Fermilab

Fermi National Accelerator Laboratory

PIP-II Beam Instrumentation (BI) - Noninvasive Beam Profile Monitor (BProM) Interface Specification Document (ISD)

Document number: ED0016036, Rev A

Document Approval

Signatures Required	Date Approved
Originator : M.A. Ibrahim, PIP-II Beam Instrumentation L3 Deputy	-
Reviewer: Victor Scarpine, PIP-II Beam Instrumentation L3 Manager	Checker in TC
Reviewer : Allen Rowe, PIP-II Integration Coordinator	Checker in TC
Reviewer: Christopher Becker, Integration Engineer	Checker in TC
Approver: Jeremiah Holzbauer, Accelerator Systems L2 Manager	Approver in TC
Stakeholder Reviews performed off-line using ISD Metadata sheets	Dataset in TC

Revision History

Revision	Date of Release	Description of Change
-	February 2022	Initial Release. ISD released for CD-3. Update required with completed stakeholder review.
A	May 2024	(cadornaa) Updated approval list; Updated BI document references; Updated to reflect MCID Rev AJ; Updated for FDR based on Laserwire Mini-review and follow-up to recommendations

Managed by Fermi Research Alliance, LLC for the
U.S. Department of Energy Office of Science
www.fnal.gov

U.S. DEPARTMENT OF ENERGY | Office of Science

Page left intentionally blank.

Table of Contents

1. Purpose 5
2. Scope 5
3. Acronyms 6
4. Reference Documents 7
   4.1. List of Figures 7
   4.2. List of Tables 8
5. Roles and Responsibilities 9
   5.1. Author(s) 9
   5.2. Owner 9
   5.3. Reviewer 9
   5.4. Approver 9
   5.5. Stakeholder 9
6. Interface Description Summary 10
   6.1. MICD Lookup Table for Noninvasive BProM Interfaces 11
7. Vacuum Interfaces 13
   7.1. Mechanical 14
      7.1.1. Beam Line Vacuum 15
      7.1.2. Optical Transport Line 15
   7.2. Alignment 16
      7.2.1. Optical Transport Line 16
      7.2.2. Beamline Boxes 16
      7.2.3. Mirror Boxes 17
   7.3. Cleaning 18
   7.4. Thermal 18
   7.5. Radiation 18
8. Installation Interfaces 19
   8.1. Deliverables 19

8.2. Location 20

8.3. Mounting 20

8.3.1. Optical Transport Line 20

8.3.2. Mirror Box 21

8.3.3. Laser Room Wall Support 22

8.3.4. Beam Line Components 22

8.3.5. Alignment 23

8.4. Rigging Equipment 23

9. Building Infrastructure Interfaces 24

9.1. Environmental 24

9.2. Cable Penetration 25

9.3. Cable 25

9.3.1. Cable Selection 26

9.3.2. Common mode chokes 26

9.4. Relay Rack 27

9.5. AC Power 28

9.6. Grounding 28

9.7. LCW 28

9.8. Laser Room 29

10. LLRF Interfaces 30

11. MPS Interfaces 30

12. Control System Interfaces 31

12.1. Ethernet Network 32

12.2. Clock & Timing System Interface 33

12.3. Motion Control Interfaces 33

13. Safety Systems Interface 34

1. Purpose

Interface Specification Documents (ISDs) contain the information or references to the information that is necessary to fully define and complete the given interface between WBS systems [1]. Interfaces are defined globally in the PIP-II Master Interface Control Document (MICD) [2], which then reference the pertinent ISDs which contain the particular interface details. The ISD contains all the information or references to the information that is necessary to fully define and complete the given interface.

Key cost, schedule, technical and programmatic assumptions are provided in PIP-II Project Assumptions [3].

2. Scope

This ISD includes describes the interfaces between the **Beam Instrumentation (BI) Noninvasive Beam Profile Monitor (BProM) System** and other PIP-II supporting systems, subsystems and devices. Included are the mechanical and electrical interfaces needed for installation as well as the information-passing interfaces. The interface locations are identified. Subsystems that connect to or cross the boundary are identified.

Interface specifications are upwards traceable to the associated Global Requirements Documents (GRDs) [4], Physics Requirements Documents (PRDs) [5][6][7], Functional Requirement Specifications (FRSs) [8], and Technical Requirement Specifications (TRSs) [9][10] where applicable.

3. Acronyms

BAL	Booster Absorber Line
BI	Beam Instrumentation
BLDGI	Building Infrastructure (WBS)
BProM	Beam Profile Monitor
BTL	Booster Transport Line
CAM	Control Account Manger
CM	Cryomodule
CMPLX	Linac Complex (WBS)
CNTRL	Controls (WBS)
DAQ	Data Acquisition
EMI	Electromagnetic Interference
FESHM	Fermilab ES&H Manual
FRS	Functional Requirements Specification
GRD	Global Requirements Document
HV	High Voltage
HWR	Half Wave Resonator
IDL	Installation Deliverables List
ISD	Interface Specification Document
L2M	Level 2 Manager
L3M	Level 3 Manager
LCW	Low Conductivity Water
LEBT	Low Energy Beam Transport
LI	Linac Installation (WBS)
LLRF	Low Level Radio Frequency
LV	Low Voltage
MEBT	Medium Energy Beam Transport
MICD	Master Interface Control Document
MPS	Machine Protection System
OTL	Optical Transport Line
PIP-II	Proton Improvement Plan II Project
PPE	Personal Protection Equipment
PRD	Physics Requirements Document
QC	Quality Control
RFI	Radio Frequency Interference
SCL	Superconducting LINAC
SS	Safety System (WBS)
TC	Teamcenter
TIO	Technical Integration Office
TLBA	Transfer Line and Beam Absorber Line

