PIP-II Installation and Commissioning

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PIP-II Machine Advisory Committee Meeting

1-3 June 2021

A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Outline

- Scope of I&C
- PIP2IT Test Infrastructure
- PIP-II Building Infrastructure
- PIP-II Linac Installation
- Summary

Scope of I&C

- The PIP-II Installation and Commissioning (I&C) WBS includes:
  - 121.04.01 Project Management (PM)
  - 121.04.02 Warm Front End (WFE)
  - 121.04.03 Test Infrastructure (TI)
  - 121.04.04 Building Infrastructure (BI)
  - 121.04.05 Linac Installation (LI)
  - 121.04.06 Beam Commissioning (COM)
  - 121.04.07 Accelerator Physics (AP)

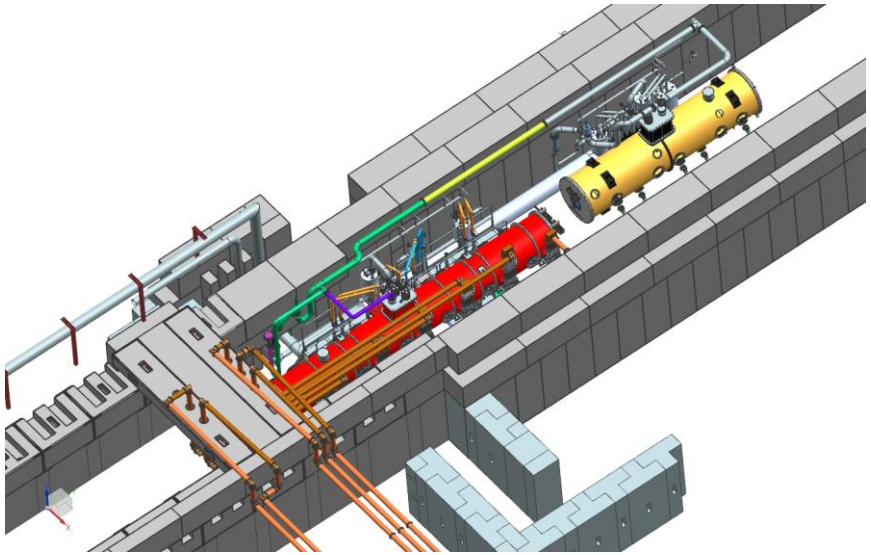
See PIP2IT talk (Pozdeyev)

Will be discussed in this talk

See PIP2IT talk (Pozdeyev)

PIP-II Injector Test (PIP2IT)

- The PIP2IT accelerator is a testbed for the PIP-II WFE, HWR and SSR1
  - Testing of an integrated system with beam
  - Verification of key PIP-II components and technologies
- The PIP2IT facility will be converted to a test stand for PIP-II's cryomodules

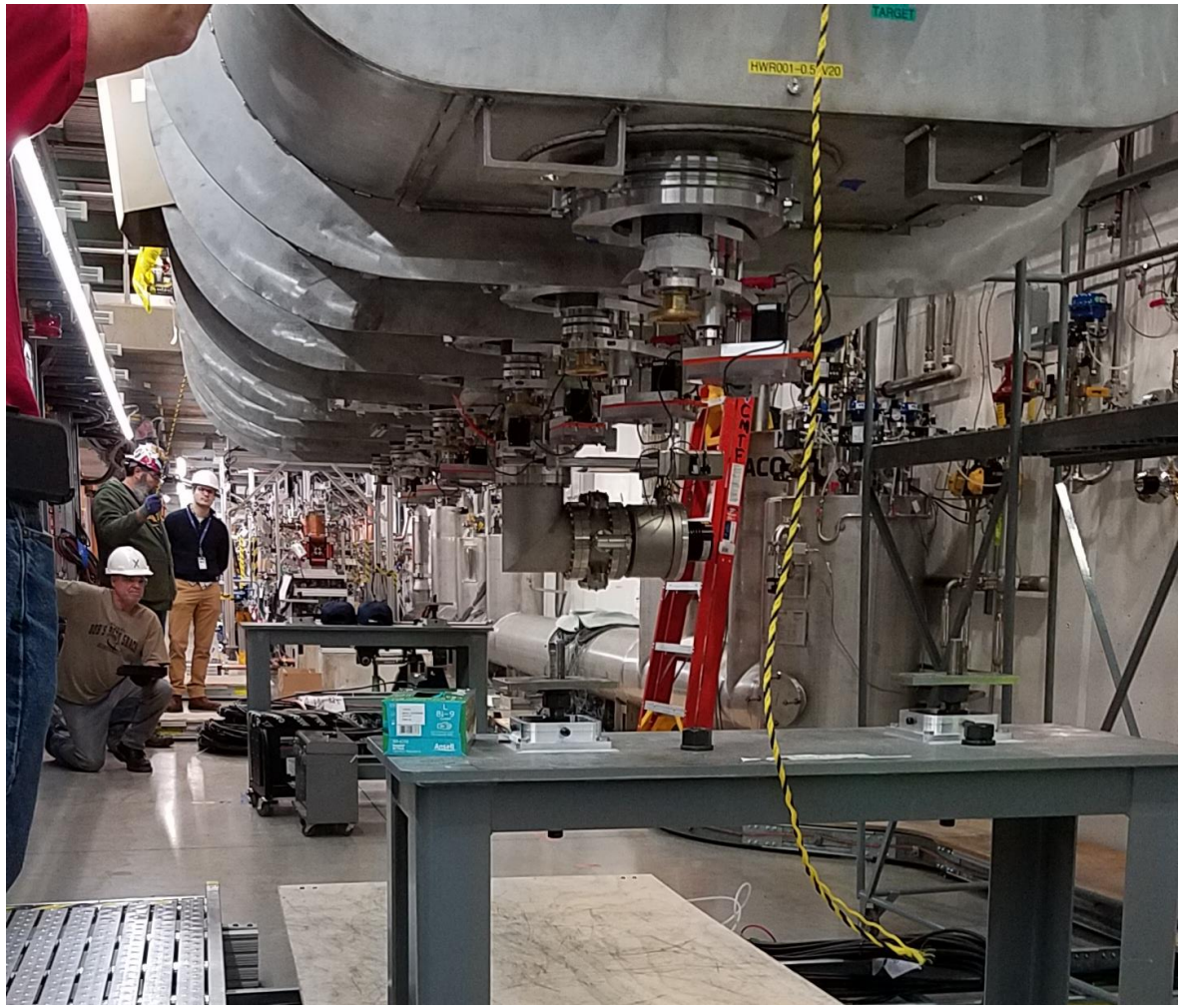


PIP2IT Status/Accomplishments

- I&C responsibilities for PIP2IT:
  - Construction and installation of test cave, infrastructure and utilities ✔
  - Installation of accelerator components ✔
  - Beam commissioning (see Pozdeyev PIP2IT talk) ✔
  - Disassembly/removal of PIP2IT accelerator components & storage of equipment
  - Conversion of PIP2IT into cryomodule test stands (for no-beam cold RF testing)

PIP2IT Test Infrastructure (TI) Scope and Status Summary

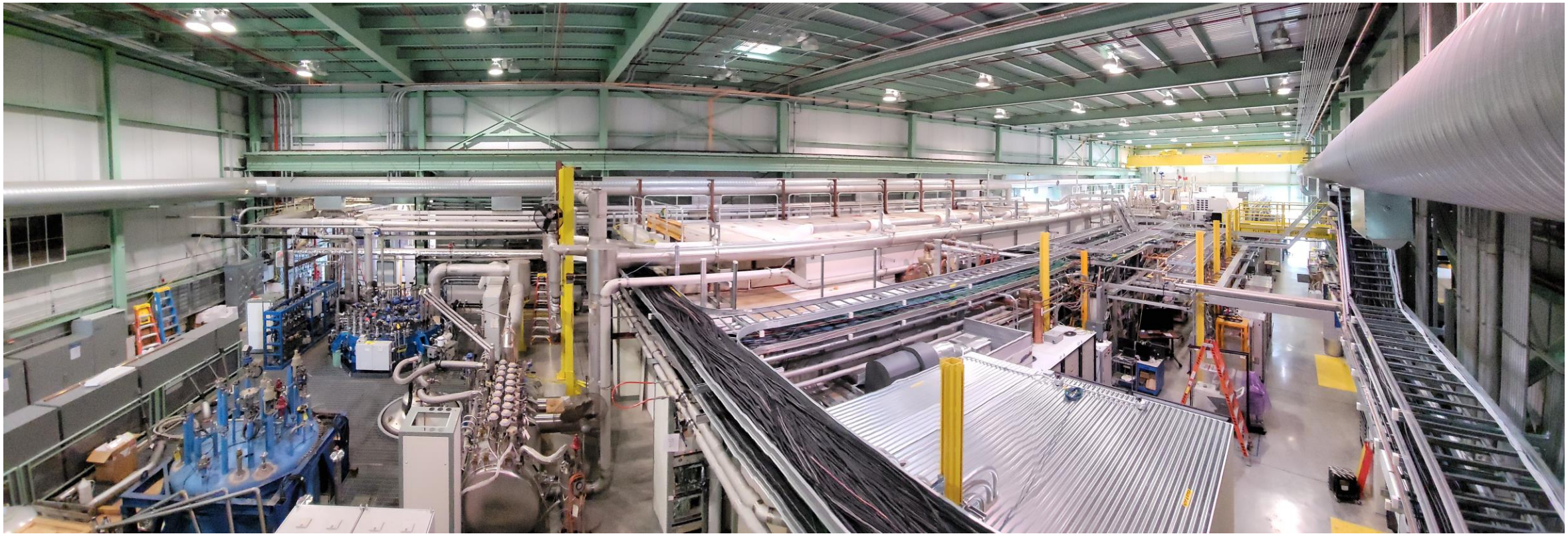
- Installation of and operations support for the PIP2IT accelerator facility
  - Mission completed with the beam test program, April 2021
- Design of PIP2IT fluids and electrical systems
  - Developed an implemented solutions that will be carried forward into PIP-II
- (PIP2IT Disassembly)
  - Different WBS, same team
  - Removal of accelerator equipment to storage, ongoing now
- 650MHz Test Stand Modifications
  - Preparing for installation start in June (following HWR systems removal)



HWR installation at PIP2IT

PIP2IT Test Infrastructure

- Construction of PIP2IT's infrastructure from 2013-2021 provided opportunities to develop
  - Design practices
  - Work planning
  - Team coordination



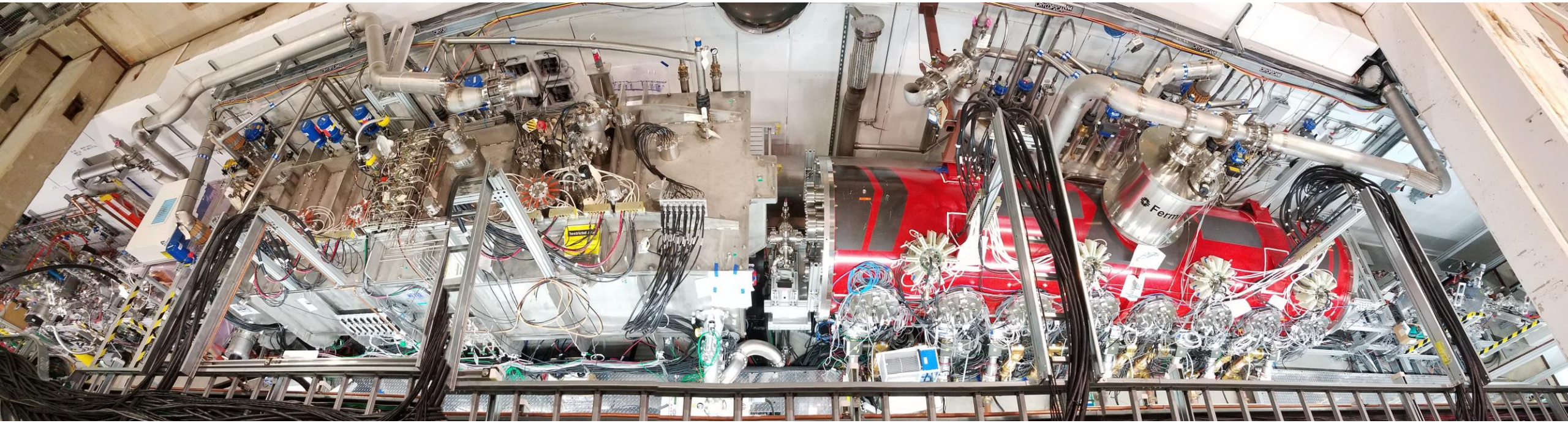
PIP2IT Test Infrastructure – Building Infrastructure Experience

- Successful features carried forward to PIP-II Building Infrastructure Design
  - RFQ cooling system (water-based tuning and resonance control)
  - Coupler air cooling
  - Ion Source chiller
  - Dissolved oxygen removal technology
  - Cable database implementation

RFQ cooling system

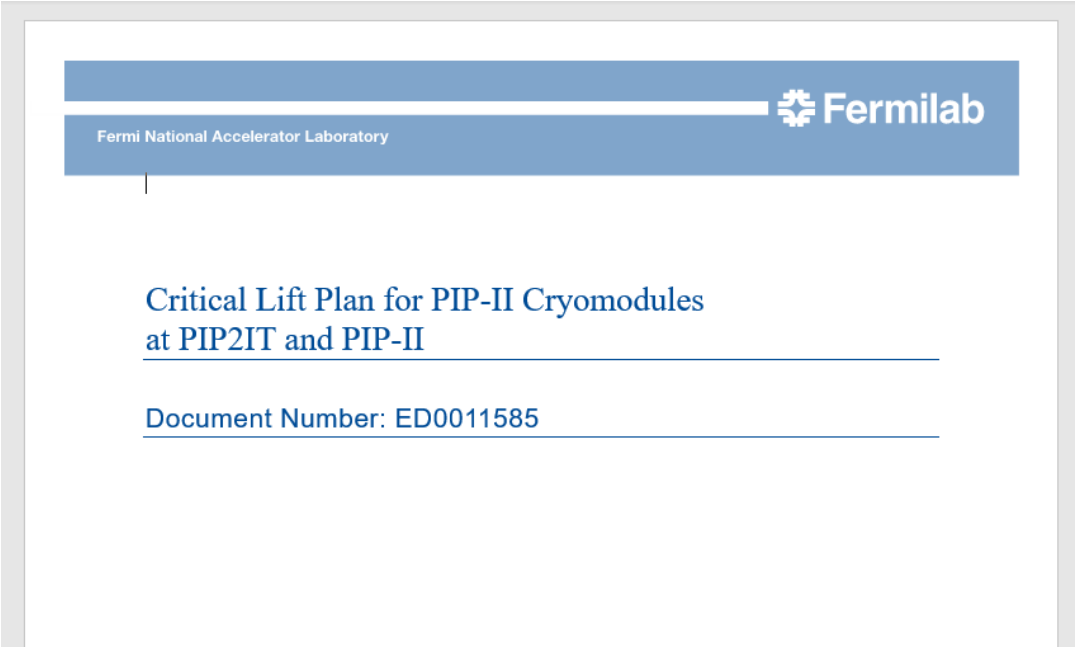
PIP2IT Test Infrastructure - Installation Experience

