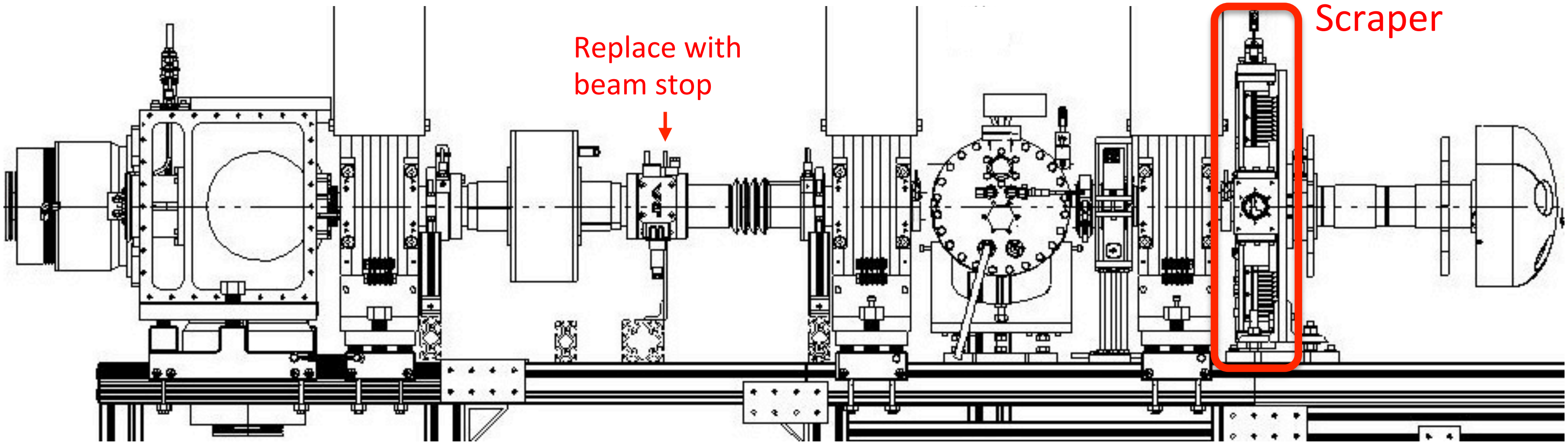
PXIE Goal for FY15:

- Acceptance and Commissioning of RFQ
  - Driving LEBT work: beam requirements
  - Driving Infrastructure work: LCW systems
  - Driving RF power installation: 162.5MHz 75 kW
  - Driving MEBT procurement and design: to measure beam coming out of the RFQ

Ion Source and LEBT installation status

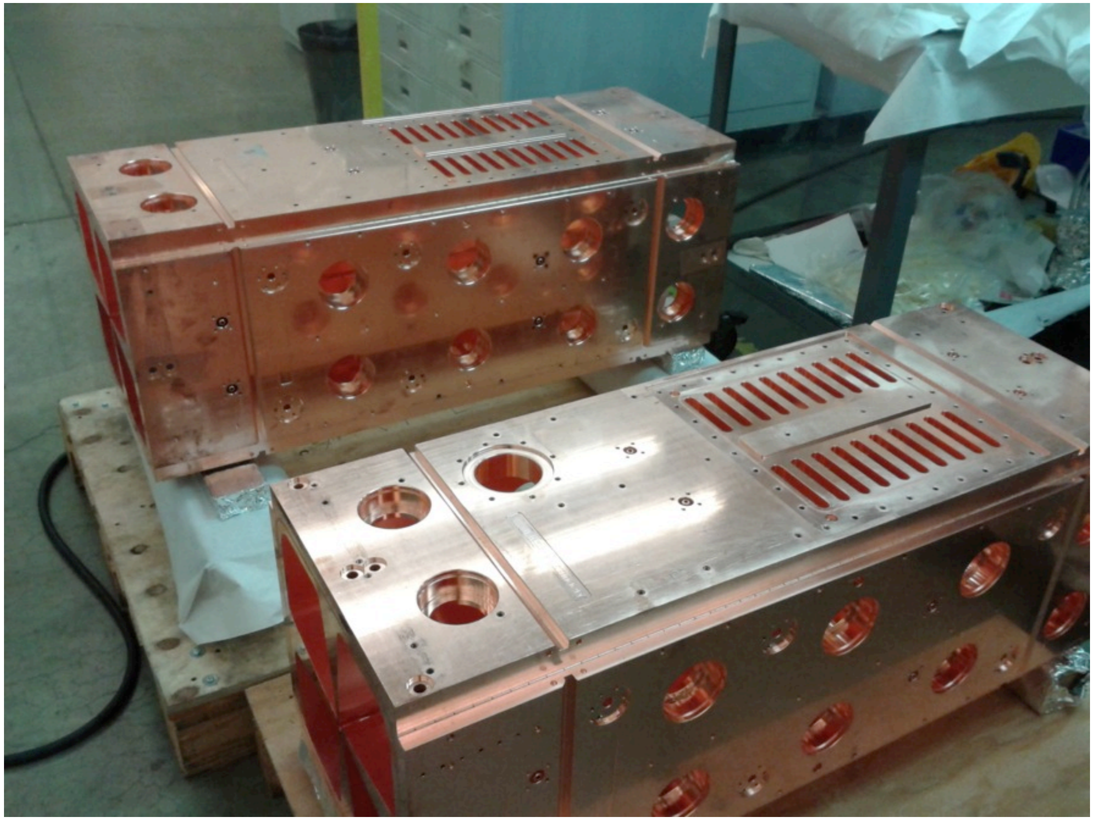
- Installation almost complete for RFQ commissioning