TRS	Technical Requirements Specification
UHV	Ultra-High Vacuum
VAC	Vacuum (WBS)
WBS	Work Breakdown Structure
WFE	Warm Front End

4. Reference Documents

#	Reference	Document #
1.	PIP-II WBS Dictionary	PIP-II docDB 599
2.	PIP-II Master Interface Control Document (MICD)	ED0010433
3.	PIP-II Project Assumptions	PIP-II docDB144
4.	PIP-II Global Requirements Document (GRD)	ED0001222
5.	PIP-II Parameters Physics Requirements Document (PRD)	ED0010216
6.	PIP-II Misalignment Tolerances PRD	ED0010231
7.	PIP-II BI Physics Requirements Document (PRD)	ED0010230
8.	PIP-II BI Functional Requirements Specifications (FRS)	ED0008303
9.	PIP-II Noninvasive BProM Technical Requirements Document (TRS)	ED0013714
10.	PIP-II BI DAQ Electronics TRS	ED0013715
11.	PIP-II BI Ethernet Networking Requirements	ED0030907
12.	PIP-II BI Server Software Requirements Specifications	ED0030906
13.	PIP-II Document Management and Control Procedure	PIP-II docDB 2946
14.	PIP-II UHV Certification Specification	ED0026278
15.	Producing Very Low Particulate UHV Components	ED0003571
16.	PIP-II Lattice Files	ED0011224
17.	PIP-II BI Installation Deliverables List (IDL)	ED0011271
18.	PIP-II BI Quality Control (QC) Plan	PIP-II docDB 5520
19.	PIP-II 800 MeV SCL Optics	PIP-II docDB 119

4.1. List of Figures

Figure 6-1 : Interface Map between BI and PIP-II WBS Teams 10
Figure 7-1 : Diagram of Laserwire Station 15
Figure 7-2 : Alignment Activities for Beamline Box 17
Figure 7-3 : Alignment Activities for Mirror Box 17
Figure 8-1 : Laserwire station locations 20
Figure 8-2 : Beam Tube Hangers 21

Figure 8-3 : Mirror Box Hangers Tube Hangers ... 21
Figure 8-4 : HWR Hatch Hanger ... 22
Figure 8-5 : Laser Room Wall Support ... 22
Figure 9-1 : Diagram of PIP2IT Laser Hut ... 29
Figure 12-1 : Block Diagram of BI DAQ Architecture ... 32
Figure 13-1 : PIP2IT Laserwire Interlock System ... 35

4.2. List of Tables

Table 6-1 : Summary of Noninvasive BProM System Interface Types ... 10
Table 6-2 : MICD Summary Table for Noninvasive BProM Interfaces ... 11
Table 7-1 : PIP-II Documentation for Vacuum Interfaces ... 13
Table 7-2 : PIP2IT Documentation about PIP2IT MEBT LaserWire Prototype ... 14
Table 7-3 : Mechanical Drawings and/or CAD Models for Noninvasive BProM Components ... 14
Table 8-1 : PIP-II Documentation for Installation Interfaces ... 19
Table 9-1 : PIP-II Documentation of Building Infrastructure Interfaces ... 24
Table 9-2 : Gallery Environment Specifications ... 24
Table 9-3 : PIP-II Documentation of Standard Cable ... 25
Table 9-4 : PIP-II Documentation of Standard Relay Racks ... 27
Table 9-5 : Summary of BI Rack Allocation ... 27
Table 10-1 : PIP-II Documentation for Phase Reference Line Interface ... 30
Table 12-1 : PIP-II Documentation for Control System Interface ... 31
Table 12-2 : PIP-II Documentation for Global Clock System Interfaces ... 33
Table 12-3 : PIP-II Documentation for Timing System Interfaces ... 33
Table 13-1 : ESH Documentation for PIP2IT Laser Lab ... 34

5. Roles and Responsibilities

5.1. Author(s)

Responsible for ISD preparation, including layout, proper format, interface identification, interface verification expectations, interface traceability, and additional descriptive detail, as appropriate. The author is expected to engage subject matter experts as needed to ensure technical content is appropriately assessed and captured. The author is also expected to identify all applicable stakeholders to their noted interface(s). In some cases, the author can also have the role of the document Owner.

5.2. Owner

Primary stakeholder and responsible for identifying the goals, objectives, and roles/responsibilities pertaining to the document and for assuring activities/expectations are performed as described. This is typically the L3M of the sub-system to which this ISD belongs. The document owner is responsible for maintaining document content, revisions, and updates. An Owner is considered a “Checker” in TC workflow release when they are not the document Author.

5.3. Reviewer

Technical Integration Office (TIO) reviewers are responsible for ensuring ISD format is consistent with project standards, the appropriate document owner/author/reviewer/approver have been identified, the appropriate review process was implemented, and the appropriate document release process is executed. The TIO reviewers are required to be aware that the ISD document exists and is maintained within the framework of the project Document Management and Control Procedure[13]. A Reviewer is considered a “Checker” in the TC workflow release.