- The Linac Installation team coordinated PIP2IT installation
  - Team was onboarded early to take advantage of opportunity to gain experience
  - Experience and lessons learned carried forward to PIP-II installation planning
  - Especially relevant to PIP-II acceptance, verification/validation and traveler plans



PIP2IT Disassembly

- PIP2IT is being disassembled and stored, in preparation for reinstallation in PIP-II
  - Another opportunity to optimize our PIP-II processes and documentation

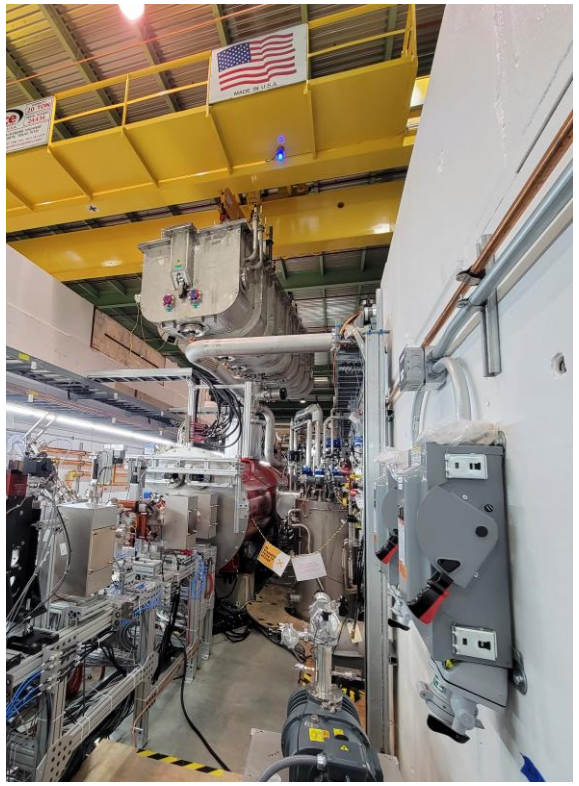


Fermilab

Fermi National Accelerator Laboratory

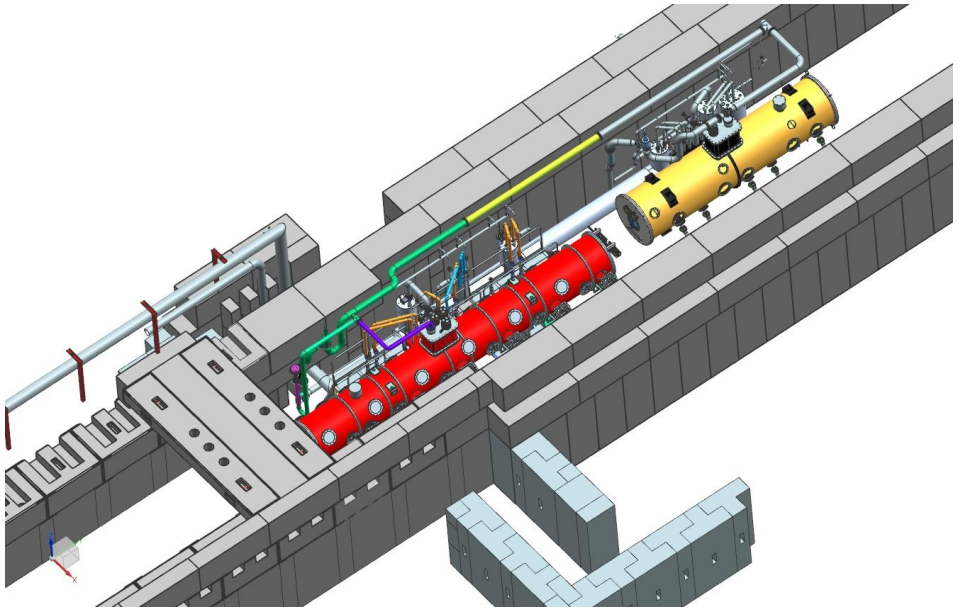
Critical Lift Plan for PIP-II Cryomodules
at PIP2IT and PIP-II

Document Number: ED0011585



650 Test Stand Modifications

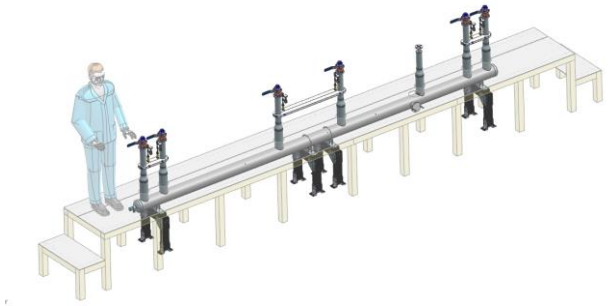
- PIP2IT is being turned into a test stand for PIP-II cryomodules
  - Accommodates 1 SSR module + 1 650MHz module
  - Capability to test modules independently, simultaneously
  - 2K operation with RF
- Test Infrastructure Responsibilities
  - Electrical and mechanical infrastructure & utility modifications
  - Integration and installation support for all sub-systems
  - Cryogenic Transfer Line
    - Adapts existing HWR bayonet interfaces to standard 650MHz cryomodule interfaces



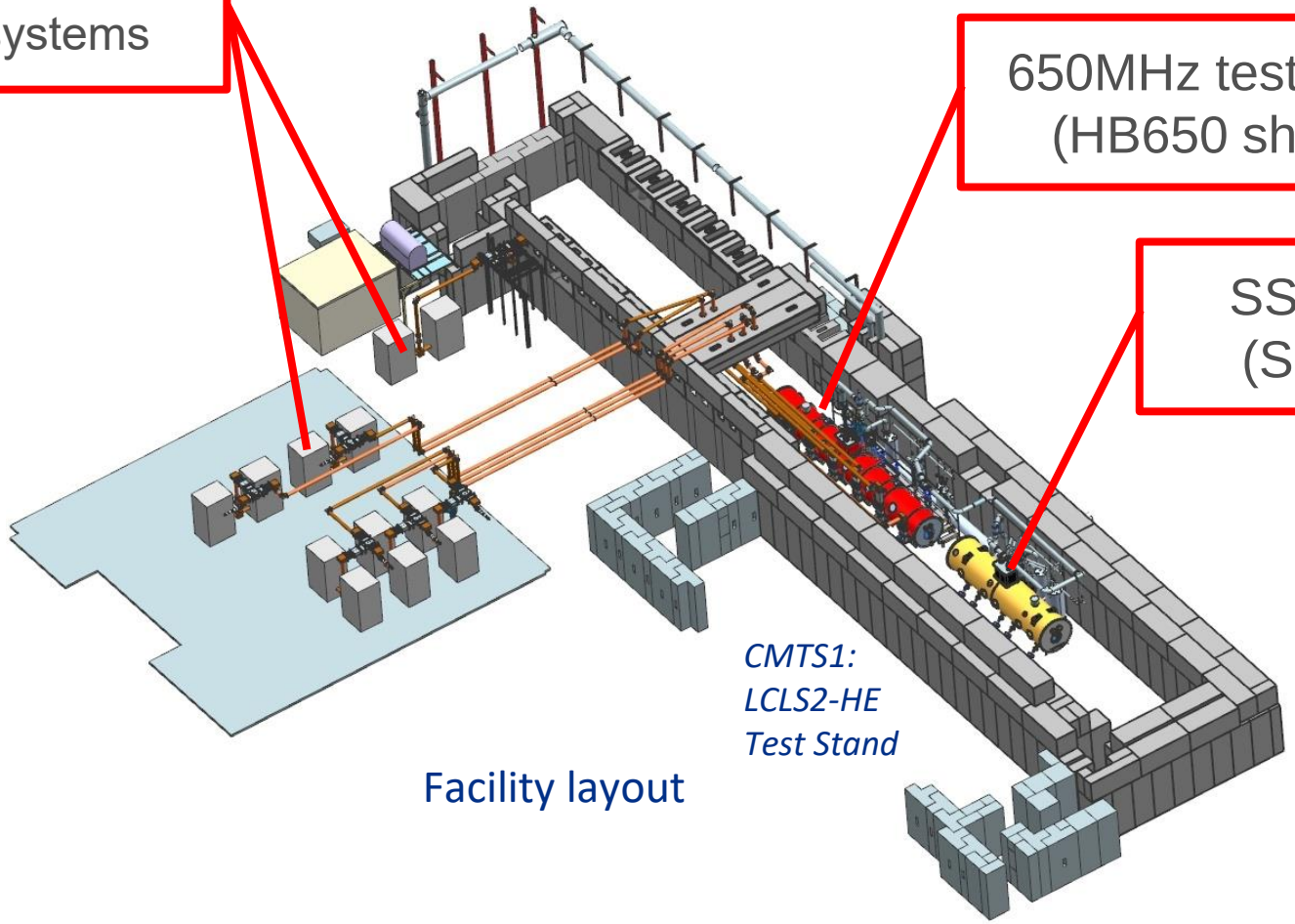
3-D Model of 650 MHz and SSR cryomodule test stands

650 Test Stand Overview 3D Models

650MHz
amplifier systems



New cryogenic transferline



Facility layout

650MHz test stand
(HB650 shown)

SSR test stand
(SSR2 shown)

Building Infrastructure (BI) – Scope and Status Summary - Electrical

- Design of Electrical distribution from CF interface point to system equipment
  - Power distribution and grounding
  - Cable, connectors, and tray routing, overall cable plant management
  - Similar scope successfully managed and completed for PIP2IT
  - PIP-II preliminary design is complete, preparing final design
  - BI team actively supporting PIP-II CF design
- Design of PIP-II cable database
  - Cable database prototype has been created
  - Testing of database and implementation currently underway using PIP2IT 650 MHz test stand reconfiguration
- Design and layout of relay racks for PIP-II
  - Prototype racks have been purchased and set up for users inspection/feedback

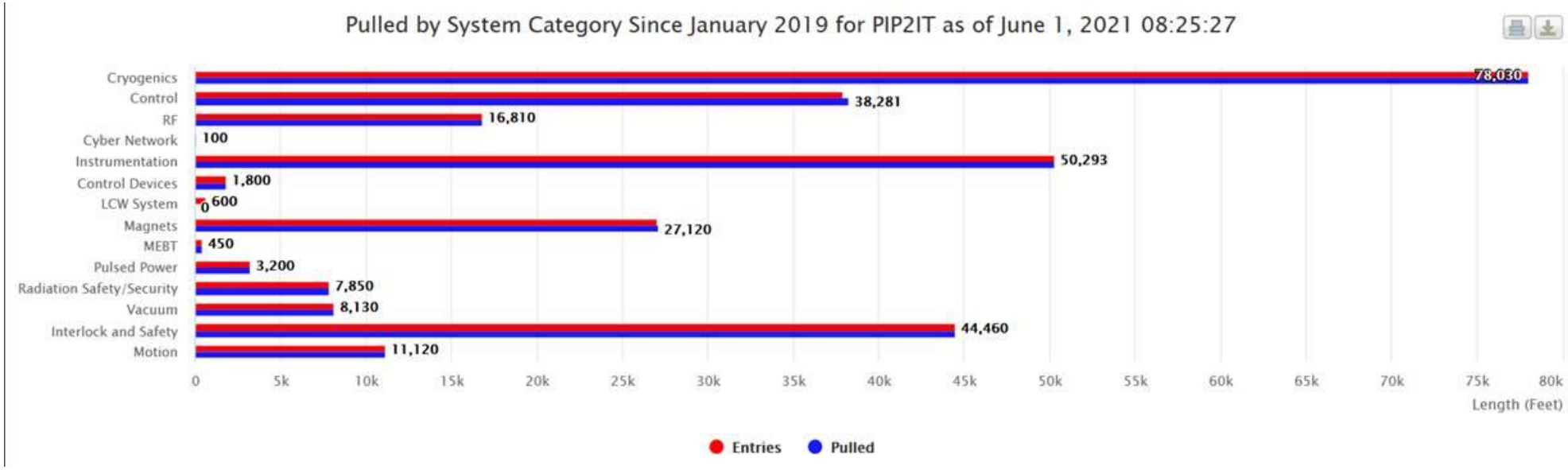
Building Infrastructure – Electrical Lessons Learned from PIP2IT

- Design
  - It's helpful if rack layouts are finalized early
  - Include overhead in cabling plans to accommodate late changes
  - Enforce standardized cables
- Cable Database
  - Database, sequence of work, must be constantly monitored and maintained
  - Fully define cable routes
  - Track special cable considerations in Database prior to pull
- Installation
  - Be flexible with cable pulls when necessary
  - Protect cable after installation to avoid damage
  - Have a central cable store, with an adequate staging area for electricians
  - Enforce labeling before installation

