Update of PXIE FRS

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PIP-II technical meeting

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Motivation

- Reflect the transition from PX to PIP-II
- Clarify infrastructure requirements/limitations
- State clearly that PXIE is the same CW machine that has been envisioned in 2011
- Get feedback from the team and modify the FRS draft accordingly before sending it to management for signing
  - The draft is in Teamcenter ED0001223-A;1
  - A copy of this draft in PIP-II DB (today's presentation)
    - http://pip2-docdb.fnal.gov/cgi-bin/ShowDocument?docid=41
  - Previous version of PXIE FRS is in PX DB
    - http://projectx-docdb.fnal.gov/cgi-bin/ShowDocument?docid=980

- Corrections by C. Baffes, V. Lebedev, and P. Derwent

Suggested changes

- Transition from PX to PIP-II
  - Change references
  - Include explicitly pulse mode
  - Adjust current from 1 mA to 2 mA CW to fit to PIP-II specs
  - Leave the requirement for full HEBT
    - 50 kW CW dump; 10^{-9} extinction ratio resolution
- Because CMTF building infrastructure capacities are now well defined, put clearer numbers for PXIE infrastructure constrains
- State that we would like to work with HWR and SSR1 independently as a requirement for cryo
  - Basis for future cryo distribution system specs

PIP-II and PXIE

1. Introduction:

PIP-II is a high intensity proton linac conceived to support a world-leading physics program at Fermilab [1]. Initially PIP-II will provide high intensity beams for Fermilab neutrino program with future extension to other applications requiring CW linac operation (e.g. muon experiments). PIP-II is considered to be a 2 mA CW, 800 MeV H⁻ linac that should be capable of working initially in a pulse (0.55 ms, 20 Hz) mode for injection into the Booster.

The PIP-II Injector Experiment (PXIE) will be an integrated systems test for the PIP-II front end [2]. It is part of the broader program of research and development aimed at key components of the PIP-II. The successful completion of this test will validate the concept for the PIP-II front end, thereby minimizing the primary technical risk element within PIP-II. Successful systems testing will also demonstrate the viability of novel front end technologies that will find applications beyond PIP-II in the longer term.

Subsystems

- A DC H^- ion source capable of delivering up to 10 mA (5 mA nominal) at 30 keV [3].
- A Low Energy Beam Transport (LEBT) section with beam pre-chopping [4].
- A CW Radio Frequency Quadrupole (RFQ) operating at 162.5 MHz and delivering up to 10 mA at 2.1 MeV [5].
- A Medium Energy Beam Transport (MEBT) section with integrated fast programmable wideband beam chopper and 21 kW beam absorber capable of generating arbitrary bunch patterns at 162.5 MHz from the RFQ beam [6].
- Two low-beta superconducting cryomodules (HWR and SSR1) capable of accelerating up to 2 mA of beam to greater than 27 MeV [7, 8].
- A High Energy Beam Transport (HEBT) section [9], which consists of (1) a beam diagnostic section, capable of measuring particle distribution including tail distributions and the extinction ratio of removed bunches at better than 10^{-9} level, and (2) a beam dump, capable of accommodating maximum beam power of 50 kW with energies of up to 30 MeV for extended periods.

Main goals

Validate critical technologies required to support the PIP-II Reference Design concept.

- Provide a platform for demonstrating operations of PIP-II front end components at full design parameters
- Integrated systems test goals:
  - 2 mA average current with 80% bunch-by-bunch chopping of the beam delivered from the RFQ
  - Efficient acceleration with minimal emittance dilution through at least 27 MeV in both CW and pulse modes
  - Demonstration of stable beam acceleration in SSR1 cryomodule with pulsed RF
- Measurement and characterization of beam extinction for the removed bunches

Infrastructure

- The available cryogenic supply from the Superfluid Cryogenic Plant (SCP) has a maximum capacity as listed in Table 1:

TABLE 1: CMTF SCP Cryogenic Capacity

Temperature Level	Capacity
2 K	500 W
5 to 8 K	600 W
40 to 80 K	4,100 W

Thanks to Jerry Leibfritz for providing the numbers.