RFQ Module Construction Status

- Module fabrication moving along: 2 of 4 modules pictured below



RF Power System Installation

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SRF R&D Scope for CD-3

- HWR and SSR1 cryomodules tested at PXIE
  - initially with RF power, then with beam
- SSR2 dressed cavities
- LB650 dressed cavities
- HB650 cryomodule tested at CMTF with RF power

- Resonance control of cavities in pulsed mode operation
  - Microphonics
  - Lorentz Force Detuning

  - active frequency control with fast piezo-based tuners

SRF Development Status (2-19-15)

Cavity	Frequency	Cavity Type	Beta	Collaboration?	Cavity EM Design Complete	Cavity Mech Design Complete	Single Cell / Prototype Ordered	Full Cavity Prototype Received	Prototype Tested	Cavities for CM Ordered	Cavities for CM Received	Cavities for CM Tested	Cavities for CM Dressed	CM Cold Mass Design	CM Parts Ordered	# of CM Assembled	Est % complete
Half Wave Resonator (HWR)	162.5 MHz	1-HWR CW	0.11	ANL	yes	yes	yes	yes	yes	9	all parts	2	2	yes	yes	10%	60
Single Spoke Resonator 1 (SSR1)	325 MHz	1-spoke CW	0.22	India	yes	yes	2	2	2	10	10	10	3	80%	70%	not started	75
Single Spoke Resonator 2 (SSR2)	325 MHz	1-spoke CW	0.47	India	yes	yes	not started	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
Low Energy 650 (LE 650)	650 MHz	5-cell CW	0.6	India, JLAB	yes	yes	5	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
High Energy 650 (HE 650)	650 MHz	5-cell CW	0.9	India	yes	yes	5 of 10	4	not started	9	4	not started	not started	5%	not started	not started	20

Green: complete

Yellow: in progress

Red: not started

HWR and SSR1 part of PXIE

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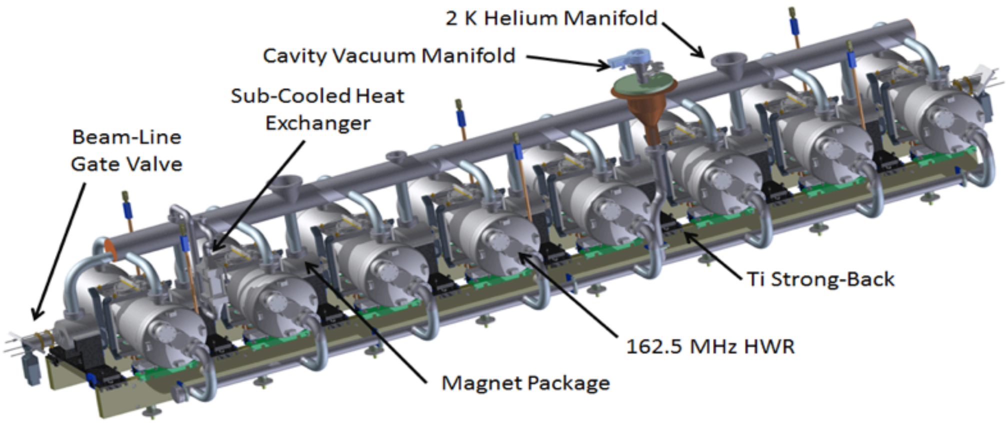
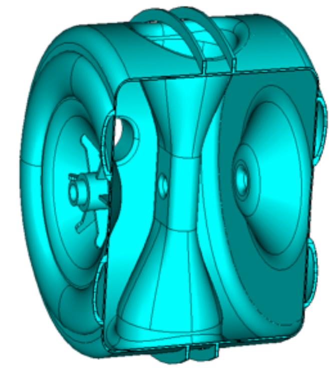
SRF R&D: Pictures from the 5 cavity types