Building Infrastructure – Cable Database

Number of Records found: 3373 Start: 1

Requester Entry Date ↑ ↓ CANUMBER ?	Spool / Batch	Approved ?	Function	Machine / Line	Origin	Destination	Cable (Code) / Length	System	Building / Penetration
					CMTF				
Michael Kucera 3527 Apr 06 2021	/		ZSHIFC2 (more)	PIP2IT (P)	Rack_226	Rack_421	RG58 GREEN (CB) / 80	Control (E)	CMTF /
HEBT Insertable Faraday Cup S&H output to PXMC2									
Michael Kucera 3526 Mar 25 2021 Entered by: John Van Bogaert	/		HRMLINK2 (more)	PIP2IT (P)	Rack_101	Rack_222	Special (to be supplied by FNAL) (SP) / 70	Control (E)	CMTF /
HRM Serial Interface Link2									
Michael Kucera 3525 Mar 19 2021	/		CommNet (more)	CMTS1 (1)	Rack_599	Rack_457	CAT 6 (Network) (DF) / 50	Motion (MT)	CMTF /
Communication cable from PLC to Cryo-Con transmitter									
Michael Kucera 3524 Mar 19 2021	/		xTMTC8Ex (more)	CMTS1 (1)	Rack_599	Rack_457	2 PAIR T.S. #22 Belden #82723 (N3) (N3) / 50	Motion (MT)	CMTF /



Building Infrastructure – Prototype Relay Racks

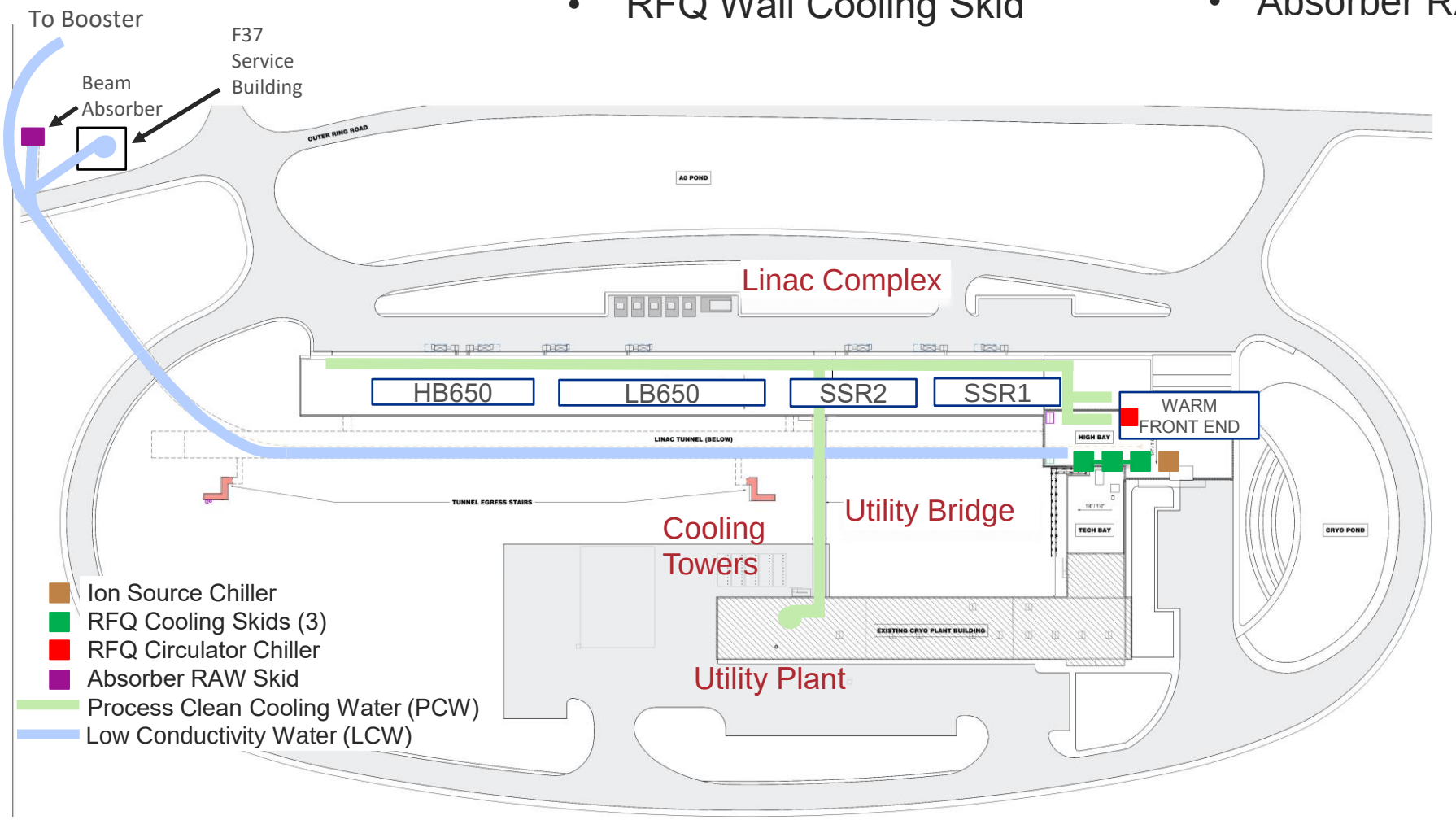
- Prototype relay racks purchased
  - Standardized, configurable options
  - Handling and ergonomics considered
  - Available for team design

Building Infrastructure (BI) – Scope and Status Summary - Mechanical

- Design of distribution process fluid piping system utilities (PCW, LCW, compressed air, utility Nitrogen) in the Linac High Bay Building and Gallery, Linac tunnel, and Beam Transfer Line
  - Includes
    - PCW pump room in the Utility Plant at the Cryoplant Building.
    - LCW pump room in the F37 Service Building.
    - Special application skids, chillers in warm front end and BTL absorber.
    - Layout planning of piping/hose connection assemblies, valve, and instrumentation
  - Management of CF interface and envelopes with process fluid systems are well understood and stable
  - Preliminary design is complete, implementing PDR recommendations.
- Procurement and installation
  - Installation of primary distribution piping is part of CF construction
  - PCW and LCW pump room system procurement and installation performed by BI
  - Linac/Gallery instrumentation and connecting hardware procured by BI, installed by Linac Installation team
  - Planning and communication with CF and LI is underway and well understood.

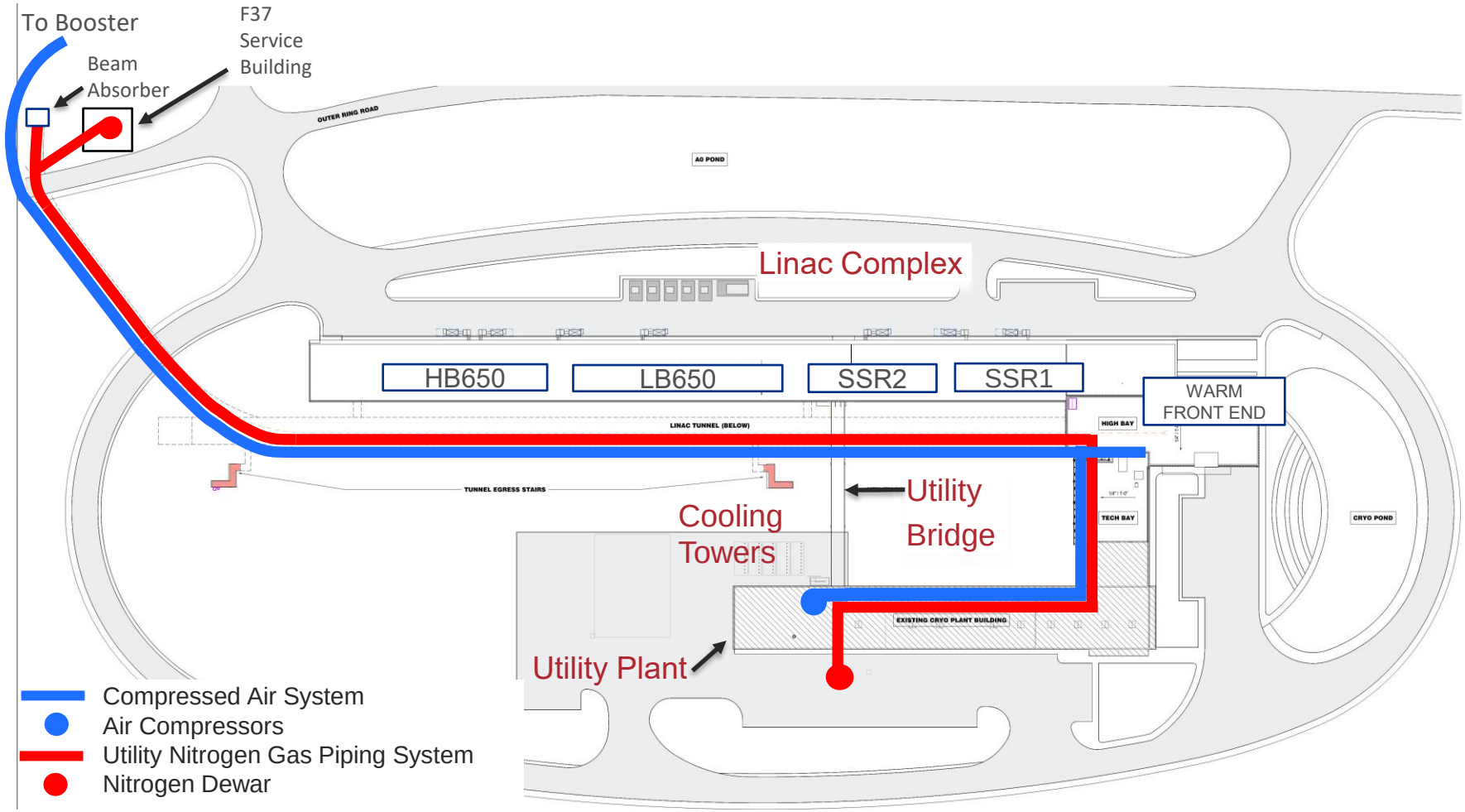
Building Infrastructure Scope – Process Water Cooling

- Process Clean Water (PCW) System
- Low Conductivity Water (LCW) System
- RFQ Intermediate Cooling Skid
- RFQ Vane Cooling Skid
- RFQ Wall Cooling Skid
- RFQ Circulator Chiller
- Ion Source Chiller
- Absorber RAW Skid



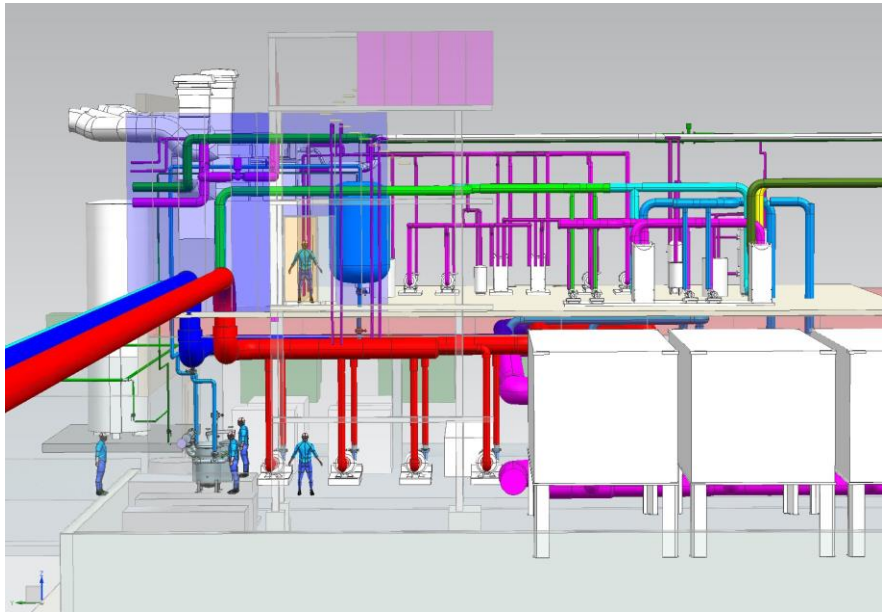
Building Infrastructure Scope – Compressed Gas

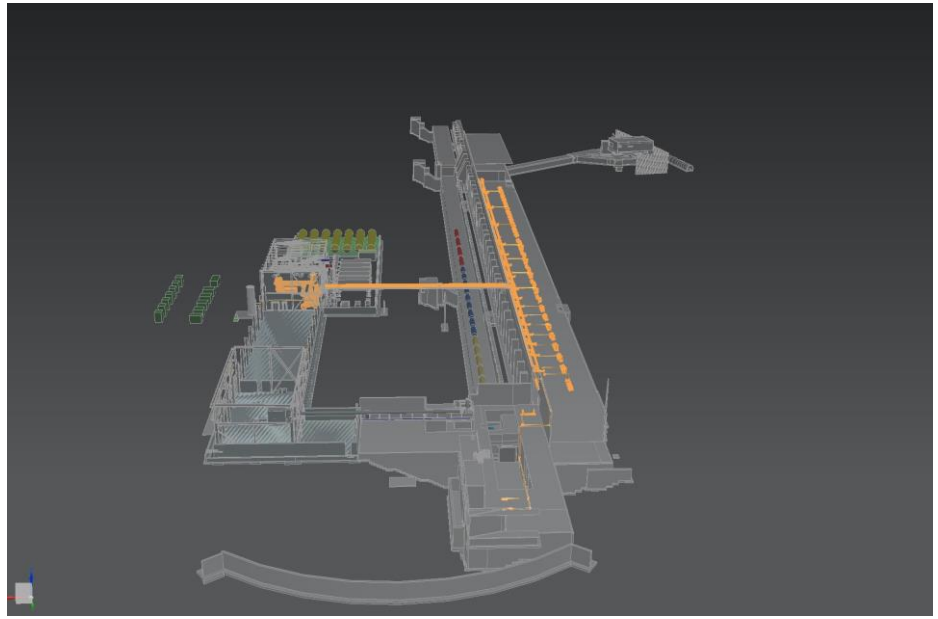
- Compressed Air System
- Utility Nitrogen Gas Piping System