5.4. Approver

The L2M shall evaluate the basis for interface definition, ensure that interfaces are properly articulated, and ensure that they align with higher level interfaces. The L2M shall ensure that CAMs, associated engineering staff, and other Systems Managers are properly engaged and notified of the document’s technical implications. Only the System Manager responsible for the work product addressed in the specification is expected to provide approval. The Approver is an “Approver” in the TC workflow release.

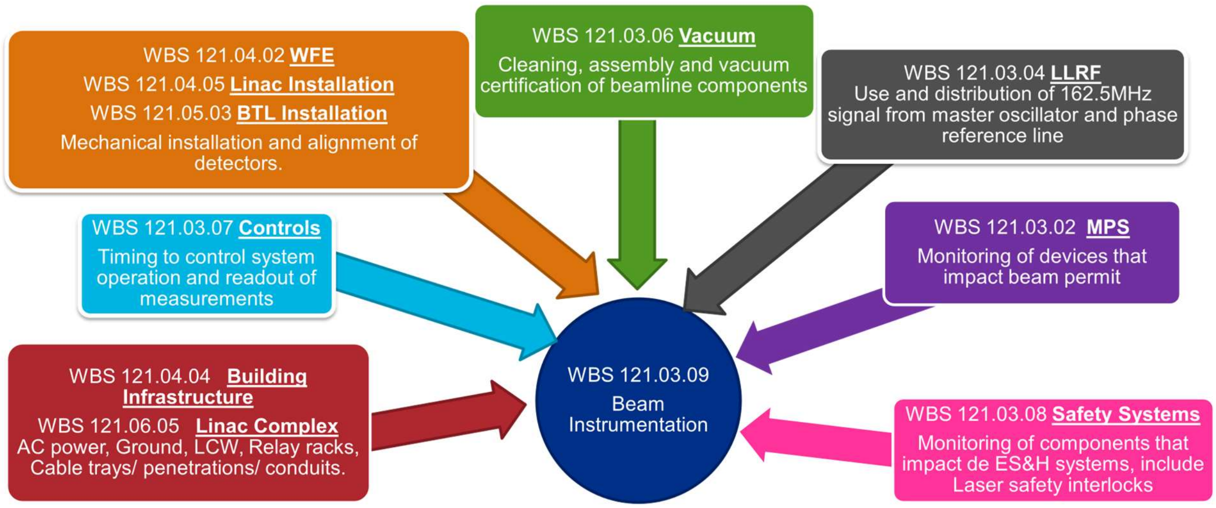
5.5. Stakeholder

Each ISD includes a metadata sheet which lists each ISD interface individually and assigns stakeholders to each. A stakeholder is the associated L3M or subject matter expert that the interface connects or interfaces to and as a result has a direct stake in the interface. Identified stakeholders are expected to be reviewers, ensuring accuracy and completeness, and general agreement of the interface and content applicable to them. Stakeholder reviewers ensure a record of decision is made offline for accepting, rejecting, or modifying the interfaces assigned to them within the ISD metadata sheet (included as a dataset in TC).

6. Interface Description Summary

As shown in Figure 6-1, BI interfaces with other WBS systems, which are globally identified in the PIP-II WBS Dictionary [2].

Figure 6-1 : Interface Map between BI and PIP-II WBS Teams



However, of these, only a subset is relevant to the Noninvasive BProM systems (Table 6-1).

Table 6-1 : Summary of Noninvasive BProM System Interface Types

√	**Vacuum**	Interfaces related to cleaning, assembling, and meeting UHV certification standards for beam line components, in order to maintain beamline integrity
√	**Installation**	Interfaces related to integration of components onto the girders and beamline as well as alignment of components within the beamline enclosure
√	**Building Infrastructure**	Interfaces related to installation of components within the service building and use of utilities within the PIP-II complex Includes interfaces related to the LCW piping and distribution system for cooling
X	**LLRF**	Interfaces related to the 162.5MHz RF signal, generated by LLRF
√	**Control System**	Interfaces related to data pathways for read, write, and plotting capabilities in the Control system Includes interfaces related to signal pathways for the global clock system Includes interfaces related to signal pathways for timing system Includes interfaces related to signal pathways for motor and motion control
X	**MPS**	Interfaces related to signal pathways needed to monitor device that may inhibit beam
√	**Safety System**	Interfaces related to monitoring E&SH concerns and limits, including laser safety interlocks

6.1. MICD Lookup Table for Noninvasive BProM Interfaces

All interfaces between WBS systems are identified and enumerated in the PIP-II MICD [2].

Table 6-2 lists all BI interfaces as well as highlights those interfaces which are relevant to the BPM system.