- Electric power is provided by 480V, 3 phase switchboards capable of delivering of at least 900 kW to PXIE equipment (RF, magnet power supplies, vacuum, diagnostics, and controls).
- The current building HVAC has enough capacity to provide heating and cooling of empty building throughout the year. On top of that, the AC system is capable of removing heat from CMTS1 equipment and, in addition, at least 70 kW of heat from CMTF equipment.
- The PXIE requires Low Conductivity Water (LCW) provided by the CMTF LCW system. The capacity of this system available for PXIE is at least 900 kW.
- The PXIE Linac will require compressed air, provided by the CMTS air system. The capacity of this system available for PXIE is 150 ft^3/min at 90-120 psig.
- The CMTF building has a 20-ton overhead crane with a maximum hook to floor clearance of 24 feet.

Main requirements

	Functional Requirements Specification - PXIE	
L1	Delivered beam energy, minimum/maximum	15/30 MeV
L2	Average beam power	≤ 50 kW
L3	Nominal/maximum Ion Source and RFQ current	5/10 mA
L4	Average beam current (averaged over >1 μsec)	2 mA (at MEBT end)
L5	Beam normalized transverse RMS emittance*	< 0.25 mm-mrad
L6	Beam normalized longitudinal RMS emittance&	< 1 eV-μs
L7	Maximum bunch intensity (ppb)	3.8 x 10^8
L8	Minimum bunch spacing	6.2 nsec (1/162.5 MHz)
L9	The MEBT shall include a Wideband Chopper capable of removing bunches in arbitrary patterns at 162.5 MHz	<5% beam loss in unremoved bunches; <0.01% residual beam in removed bunches at MEBT end
L10	Individual components should meet PIP-II requirements - Ion Source, LEBT, RFQ, MEBT, HWR & SSR1. Exceptions to this requirement shall be documented.	
L11	The MEBT shall be capable of disposing of 100% of the beam coming from the RFQ	
L12	The beamline shall be 1.3 m above floor elevation	
L13	Radiation shielding shall be sufficient for an unlimited occupancy designation, as defined by FESHM, outside the PXIE enclosure	
L14	Accuracy of measuring the beam extinction for removed bunches	$<10^{-9}$
L15	PXIE should be capable of reproducing PIP-II pulsed mode of operation for the Booster injection	0.55 ms beam pulses at 20 Hz
L16	Appropriate diagnostic systems shall be developed, installed and commissioned to verify and quantify all of PXIE requirements in this document	

- Changes are highlighted
  - Requirement that the PXIE tunnel should be identical to the future linac's is removed

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Cryogenic distribution system

Specifications for PXIE cryogenic distribution system (CDS) should be described in a separate document taking into account the following requirements.

The CDS has to allow for the ability to operate both the CMTS1 and the PXIE Linac simultaneously or separately. Warm-up/cooldown of the PXIE shall be with minimal interruption to CMTS1 operation.

The design of the PXIE CDS shall support the following operations modes to allow for independent operation of each cryomodule (HWR and SSR1):

TABLE 3: Cryogenic Operations Modes

Mode	**HWR**	**SSR1**
Non-operation	Warm	Warm
Simultaneous operation	Cold	Cold
HWR operation	Cold	Warm
SSR1 operation	Warm	Cold

It is permissible to accomplish “HWR Operation” or “SSR1 Operation” modes by removing the connecting U-tubes of the cryomodule that is to stay warm.

In transitions between Simultaneous Operation and HWR Operation or SSR1 Operation, transient temperature excursions of the non-transitioning cryomodule (i.e. the cryomodule that is staying cold) shall be < 50K (TBR) at the cavities to limit thermal cycling magnitude and avoid the Q-disease regime.

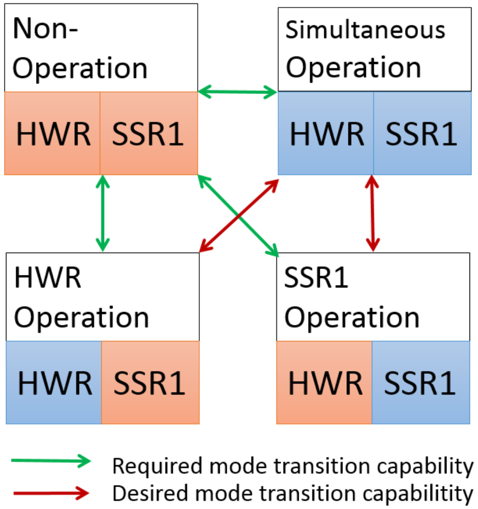

Figure 2: Required mode transitions for PXIE cryogenics

- New addition (C. Baffes)
  - Need input from Cryo