Process Clean Water (PCW) System

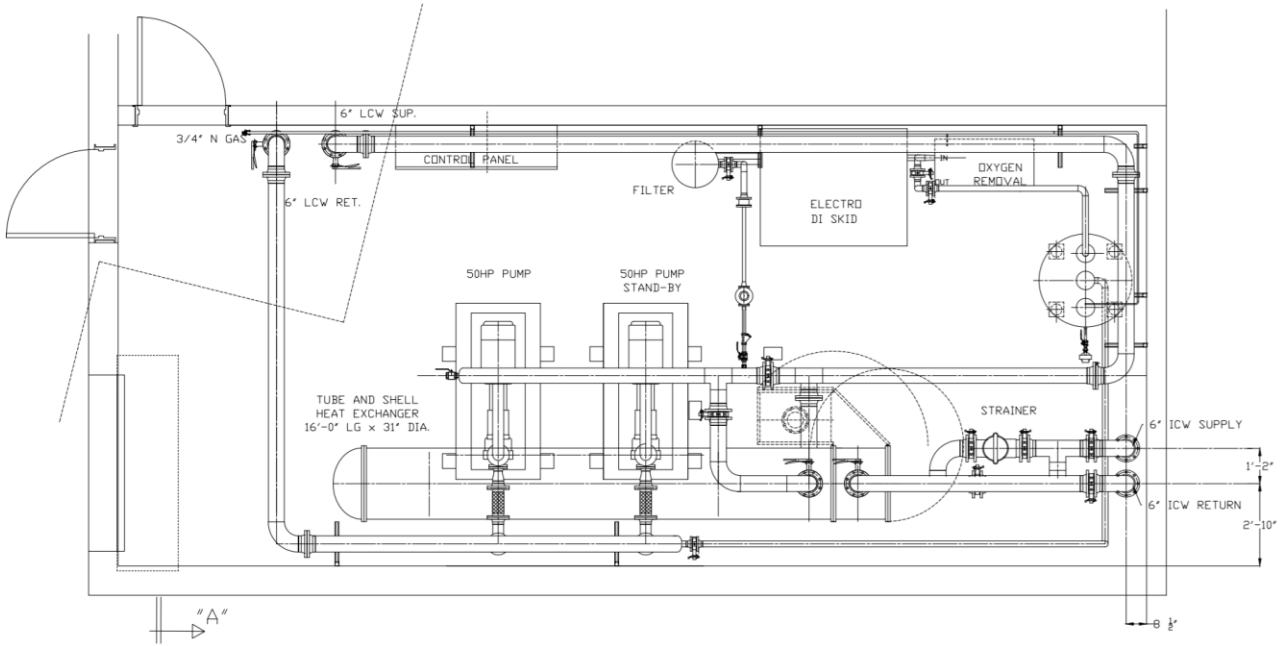
- Provides process clean cooling water to the SRF power amplifier equipment
  - Low conductivity is not a cooling water requirement for this equipment in LINAC gallery
  - As a result, a separate, smaller LCW system created for LINAC/BTL enclosures
- PCW Pump Room located in the Utility Plant
- Preliminary design is complete, implementing PDR recommendations.

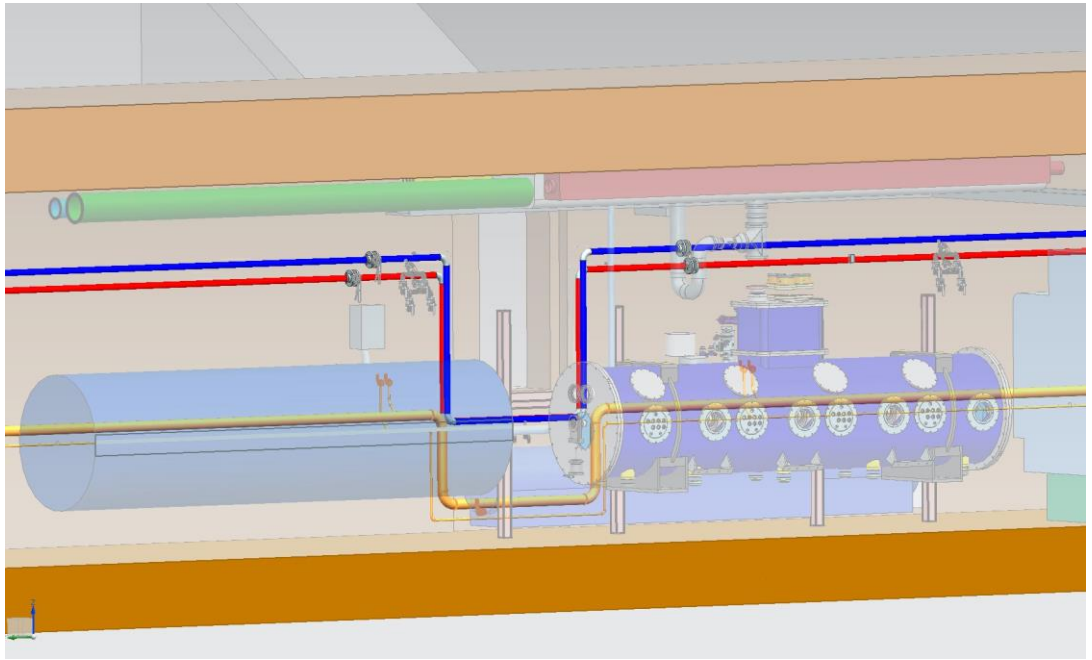




Low Conductivity Water (LCW) System

- Provides low conductivity cooling water to accelerator magnets, power supplies, and other beamline components
- LCW Pump Room located in the Utility Plant
- The preliminary design is complete

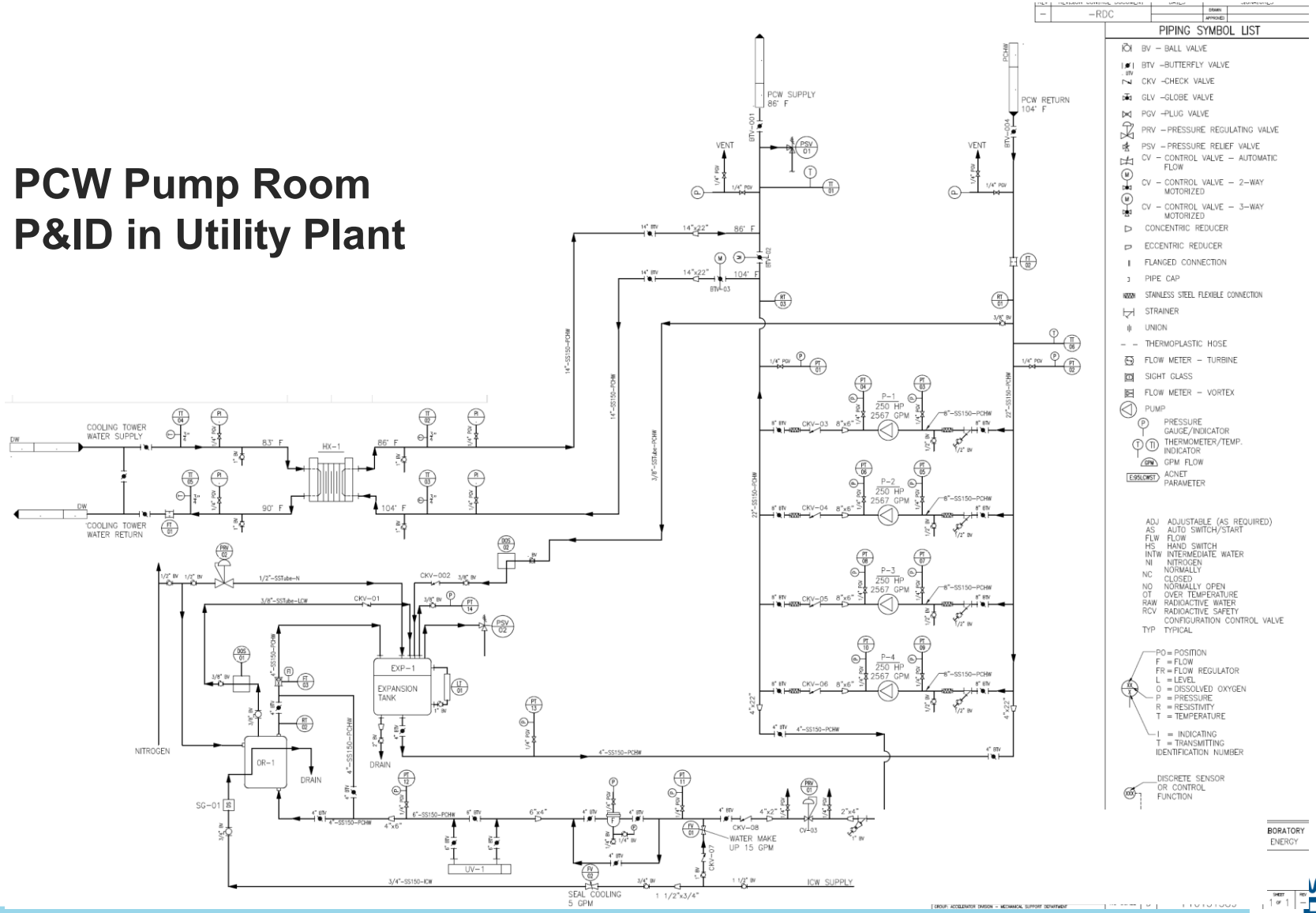




PCW/LCW - Piping and Instrumentation Diagram (P&ID)

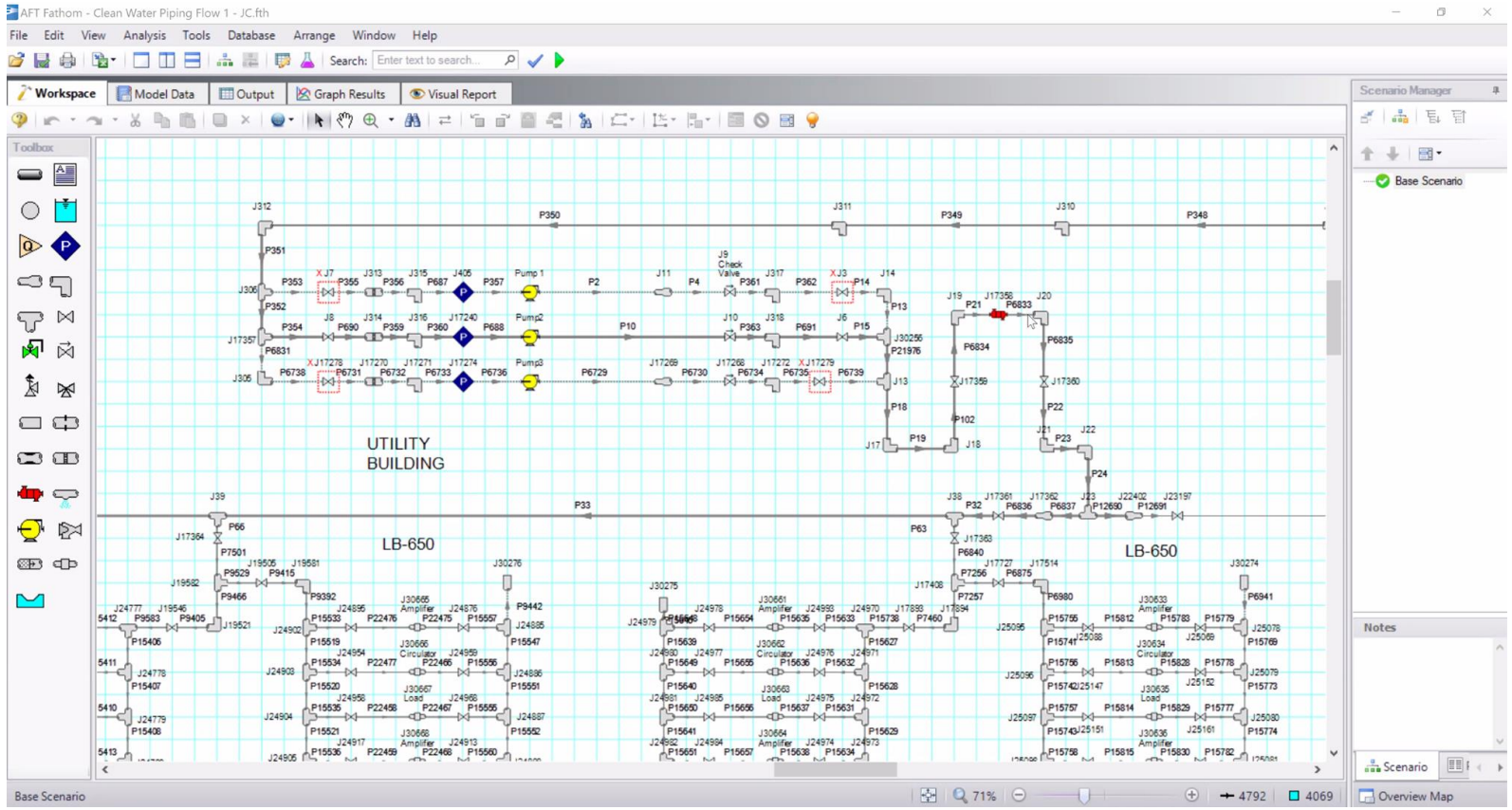
- P&ID completed for pump rooms, skids, chillers, compressed gas systems
- Currently working on complete P&ID for entire PIP-II PCW and LCW systems