Table 6-2 : MICD Summary Table for Noninvasive BProM Interfaces

MCID #	Interface Name	ISD Section
1777-001	HWR CM BPM Connections	--
1839-001	SSR CM BPM Connections	--
2554-001	One 162.5 MHz RF phase reference signal for instrumentation electronics	--
2649-001	**BI WFE and SCL Vacuum Interface for all instrumentation**	**7**
2649-002	BTL Instrumentation	--
2649-003	**Laser optical transport line vacuum**	**7**
2695-001	**Beam Instrumentation Control System Interface**	**12**
2695-002	**Beam Instrumentation Timing Interface**	**12.2**
2695-003	**Timing and control signals**	**12.2**
2695-004	**Network interface**	**12.1**
2695-005	BI invasive BProM motion control interface	--
2695-006	**General DAQ for Beam Instrumentation**	**12**
2705-002	WFE motion control interface	--
2709-002	Resistive Wall Current Monitor control interface for instrumentation cart	--
2740-001	**BI's Linac Laser Lab Interface to SS's Linac LSS.**	**13**
2785-001	Beam Instrumentation MPS Interface	--
2794-001	IS emittance scanners interface	--
2794-002	Non-Invasive BCM pickup interface to WFE	--
2794-004	LEBT EIDs interface	--
2794-005	LEBT bend beam dumps electrical interface	--
2794-006	LEBT absorber electrical interface	--
2794-007	DPI electrical interface	--
2794-008	MEBT scrapers electrical interface	--
2794-009	MEBT kickers masks electrical interface	--
2794-010	MEBT BPMs mechanical interface	--
2794-012	MEBT other current measuring devices interface	--
2794-014	MEBT wire scanners interface	--
2794-015	MEBT emittance scanners interface	--
2794-016	**MEBT laser wire interface**	**7**
2794-017	**MEBT Instrumentation Mechanical Interface**	**8**
2794-018	MEBT Absorber electrical interface	--
2796-001	**Instrumentation racks**	**9.4**

2796-002	**Power**	**9.5**
2796-003	**Grounding**	**9.6**
2796-004	**Cables for BI systems**	**9.3**
2796-005	LCW for 6 Allison Scanners	--
2797-001	**BI equipment common requirements - rigging**	**8.4**
2797-002	**Inst-Structure Interfaces, Warm Units**	**8**
2797-003	**Laser optical transport line with Linac Installation**	**8**
2809-001	TLBA Beam instrumentation	--
2822-001	**Laser Room**	**9.8**
2822-002	**Space for Beam Instrumentation racks and equipment**	**9**
2822-003	**BI Penetrations**	**9.2**
2822-004	**Support of laser optical transport line**	**9**

7. Vacuum Interfaces

Table 7-1 : PIP-II Documentation for Vacuum Interfaces

Documents	Number
PIP-II Warm Units TRS	ED0008578
PIP-II Vacuum TRS	ED0013681
PIP-II MEBT TRS	ED0014432
PIP-II Vacuum ISD	ED0016361
PIP-II MEBT ISD	ED0022346

Vacuum interfaces refer to interfaces and any requirements related to cleaning, assembling, and meeting UHV certification standards for beam line components, in order to maintain beamline integrity.

- ***2649-001 VAC-BI (BI WFE and SCL Vacuum Interface for all instrumentation)***
  - *VAC and BI shall agree on material choice and gas load specification of BI components within vacuum space. Work of leak checking, and certification will be completed by VAC.*
  - *BI provides information on the materials used inside vacuum space and connecting parameters to beam tubes. Certifying and leak checking of instruments is under BI Scope.*
- ***2649-003 Laser optical transport line vacuum***
  - *BI will provide vacuum requirements and design of optical transport line as well as vacuum connection details*
  - *Vac will connect vacuum pumping to optical transport line and support*
- ***2794-016 MEBT laser wire interface***
  - *The physical interfaces between WFE and BI are the laser wire's vacuum enclosures flanges that mate to the beam line vacuum enclosure (upstream and downstream).*
  - *WFE shall provide space in the MEBT beam line for installation of the laser wire stations; WFE shall provides the stand and spool pieces needed for installation; WFE shall define the size, materials and finish of the mating surfaces; WFE and BI shall define together specifics of the beam line configuration, for instance vacuum requirements at the location of the laser wire*
  - *BI shall provide complete laser wire units, including the vacuum chambers, all optical elements, all electronics, cables and vacuum equipment*
  - *LI shall provide installation support to BI and WFE; LI shall vacuum leak check the assemblies after installation*

Beamline vacuum chambers and optical boxes for the Noninvasive BProM systems are required to withstand vacuum pressure levels. Designs shall be based on the PIP2IT Laserwire Prototype (Table 7-3).

Table 7-2 : PIP2IT Documentation about PIP2IT MEBT LaserWire Prototype

Documents	Number
PIP2IT MEBT LaserWire Final Design Review	ED0006518
PIP2IT MEBT LaserWire	ED0006968
PIP2IT MEBT LaserWire Engineering Assessment	ED0006970
PIP2IT Laser Wire Profile Monitor MockUp	F10551622
Analysis of Laser Induced Dage to PIP2IT Vacuum Viewports	PIP-II-doc-5138

7.1. Mechanical

Unless specified in the sub-sections that follow, all mating surfaces for vacuum connections shall be Stainless Steel to Stainless Steel, with a knife edge on a copper seal.

Also, unless specified in the sub-sections that follow, all beam tube connections are to be designed to mate to 2.75” ConFlat® flanges. The flanges may (FC0017528/FC0099586) or may not (FC0099583) be rotatable depending on the particularities of the components being interfaced. The mating surfaces are made of Stainless Steel (316L or 304L), but bi-metal flanges may be used for convenience (e.g. welding).

In addition, bolt connections must be tightened at the industry recommended torque according to the flange type, but not beyond (https://www.dultmeier.com/pdfs/tech-library/C_BoltTorque.pdf).

Table 7-3 : Mechanical Drawings and/or CAD Models for Noninvasive BProM Components

Document	Number
Laser Wire Optics Box, Assembly	F10225016
Laser Wire Vacuum Chamber, Magnets, and Stand Assembly	F10223388
Optical Junction Box	F10215846

7.1.1. Beam Line Vacuum

Beamline vacuum chambers for the NonInvasive BProM systems are required to withstand vacuum pressure levels, required by the beamline sections of the pickup locations, as well as designed with UHV vacuum-friendly materials. In addition, each unit shall have at least one port for vacuum pumping.