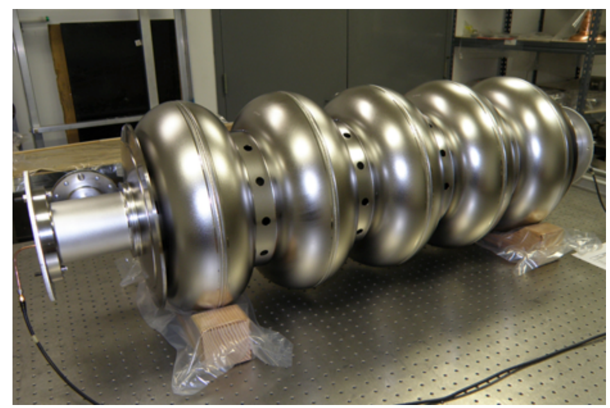
HWR

SSR1



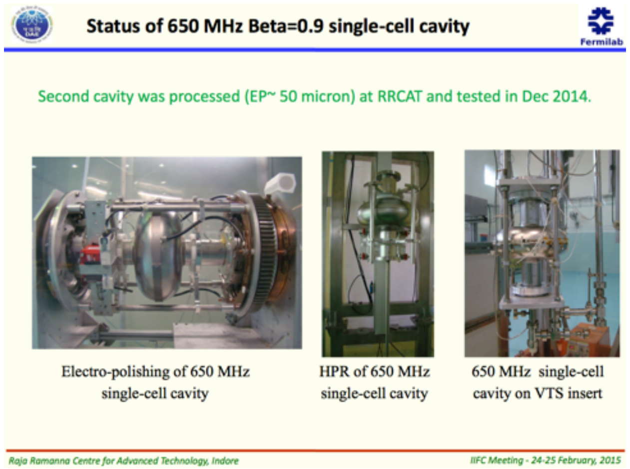
SSR2

LB650



HB650

SRF R&D: India playing a significant role



HB650 β=0.9 cavity fabricated at RRCAT

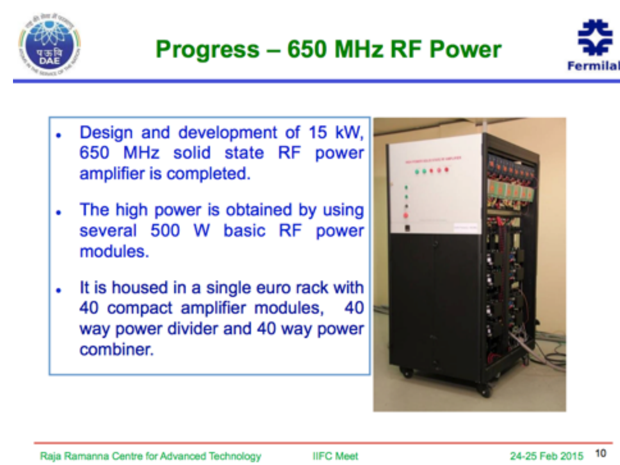
SSR1 cavity fabricated at IUAC

Few highlights from IIFC meeting in February at RRCAT & BARC

Final parameters

Parameter	Value	Unit	*Fermilab design:*
Frequency	325	MHz	
Beta	0.4		
Aperture	60	mm	
Spoke thickness (T)	71.6	mm	
Spoke width (W)	140	mm	
Spoke upper diameter (D)	176	mm	
Cavity diameter (D_{cav})	503.9	mm	
Cavity length (L_{cav})	446.2	mm	
R/Q	268	Ω	275 Ω
E_p/E_{acc}	3.43		3.53
(Assumes $L_{eff} = \beta\lambda$) B_p/E_{acc}	5.17	mT/(MV/m)	6.25

SSR2 design parameters BARC



650 MHz 15 KW SSA RRCAT Delivered in Integrated HTS

R&D Deliverables : dates updated soon

Deliverable	Date
Reference Design Report	Q1FY15
HB650 Cavity (8, TESLA shape) Vertical Test (US)	Q4FY15
HB650 Dressed Cavity (3) Horizontal Test (US)	Q4FY16
HB650 Dressed Cavity (4) Horizontal Test (India)	Q2FY17
LB650 Dressed Cavity (3) Horizontal Test (US)	Q3FY17
LB650 Dressed Cavity (2) Horizontal Test (India)	Q3FY17
HB650 Cryomodule Design (US, India)	Q2FY16
HB650 Cryomodule Power Test (US)	Q4FY17
650 MHz/30 kW rf Power Test (India)	Q4FY15
SSR1 Dressed Cavity (2) Horizontal Test (India)	Q4FY15
SSR1 Cryomodule Power Test (U.S.)	Q3FY17
SSR2 Dressed Cavity (2) Horizontal Test (India)	Q2FY17
SSR2 Cavity (2) Vertical Test (US)	Q4FY17
SSR2 Dressed Cavity (1) Horizontal Test (US)	Q4FY17
325 MHz/10 kW rf Power Test (India)	Q4FY15
650 MHz Horizontal Test Stand (US & India)	Q3FY16
HWR Cryomodule Test with Beam	Q2FY18
Front End Systems Test (warm components)	Q3FY16