PCW Pump Room P&ID in Utility Plant

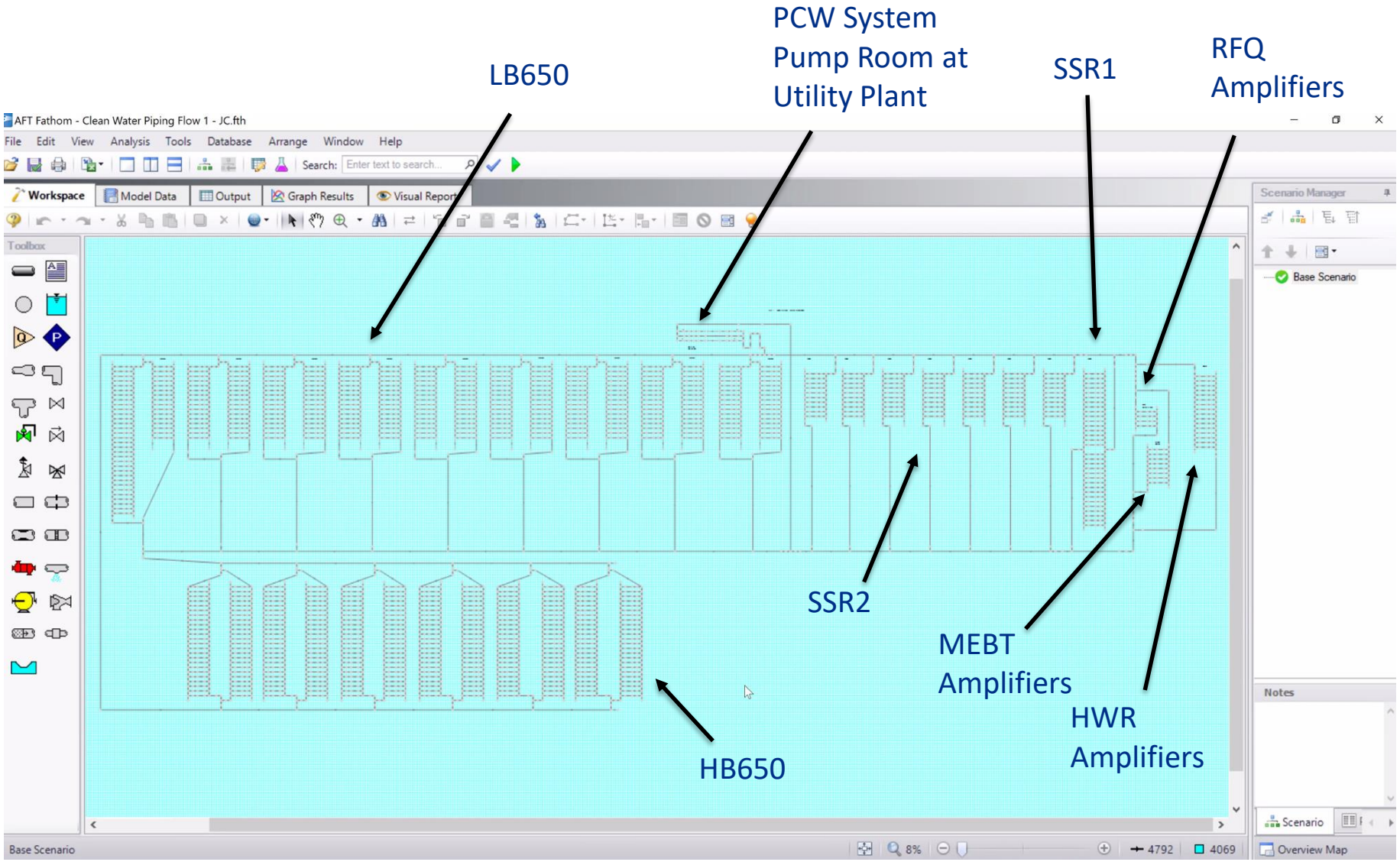


PCW/LCW - System Flow Analysis

- Comprehensive analysis of PCW and LCW systems completed
- AFT Fathom - Fluid dynamic simulation software
- Calculates pressure drop and pipe flow distribution in piping fluid systems
- Confirmed equipment selection and sizing satisfies system requirements



AFT Fathom Example – PCW to amplifiers



RFQ LCW Cooling System and Ion Source Chiller

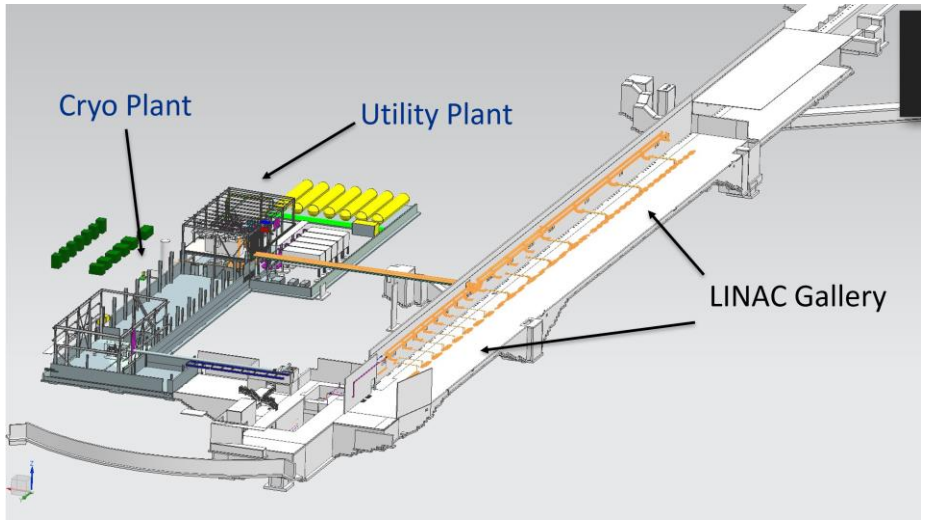
- RFQ uses three skids (Vane, Wall, Intermediate) working together as one system
  - Recirculates LCW through vane and wall sections of the RFQ
  - Cooled via intermediate skid using facility chilled water (CHW)
- Ion Source Chiller, Self-contained, Air-cooled, LCW
- Both systems successfully tested during PIP2IT operations
- Systems will be reused for PIP-II

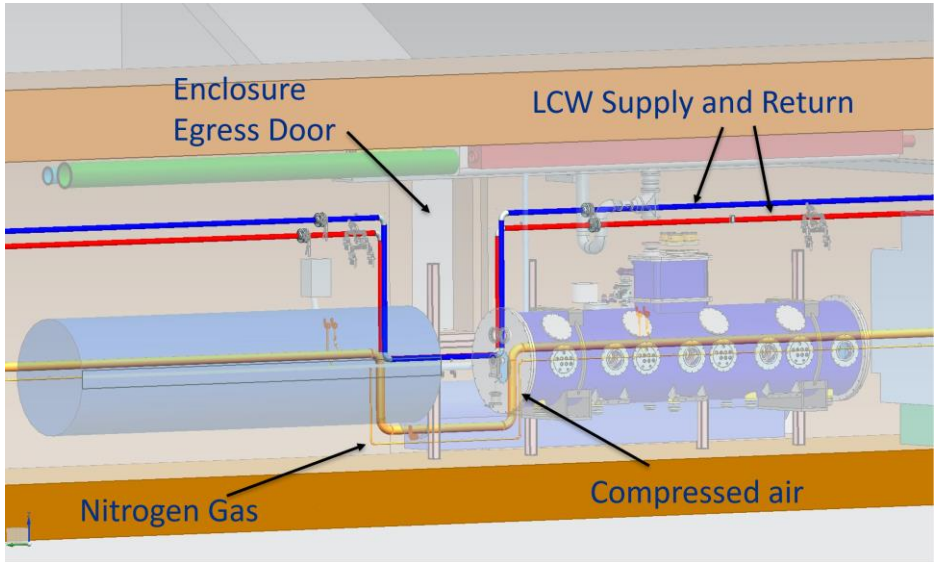
BTL Beam Absorber RAW Skid

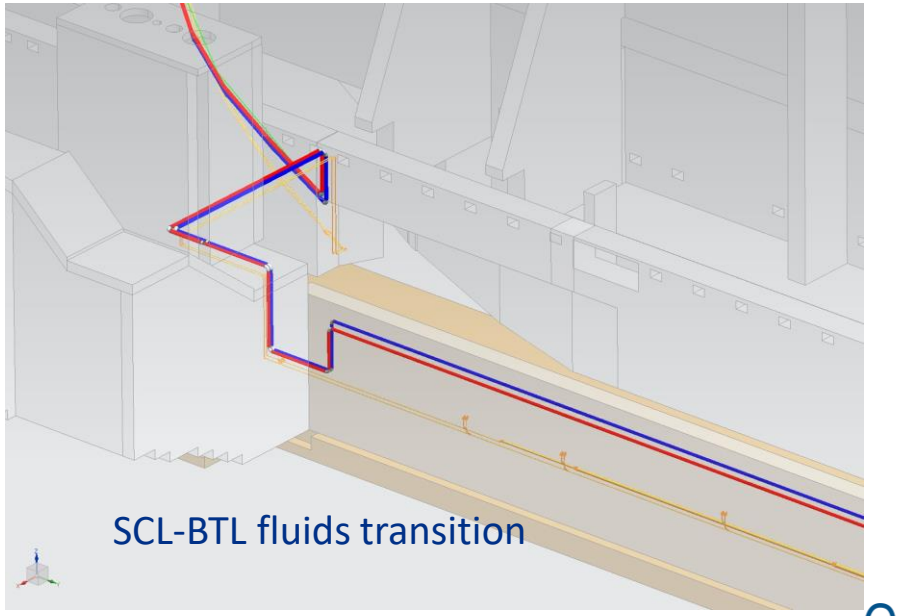
- Radioactive Water system
- Cools the Beam Absorber located in the Beam Transfer Line (BTL)
- The preliminary design is complete, final design in process
- Similar Absorber RAW Skid design successfully in operation at NML

Air and Nitrogen

- Compressed air system supports multiple end uses, including significant coupler cooling loads
- Nitrogen supports skid blankets, vacuum needs
- Preliminary design is complete, implementing PDR recommendations.







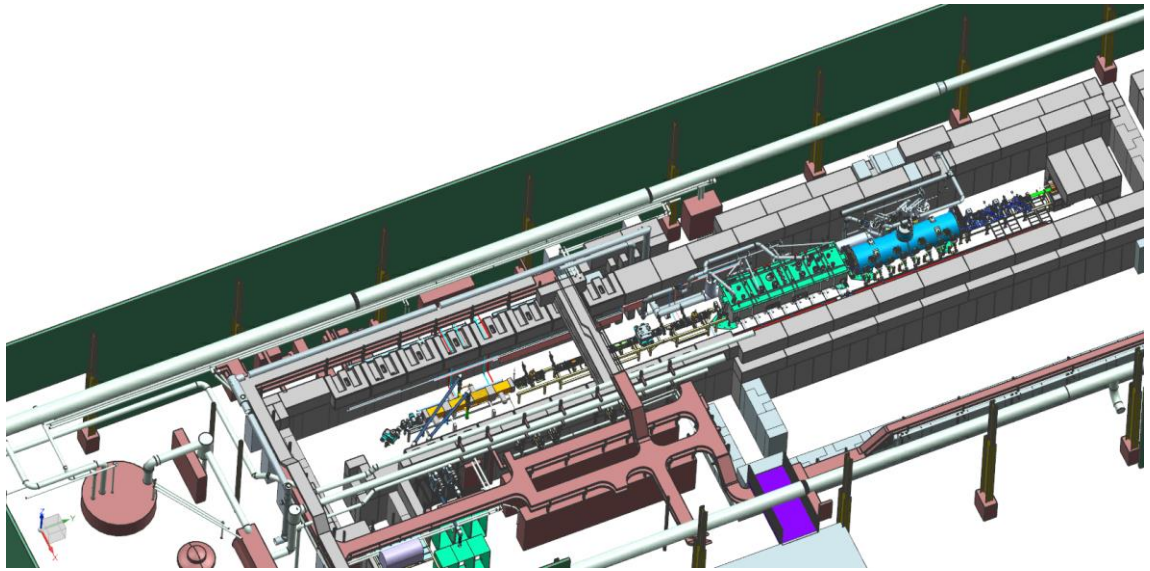
Linac Installation (LI) Scope and Status Summary

- PIP-II Integrated CAD Model
  - Mechanical model, incorporates solid models developed by PIP-II system teams
  - Model is in place and growing
- Designs for…
  - Alignment network (In design)
  - Cryomodule stands and mover (stand prototypes in use at PIP2IT)
  - Warm unit structures (PDR June 2021)
- PIP-II WFE+SCL Installation
  - Planning and execution
  - Incremental handoff to Commissioning

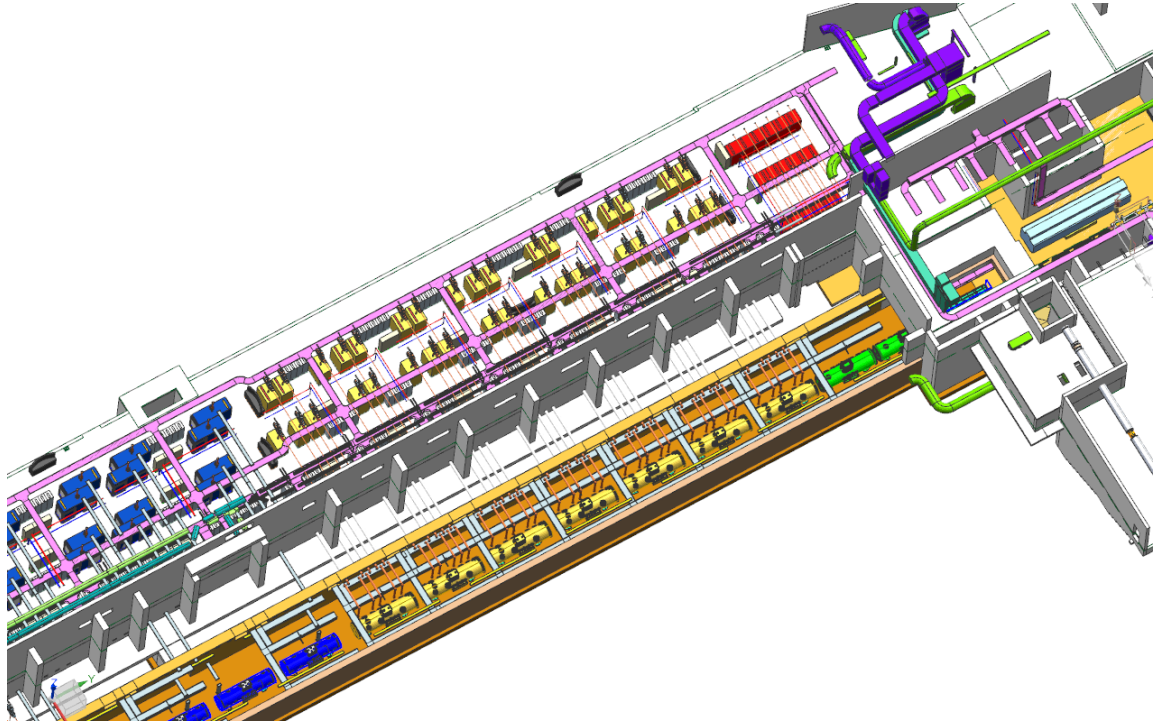
Cryomodule modular stand with HWR

Integrated CAD Model

- LI maintains the top-level PIP-II CAD model
  - Lessons learned from the PIP2IT model have been employed
  - Techniques for geometry simplification, assembly structure management and 3D scan have been incorporated
  - Robust data exchange with CF team