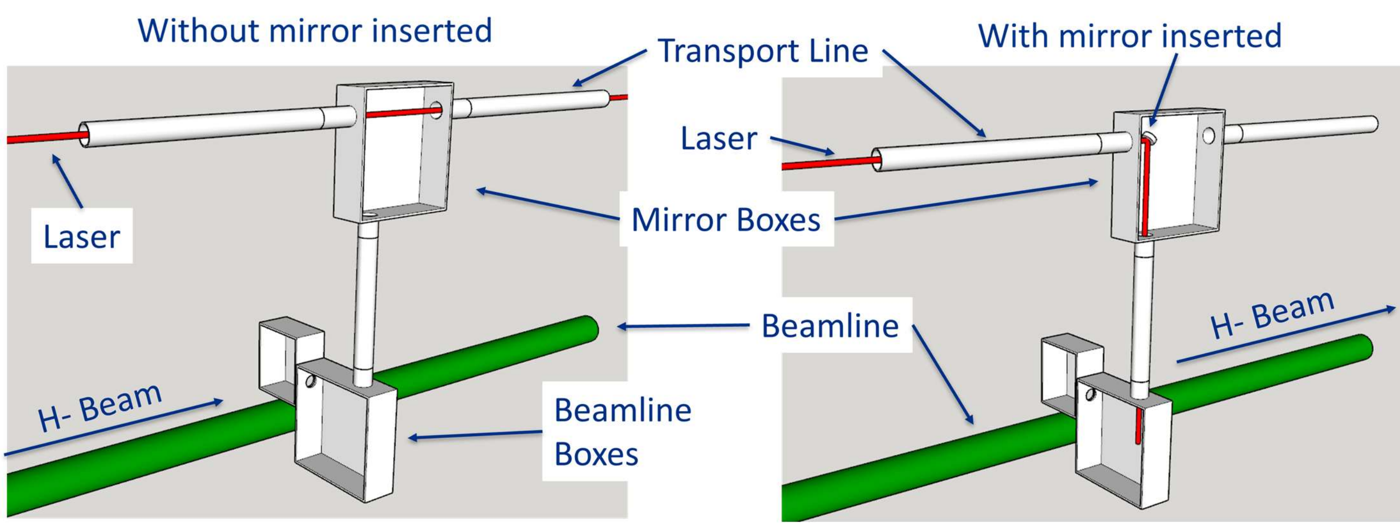
7.1.2. Optical Transport Line

The laser optical transport line is a separate vacuum system than the accelerator beamline vacuum and is designed as a rough vacuum system with the goal of achieving <250 mTorr.

Individual components and entire system shall be leak tight to a leak rate of 2.5x10^-10 Torr-L/s on a calibrated helium leak detector.

The vacuum pumping shall consist of a rough vacuum pump at the center of the beam line. Gauging consisting of quantity 4 Pirani gauges (rough vacuum) shall be installed, one at each end of the line, one near the middle, and one on the inlet of the pump. A roughing valve shall isolate the pumping from the system when needed.

Figure 7-1 : Diagram of Laserwire Station



7.2. Alignment

Fiducialization and alignment requirements of the Laserwire components are provided in PIP-II Noninvasive BProM TRS[9].

7.2.1. Optical Transport Line

Th total range of adjustability of all components is at most ±1” in all directions (xyz). Fine adjustment shall be required to maintain optically straight beam tube within 5mm.

Alignment of the optical transport line is coincident with installation of the beam transport line. Activities shall include the following:

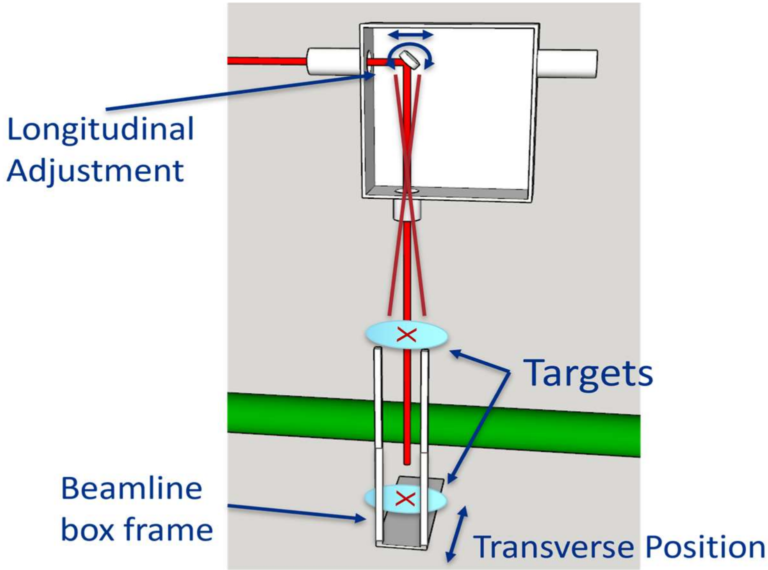
- Install laser targets at exit of laser room and end of linac
- Mark Transverse and Longitudinal installation points for each mirror box
- Install HeNe alignment laser, so that the laser is aligned between the laser target

7.2.2. Beamline Boxes

Alignment of beamline boxes shall also meet requirements, which are elaborated in PIP-II Misalignments Tolerance PRD [6]. Activities include the following :