Booster/Recycler/Main Injector

Booster

- New injection point at L11
  - Injection Girder
  - Space charge mitigation
  - New stripping foil system
  - H^0 , H^- absorber
- RF Cavity investigation/design/construction
- RF capture
  - capture scheme: paraphasing or direct injection into buckets
  - 2nd harmonic cavities (considered but probably unnecessary)
- Transition crossing
  - RF focusing method
  - RF focus free method (flattening of RF amplitude)
  - γ_t jump system (not likely)
- Damper upgrades and collimation system
  - Longitudinal quadrupole damping when going through transition
  - Longitudinal coupled bunch mode damping at high field
  - Transverse dampers for coupled bunch modes
- Evaluation of present collimation system w/ respect to expected PIP II operation
- Beam quality at extraction
- 20 Hz operations and components

Recycler/Main Injector

- RF Power in the MI
  - Two power tubes (same model)
  - Higher power tube
- Transition crossing
  - γ_T jump system
  - build γ_T quad with appropriate pipe
- Electron cloud
  - SEY measurements in situ
- Beam loss control/mitigation
  - SYNERGIA simulations for RR

- RR RF Cavity design / prototyping

Summary

- R&D program designed to mitigate cost, schedule, and technical risk prior to CD-3
- Front End Development: PXIE
  - Primary goal for FY2015 is acceptance and commissioning of RFQ
- SRF Development: 5 cavity types
  - IIFC playing a significant role
- Defined set of deliverables covering
  - SRF
  - Power
  - Test Stands
  - Beam Delivery
- R&D plan for Booster/Recycler/Main Injector under development
- Goal: ready for construction start in 2019

- Backups

Major PXIE Features

- "Adiabatic optics" – small beta-function variation
  - Mitigation of space charge
- LEBT
  - LEBT chopper
    - Supports machine tuning in pulsed mode: $\Delta t \sim 0.5 - 10\ \mu s$, f_{rep}=60 Hz
- RFQ
  - 162.5 MHz RFQ
    - freq. low enough for bunch-by-bunch chopping, $T \approx 6.2$ ns, bandwidth of ~ 1 GHz
- MEBT
  - "Two-kickers chopping" makes chopping possible with present technology
  - 21 kW beam dump for chopped-out beam
  - Differential pumping to minimize H_2 leakage to the SC cryomodules and RFQ

Major PXIE Features (continue)

- SC cryomodules operating at 2 K
  - Solenoidal focusing
  - Warm gap between cryomodules
  - Fast vacuum valves at both sides of the cryomodules
- RF separation at the top energy for beam extinction studies, f=1.5*162.5 MHz
  - Can help in measurements of bunch length and longitudinal tails
- Instrumentation (not a complete list)
  - Toroids, BPMs, wire scanners, laser wires, scrapers
- Spectrometer at the end of the machine
- 50 KW beam dump
  - can support operation up to 2 mA beam current

PXIE stages

- Stage 1:
  – Ion source, LEBT, prototype chopper
  – RFQ at full power
  – Full MEBT with prototype kickers, (possibly) prototype absorber, temp. dump, bunchers, diagnostics
  – Cryo system
  – SSR1 CM – cold and rf powered, no beam
- Stage 2:
  – HWR CM – cold and rf powered, no beam
- Stage 3:
  – Full diagnostics line, final MEBT kickers, final 50 kW beam dump, 1-mA CW beam delivered to the dump.

PXIE time line

- Stage 1 complete – early FY17 (~Nov 2016)
  - Beam delivered to the end of MEBT with nearly final parameters (2.1 MeV, 1 mA CW, 80% arbitrary chopping)
  - installation of SSR1 cryomodule
- Stage 2 complete – Mar 2018
  - installation of HWR cryomodule, cold and ready for beam
- Stage 3 complete – September 2018

FY2015 Goals: PXIE

- Anticipate RFQ delivery in April 2015
  - Goal to be prepared operate RFQ when it arrives

  - Necessary support infrastructure
  - Ion Source/LEBT : characterize beam
    - know the input beam to RFQ!
  - MEBT Diagnostics and equipment

- to characterize the RFQ beam

SRF R&D : General Issues

- Future CW operation → cryo-losses → high Q0 is desired;
- Low beam loading → microphonics;
- High-Order Modes → “to damp, or not to damp?”
- Lorentz Force Detune (LFD) : low current pulsed operation?