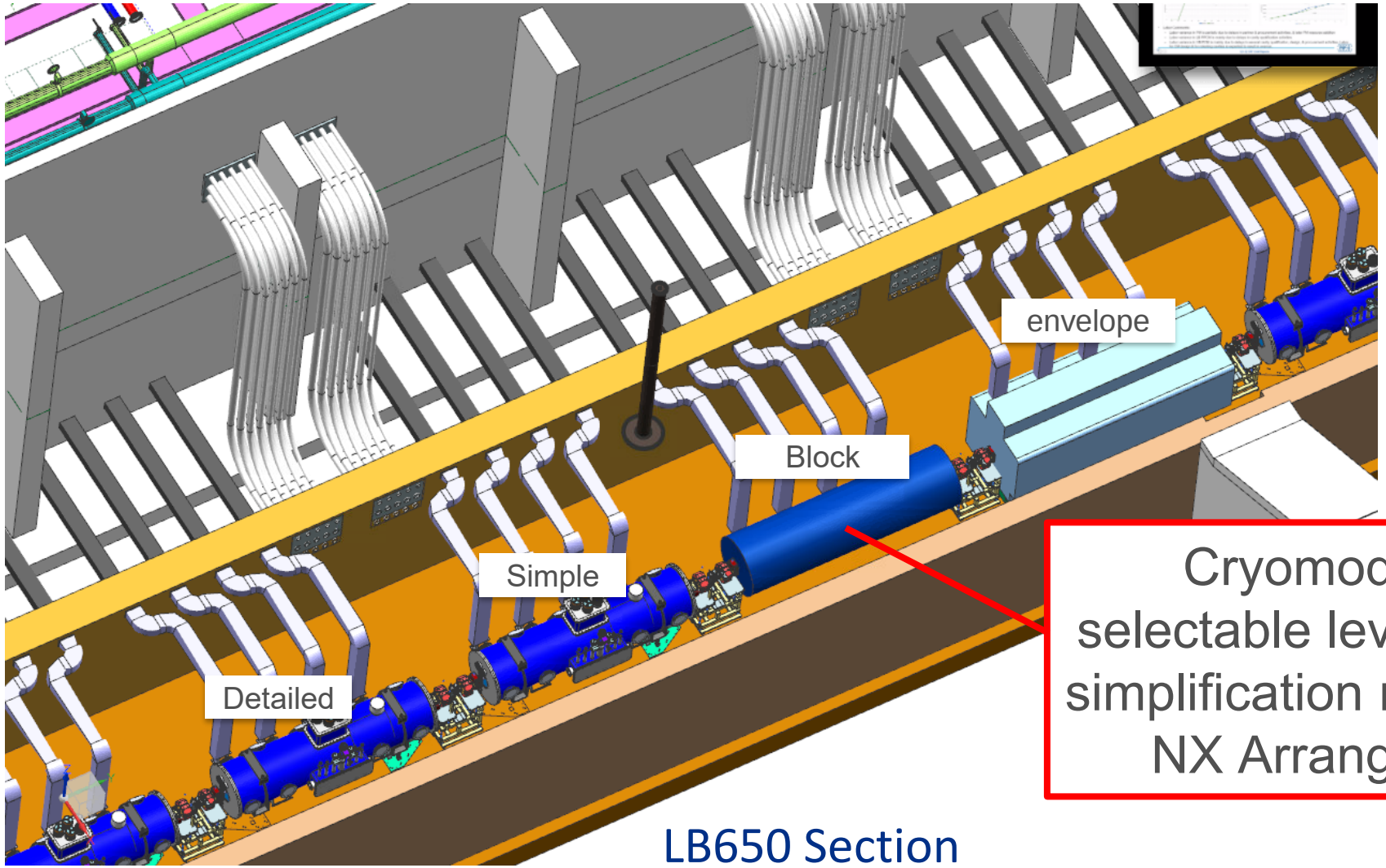


PIP2IT Integrated CAD model



PIP-II Integrated CAD model

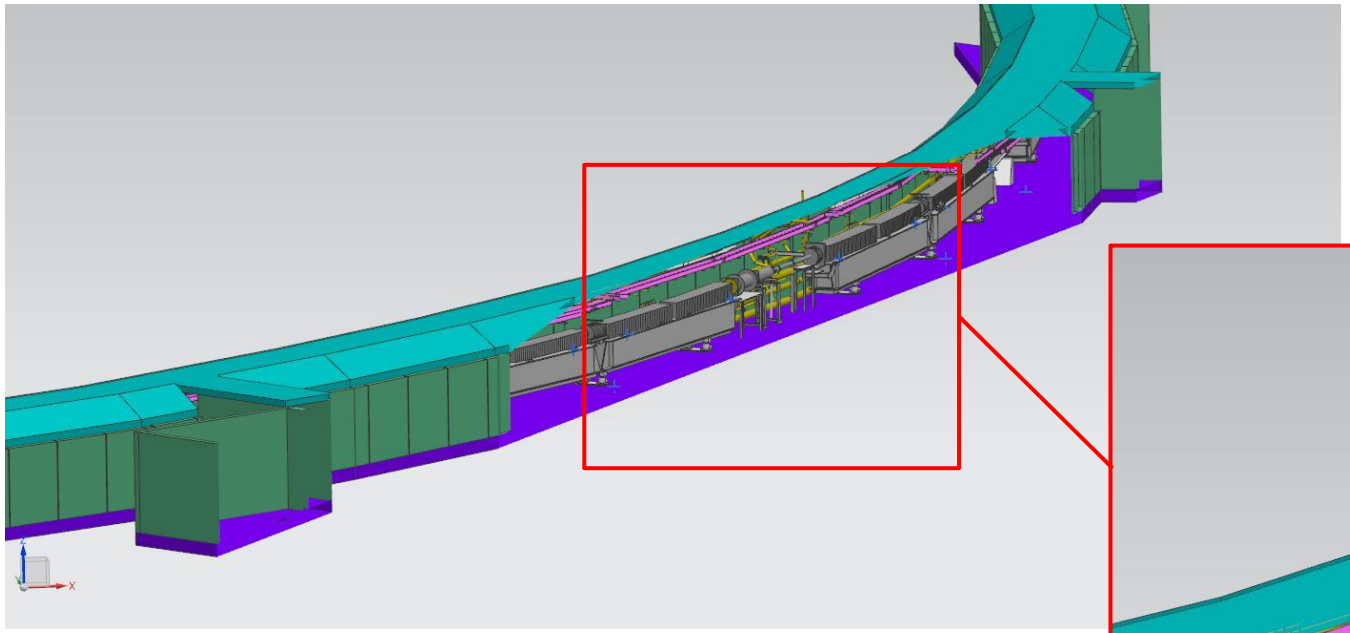
Integrated CAD Model – Simplification Scheme

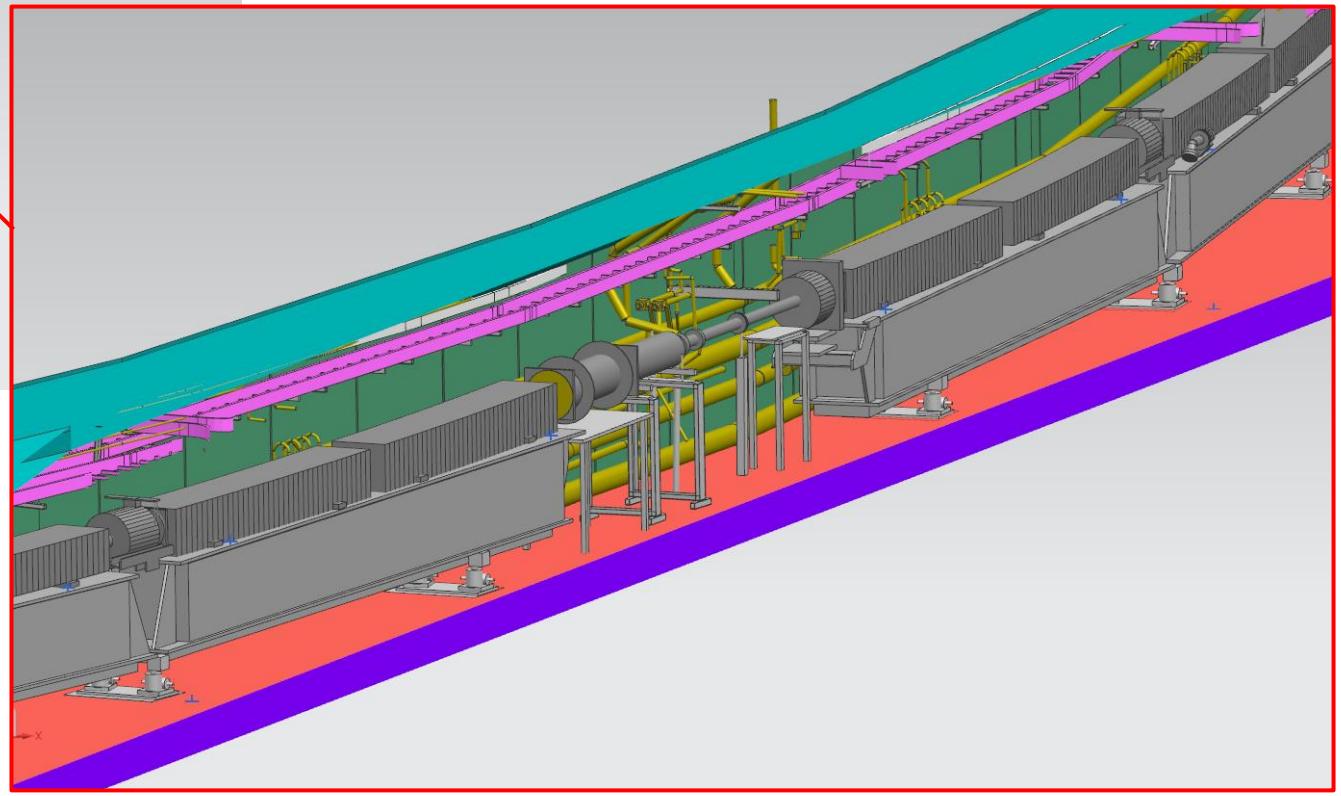


Cryomodules – selectable level of visual simplification managed in NX Arrangements

LB650 Section

Integrated CAD Model – Existing Booster





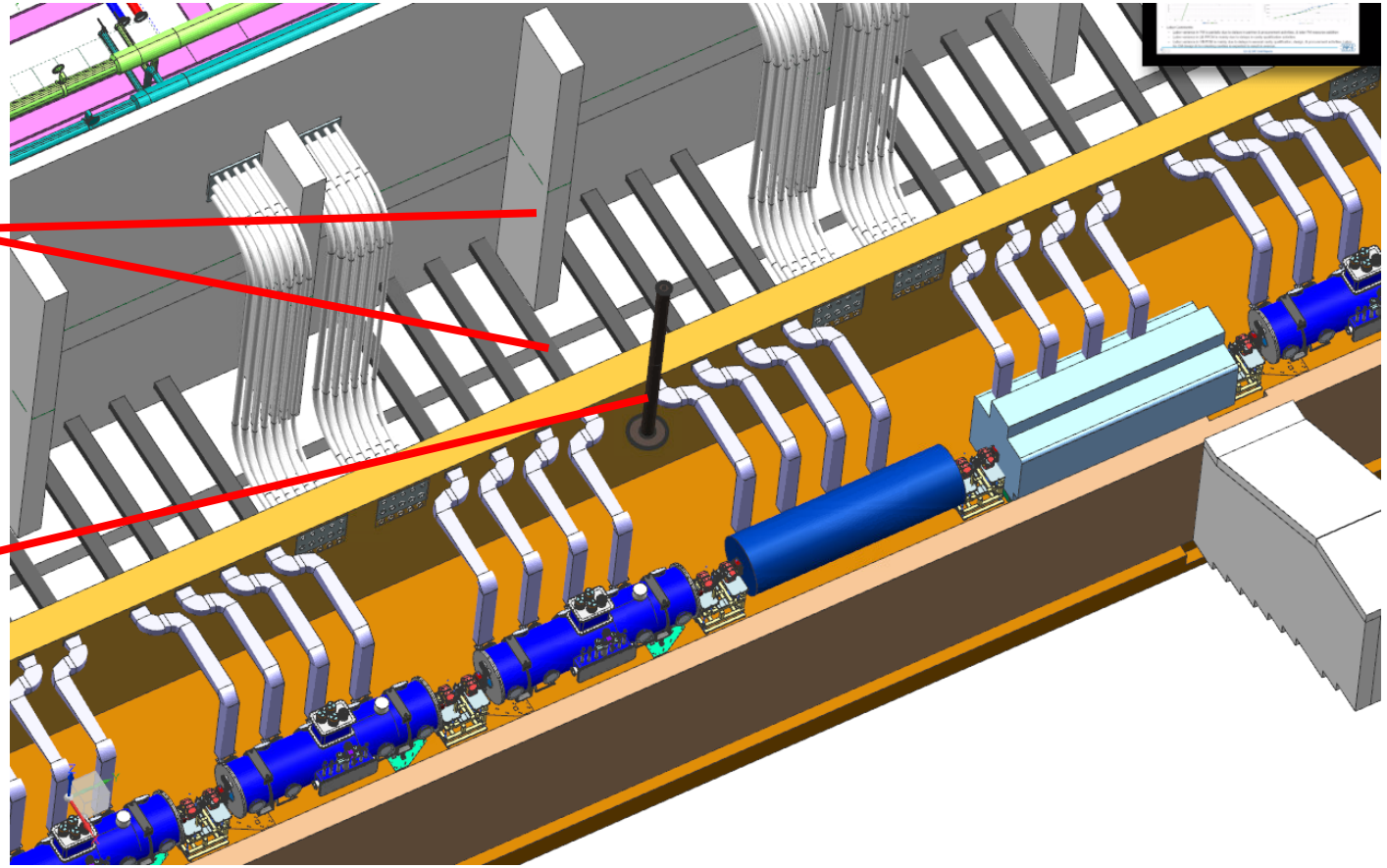
3D scan of existing booster tunnel and equipment in PIP-II injection region