- Beamline box alignment can be done anytime after the transport line installation
- Install mirror box mirror with longitudinal position adjustment
    - Align mirror with alignment laser
- Install alignment ‘beamline box frame’
    - Open frame which fits as a real box and has a pair of vertical laser targets
- Adjust downward alignment laser trajectory
    - Mirror box mirror longitudinal adjustment and mirror adjustability
    - Transverse position of beamline box frame
    - Must traverse center of the two targets

Figure 7-2 : Alignment Activities for Beamline Box

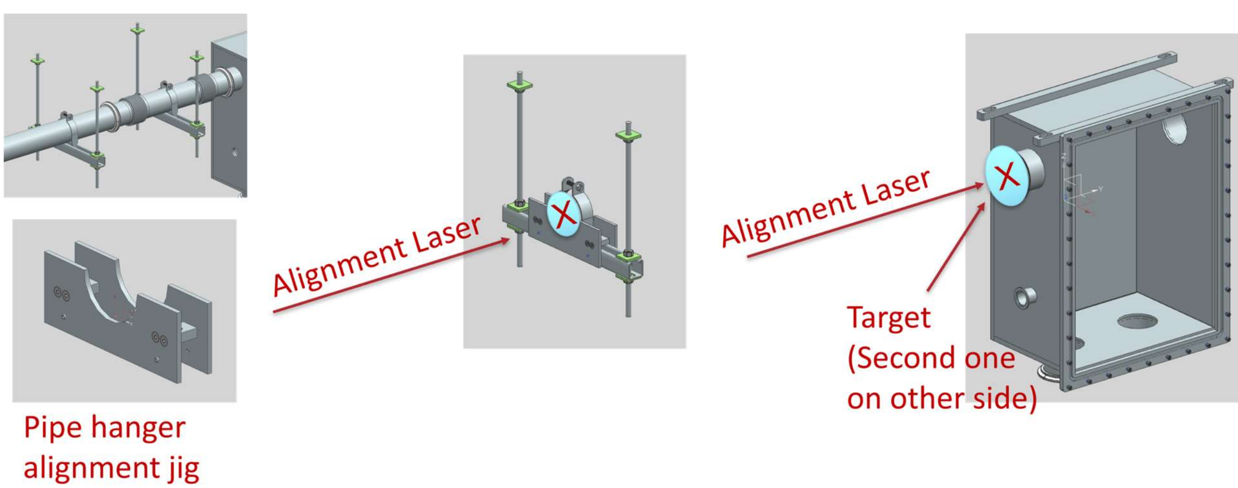


7.2.3. Mirror Boxes

Alignment activities (Figure 7-3) of the mirror boxes shall include the following:

- Install all mirror boxes
  - Adjust longitudinal position to nominal as indicated by Alignment Team markings
  - Adjust each box transversely such that the input and output flanges are concentric with alignment laser
- Install pipes onto pipe hangers between mirror boxes
  - Install using jig with laser target
    - Aligning done prior to setting pipe

Figure 7-3 : Alignment Activities for Mirror Box



7.3. Cleaning

Standard UHV cleaning and handling techniques, as defined by the PIP-II UHV Certification Specifications [14], shall be used for vacuum components and shall adhere to processes and procedures in Producing Very Low Particulate UHV Components [15]. This covers the general chemical cleaning, UHV flange cleaning, welded bellows chemical cleaning, clean room requirements, PPE and handling practices, and storage of assemblies.

On the other hand, due to the less stringent vacuum required, only minimal cleaning of the laser optical transport line is needed.

7.4. Thermal

Components installed in the enclosure, shall withstand operating temperatures between -40ºC and 100ºC. No in-situ baking is planned, but if required, procedures for lower baking temperature limits shall be implemented for accessible parts, in coordination with Vacuum.

7.5. Radiation

The components, including the pickups, connectors, cables, feedthroughs, and any electronics boxes, may be subjected to raised radiation levels at enclosure locations. If needed, materials used for these components shall be selected to withstand those radiation levels.

8. Installation Interfaces

Table 8-1 : PIP-II Documentation for Installation Interfaces

Documents	Number
PIP-II LINAC Installation FRS	ED0007996
PIP-II Warm Unit Structures TRS	ED0008578
PIP-II MEBT TRS	ED0014432
PIP-II MEBT ISD	ED0022346

Installation interfaces refer to the interface required for the integration of components onto the girders and beamline as well as alignment of components within the beamline enclosure.

- **2794-017 MEBT Instrumentation Mechanical Interface**
  - *WFE shall provide girders made of 80/20 slotted framing rails*
  - *BI shall provide stands for all instrument deliverables to the MEBT. Those include (but may not be limited to) the emittance vacuum chamber, RWCM, ACCTs, DCCT, Laser profile Monitor and the FFC.*
  - *LI shall facilitate installation of the stands and instrumentation on the girders. They shall provide all the standard mounting hardware (e.g. fasteners, brackets…)*
- ***2797-002 Inst-Structure Interfaces, Warm Units***
  - *The Warm Unit Structures shall provide volume and support for instrumentation hardware as defined in the referenced* drawings.
  - *BI team designs and delivers the instrumentation hardware.*
  - *LI team delivers the warm unit structures, which provides support and alignment for the instrumentation hardware.*
  - *LI team delivers the warm unit structures, which provides support and alignment for the instrumentation hardware.*
  - *LI team integrates the warm units prior to installation in the SCL, and provides installation in the* SCL.
- ***2797-003 Laser optical transport line with Linac Installation***
  - *BI provides laser transport line specification and requirements*
  - *LI determines not-to-exceed envelope for laser optical transport line.*