Integrated CAD Model – Integration with Conventional Facility

- Design is coordinated with the CF team
  - 2-way data exchange to allow parallel design with CF's A&E
  - Linac Complex CF design is complete as of April 2021

Lattice-based penetration locations coordinated with CF structure

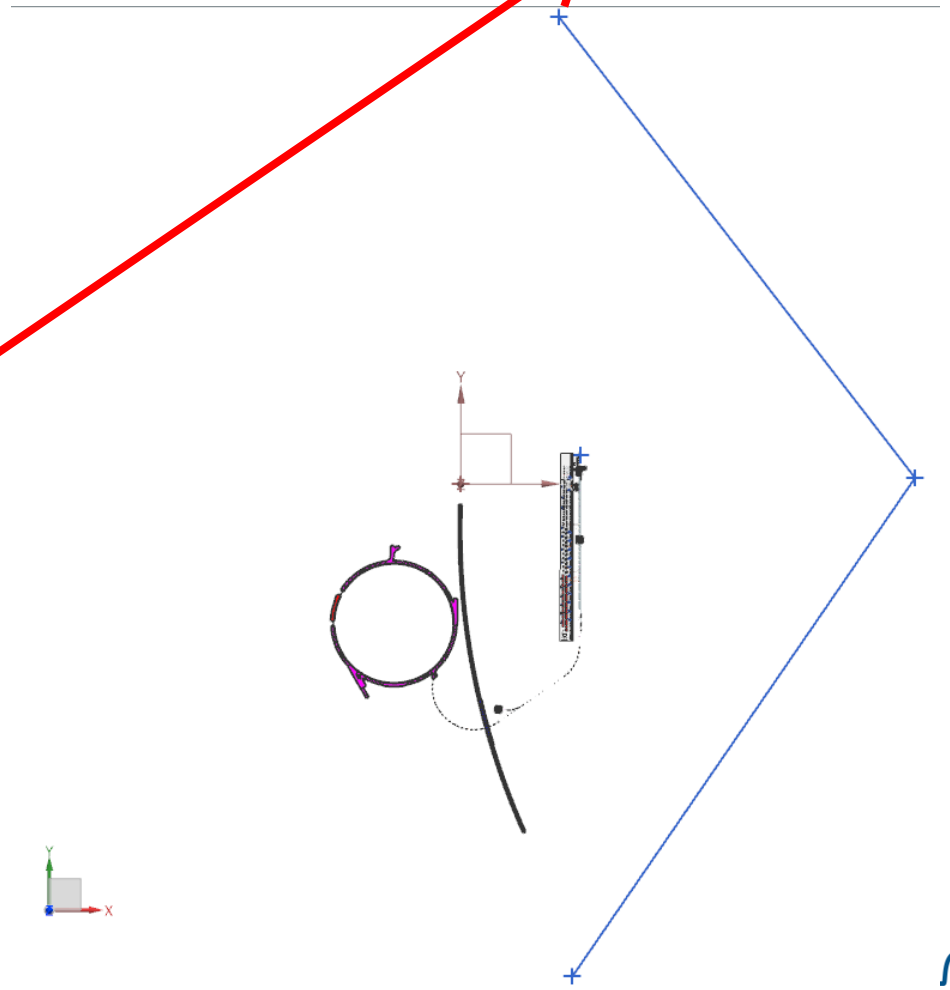
Alignment network sight risers (line-of-sight to surface of shielding berm)



Integrated CAD Model
CF Interface and Alignment Network

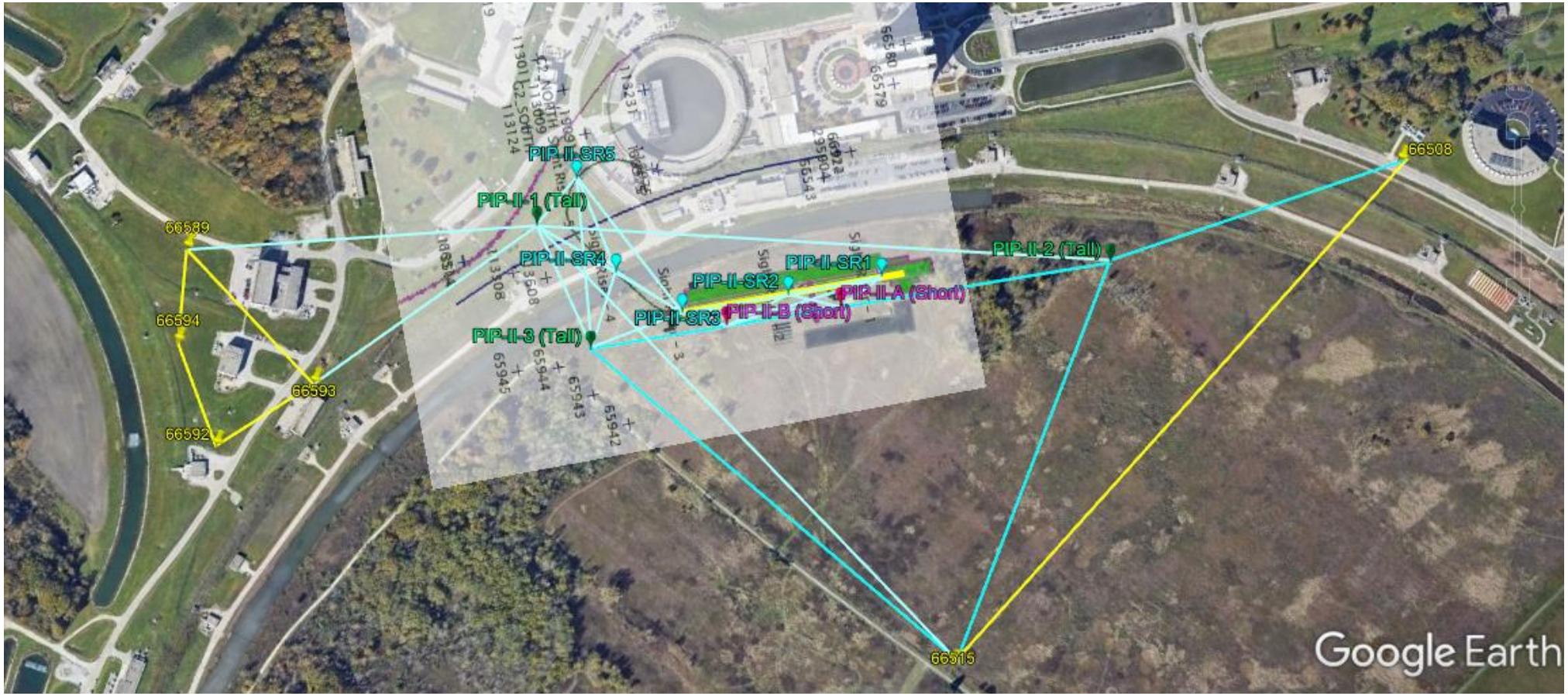
Existing external survey monuments:
Incorporated in CF, CAD
and alignment network designs

Monument Type	Control ID	X	Y	Z	Comments
CONCRETE PIER	66508	30602.27473	31061.21114	227.7185171	Ex Monument, C PIER (DUSAF) Mon. #8. Elev. at brass plug.
CONCRETE PIER	66515	31045.09135	30487.61974	228.5540076	Ex Monument, C PIER (DUSAF) Mon. #15 Elev. at top of Steel Plate
CONCRETE PIER	66593	30619.05981	29867.22127	228.8534366	Ex Control, S. steel plate GPS/MEKO. ADJ. 01/MAR/02 VIRGIL BOCEAN

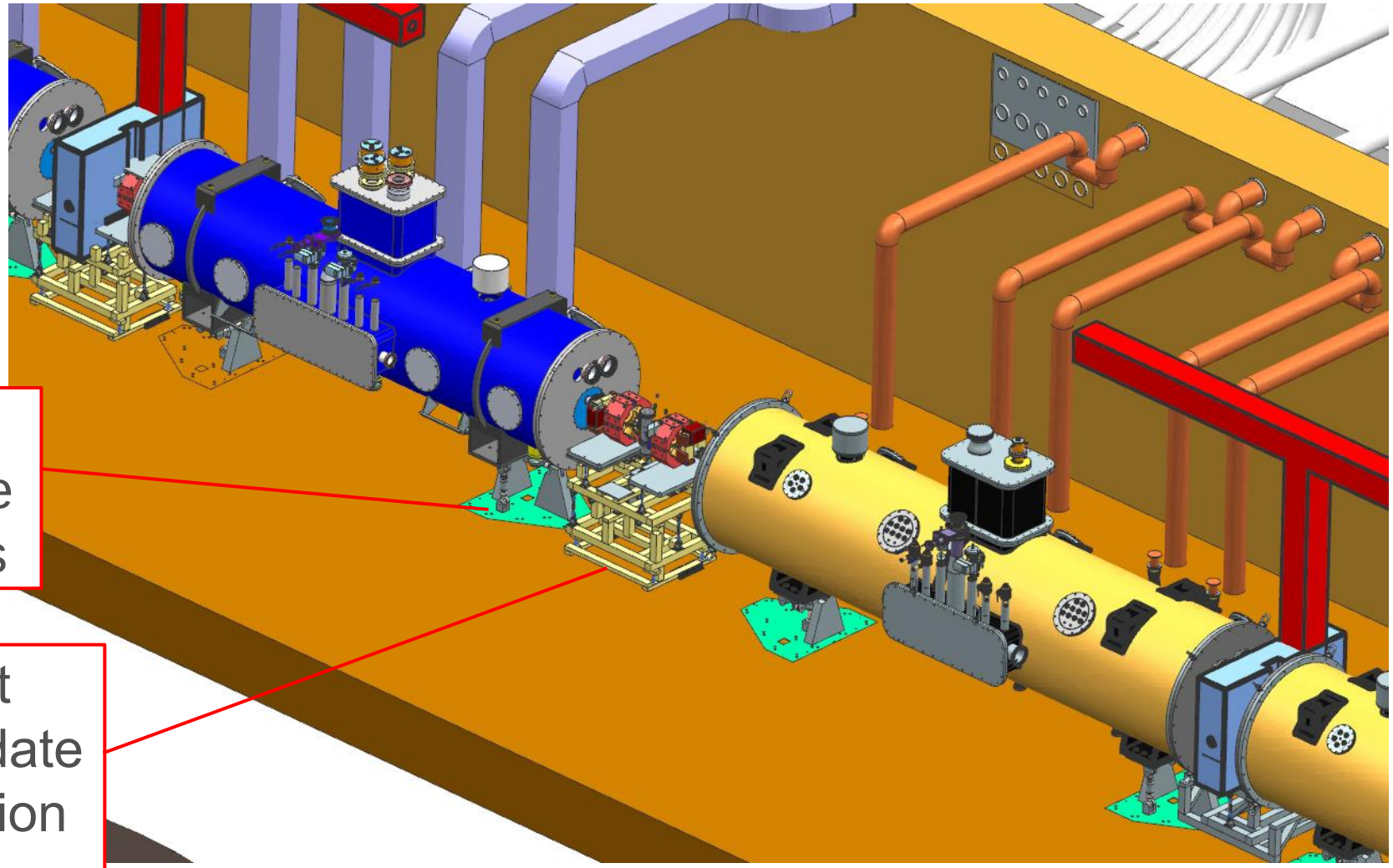


Alignment Network Design

- Surface network designed to allow for line-of-sight and GPS survey techniques
- Underground network designed for laser tracker survey



Linac Installation Design Tasks



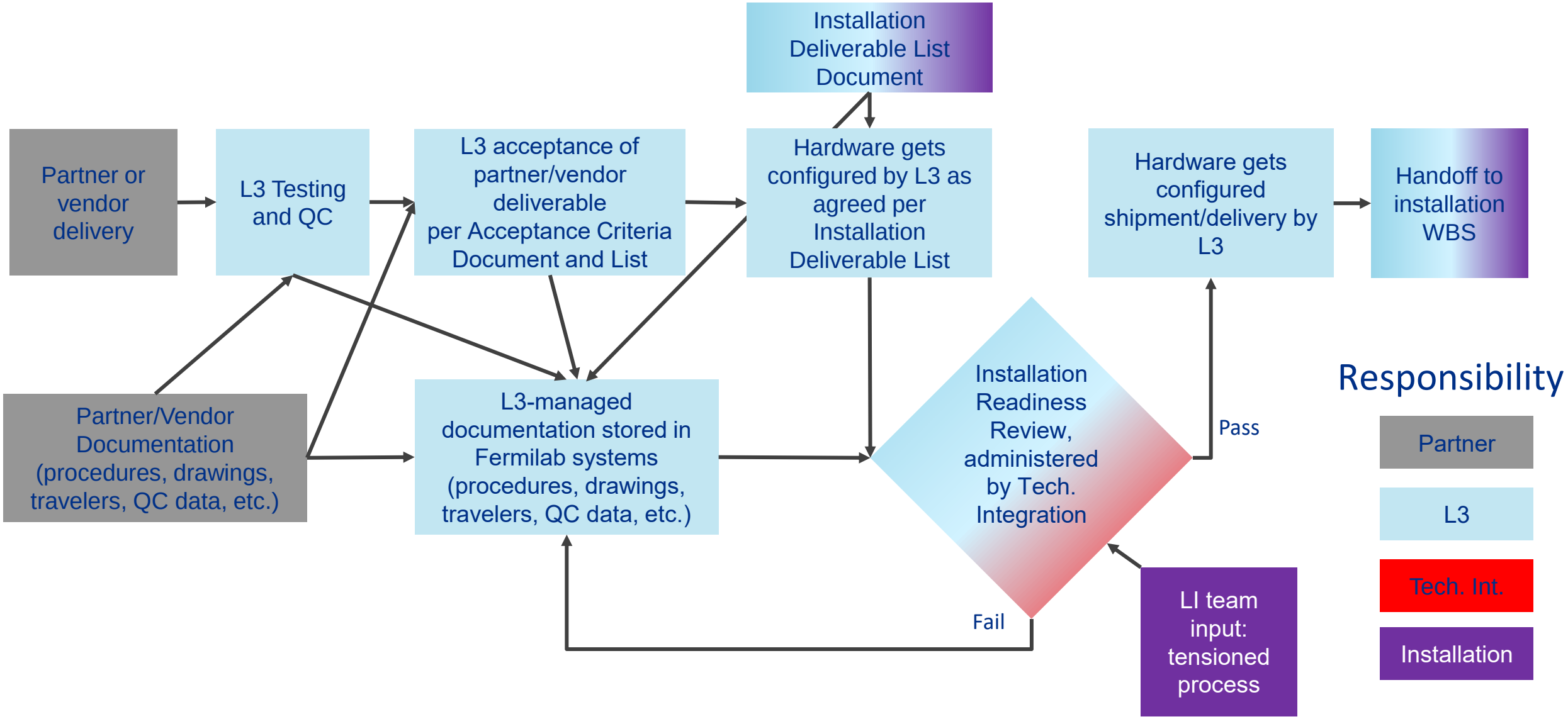
Modular cryomodule stands accommodate all cryomodule styles