8.1. Deliverables

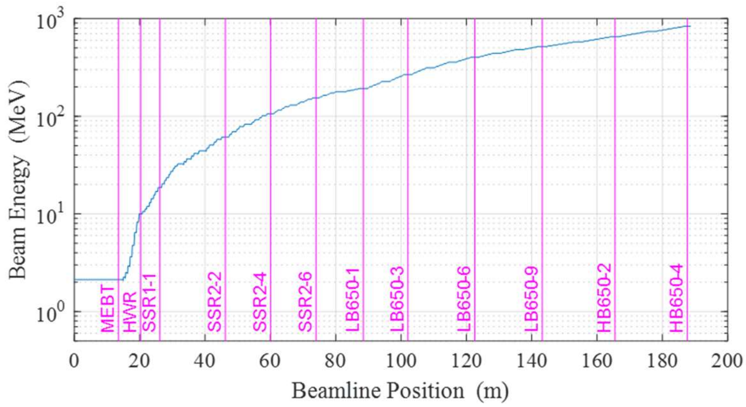
Completion of the PIP-II BI Installation Delivery List (IDL) [17] and corresponding handoffs through Installation Readiness Reviews shall ensure the readiness of all components, within in the enclosure and gallery, for ownership transfer to installation.

In addition, all acceptance criteria, acceptance procedures, verification procedures, assembly procedures, and associated travelers or checklists are listed in the BI QC Plan [18].

8.2. Location

There are 12 laserwire stations in the MEBT, HWR, and SCL. The laser room is upstream of the H- source, which is at 0m in Figure 8-1.

Figure 8-1 : Laserwire station locations



The locations are identified based on the PIP-II Parameters PRD [5], PIP-II Lattice Files [16], and PIP-II 800MeV SCL Optics [19].

8.3. Mounting

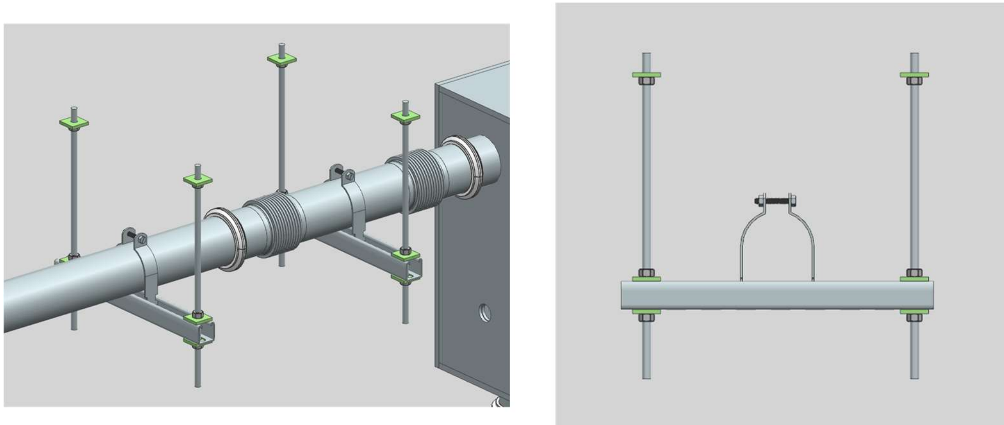
8.3.1. Optical Transport Line

The optical transport line (OTL) has a 90mm (3.54”) aperture and is approximately 200m (650’) in total length. It shall mounted from the PIP-II enclosure ceiling with beam tube hangers (Figure 8-2). There is a 12” x 12” envelope for installation.

It shall span the gap at the HWR hatch (no ceiling to mount to) and integrate the upstream end of the beamline into the Laser Room.

Using common Unistrut parts, the beam tube hangers are designed to provide a wide range of alignment with sufficient adjustment. Due to concrete anchor requirements in ceiling (FESHM7080), these shall need to be mounted one of two ways: a) suspended from existing Unistrut embedment or b) suspended from additional hung sections of Unistrut (spanning from embedment to embedment).