Modular warm unit structures accommodate varying instrumentation suite

Linac Installation Process Design – Current Focus

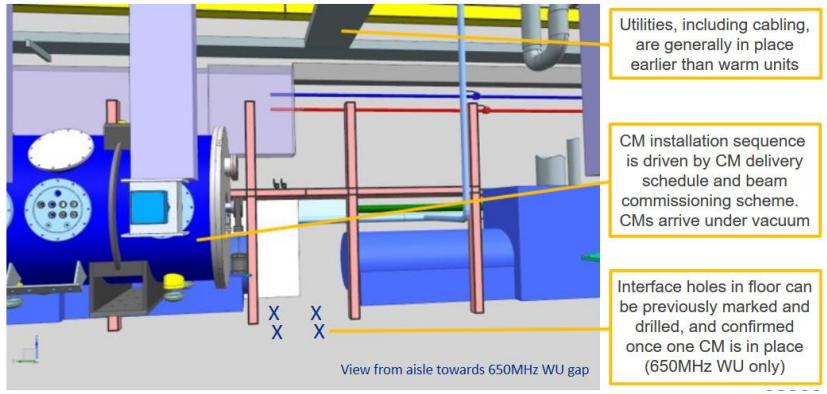
- Hardware Acceptance Framework
  - Installation Readiness Review (IRR) – gate at hardware delivery
- Sequencing
  - Visual storyboarding being used to define overall installation sequence
  - System design teams are developing installation plans for their specific designs, presented (at a minimum) at reviews
- Traveler Framework
  - Working to identify travelers to describe the full scope of work between IRR and handoff to beam commissioning
- Verification and Validation (V&V) Framework
  - Building a plan for system validation at each level of integration

PIP-II Installation Readiness Reviews



Sequencing and Storyboarding

Example – Detail storyboard frames for 650MHz Warm Unit Installation

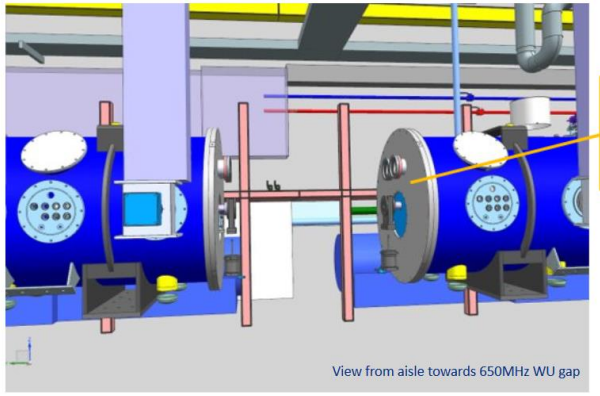


Utilities, including cabling, are generally in place earlier than warm units

CM installation sequence is driven by CM delivery schedule and beam commissioning scheme. CMs arrive under vacuum

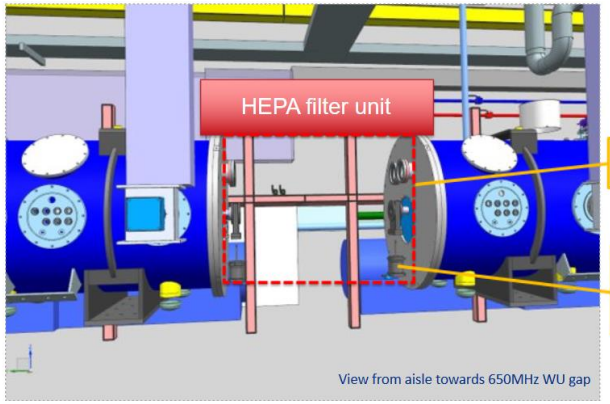
Interface holes in floor can be previously marked and drilled, and confirmed once one CM is in place (650MHz WU only)

1



CMs are placed and aligned on both sides of a WU gap before the WU is installed

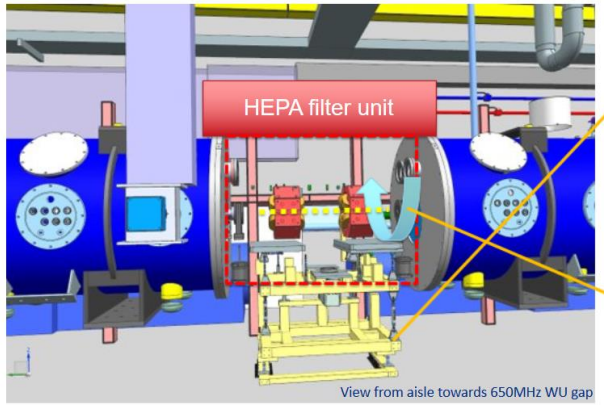
2



Establish clean volume

Beamline gate valves (pneumatic) not connected to compressed air: config controlled closed

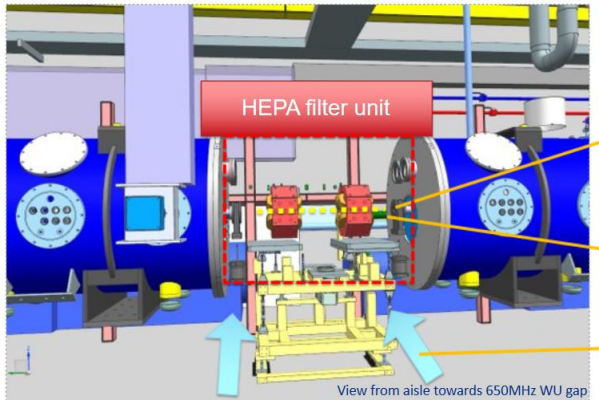
3



Warm unit inserted, offset to aisle side ~200mm, under cleanroom coverage.

Set preliminary ROLL alignment of warm unit package. Alignment PRD tolerance = 3mrad

4

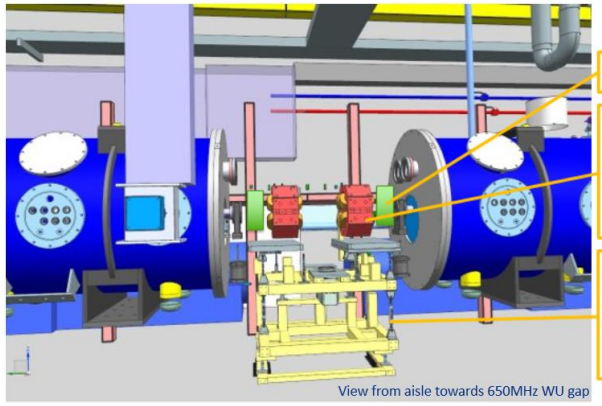


Working from back side, remove CM transportation gauging and/or gate valve blanks

Working from aisle side, remove blanks from WU vacuum flanges

Slide warm unit in to align interfacing flanges

5



Install correctors

Install water connections from back side

Install cables and electrical connections from aisle side

Fine alignment in X,Y,Z, Pitch, Yaw. Roll of magnets can be corrected individually if needed

6

Traveler Framework

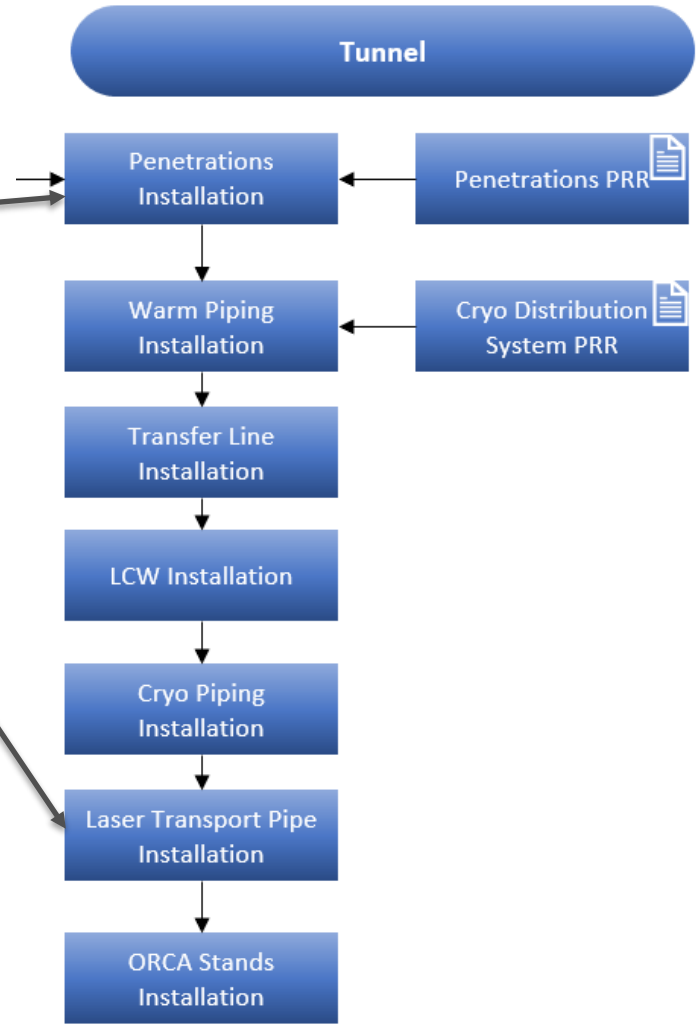
- Developing a hierarchical list of the travelers to be developed
  - Utilizing a “traveler tree” framework
- Goals
  - Identify the work and guide traveler writing
  - Identify dependencies between systems
  - Identify small-scale milestones
    - e.g. subsystem Operational Readiness Clearance reviews
    - Coordinate tree structure with these milestones
  - Facilitate Verification and Validation efforts

Traveler Framework

		HWR CM	SSRs CM	650 CMs	Cryo Dis	MPS	HPRF/Dis	LLRF	Mag/PS	Vac	Controls	Safety System	Instr.	WFE	Bldg Inf.
	Procedure / Travelers	121.02.02	121.02.03	121.02.04	121.02.06	121.03.02	121.03.03	121.03.04	121.03.05	121.03.06	121.03.07	121.03.08	121.03.09	121.04.02	121.04.04
Enclosure	Assemble, Test, Verify	X	X	X	X	X	X	N/A	X	X	X	X	X	X	PRR
Enclosure	Transportation	X	X	X	PRR	N/A	X	N/A	X	N/A	N/A	N/A	N/A	X	PRR
Enclosure	Installation	X	X	X	PRR	X	X	X	X	X	N/A	PRR/X	X	X	PRR
Gallery	Assemble, Test, Verify	N/A	N/A	N/A	N/A	X	X	X	X	X	X	X	X	X	PRR
Gallery	Transportation	N/A	N/A	N/A	N/A	N/A	X	N/A	X	N/A	N/A	N/A	X	X	PRR
Gallery	Installation	N/A	N/A	N/A	N/A	X	X	X	X	X	N/A	X	X	X	PRR
Control Room	Connections and Check out	X	X	X	X	X	X	X	X	X	X	X	X	X	N/A
Control Room	Beam Commission	X	X	X	X	X	X	X	X	X	X	X	X	X	N/A

X: Documentation Needed | X: Traveler Needed | PRR: PRR Needed | N/A: Not Needed

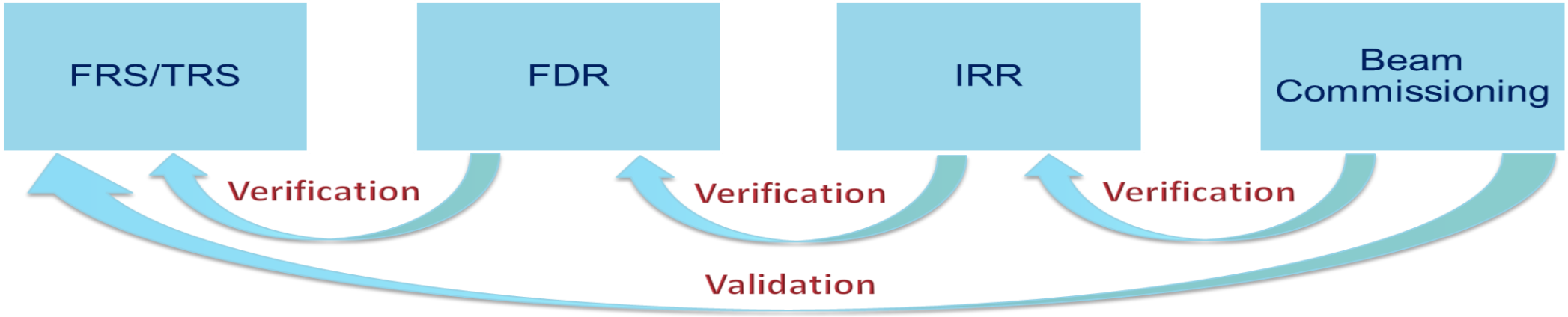
Example – traveler identification by system



Hierarchical traveler tree

Verification and Validation (V&V)

- Verification is the confirmation that specified requirements have been fulfilled
- Validation is the confirmation that the intended use has been fulfilled
  - In most cases, large-scale system function and performance
- Steps defined and data captured within the traveler framework
- Verification and Validation scope
  - Oversee the implementation of the quality plan
  - Confirm functionality of integrated systems
  - Make sure the machine works!
  - Bridge between installation and beam commissioning teams and efforts



I&C Summary

- PIP2IT Accelerator construction and operation was a key training ground for the I&C Team
- Lessons learned are being carried forward into 650 Test Stand and PIP-II designs and plans
- Hardware and process designs for PIP-II are advancing