Figure 8-2 : Beam Tube Hangers

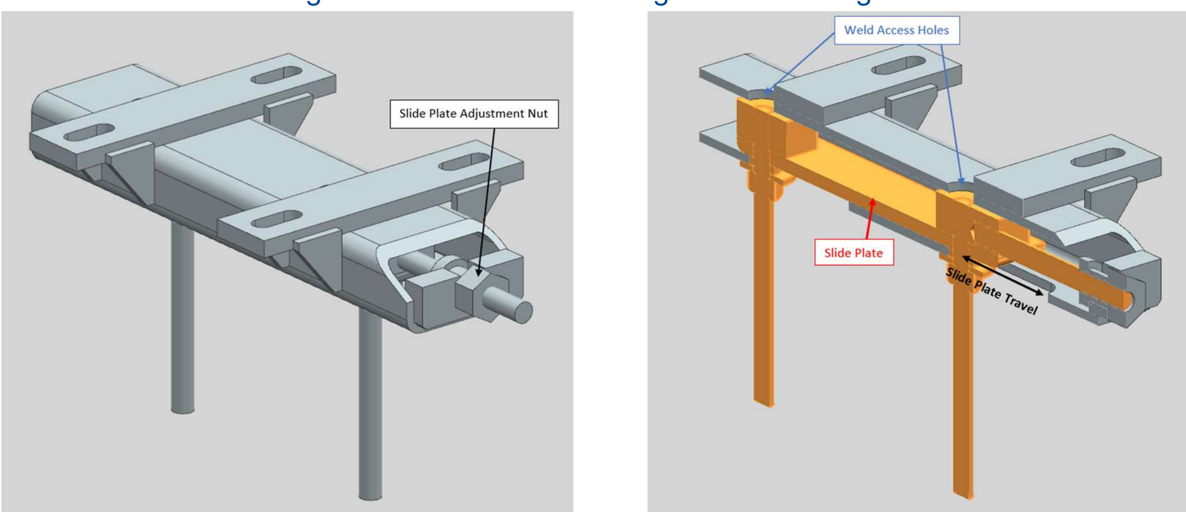


8.3.2. Mirror Box

Together with the OTL, the mirror box has a 12” x 12” envelope for installation to the PIP-II enclosure ceiling.

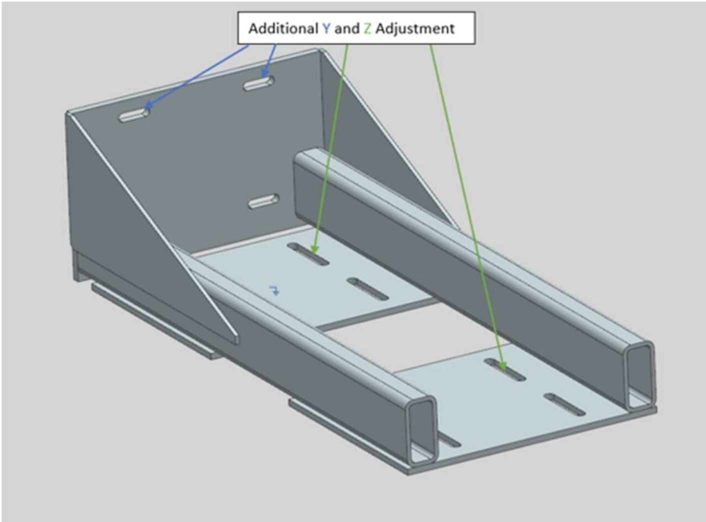
The mirror box hangers are constructed of steel, with slotted ceiling plates to adjust for installation obstructions (rebar) and provide z-adjustment as well as a slide plate design with threaded rod hangers to provide x and y adjustment. Access holes at the top shall provide the capability to tack weld threaded rod for safety.

Figure 8-3 : Mirror Box Hangers Tube Hangers



Furthermore, the footprint of HWR hatch require additional requirements for installation. Since there is no ceiling under the HWR hatch, a HWR Hatch Hanger shall be constructed to essentially imitate an extension of the ceiling.

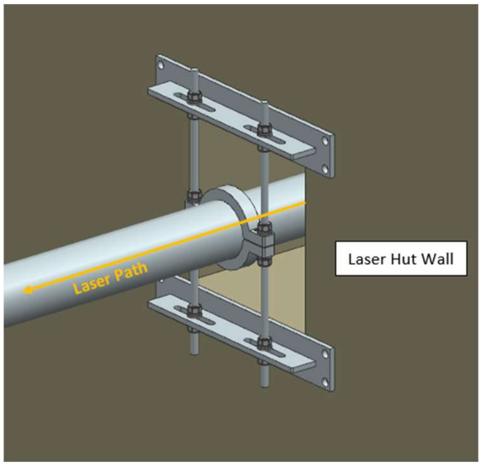
Figure 8-4 : HWR Hatch Hanger



8.3.3. Laser Room Wall Support

Vacuum loads are expected at the upstream and downstream ends of the OTL. Because the Laser Room wall is concrete, the Laser Room Wall Support shall be mounted to the outside Laser Room wall and provides support at the upstream end of the OTL. The design contains sufficient alignment considerations in x, y, and z directions.

Figure 8-5 : Laser Room Wall Support



8.3.4. Beam Line Components

If needed, installation interfaces are load-bearing support stands and/or adjusting plates that mount on the main beam line frame made out of 80/20 slotted framing “rails”. The beam line frame is divided into “girders”, free-standing sub-sections of the frame, which allow mounting groups of beam line components offline (and in parallel) and facilitate installation. The girders, including the aluminum framing for the main rails as well as 80/20 fasteners and adjustment blocks.

8.3.5. Alignment

Mirror Boxes, Beam Tube Hangers, and Laser Room Wall Support shall have alignment in x, y, and z directions. The total alignment adjustment shall be ±1” in all directions. Fine alignment adjustments shall also be required.

8.4. Rigging Equipment

- ***2797-001 BI equipment common requirements – rigging***
  - *BI will define the design.*
  - *BI will provide the rigging interfaces*
  - *LI will integrate these systems within the PIP2 footprint*

Large subassemblies components, or any dismountable part thereof bigger than what can be handled by a single individual, shall include rigging interfaces for vertical lifting with a crane and/or forklifting interfaces for lifting with a forklift or pallet jack. All rigging components shall comply with requirements of relevant FESHM chapters (e.g., marking of rigging components). All lifting interfaces as well as all payload weights shall be clearly marked.

In addition, all lifting procedures shall be listed in the BI QC Plan [18].

9. Building Infrastructure Interfaces

Table 9-1 : PIP-II Documentation of Building Infrastructure Interfaces

Documents	Number
PIP-II High Bay Building TRS	ED0006757
PIP-II LINAC Gallery TRS	ED0006793
PIP-II LINAC Complex TRS	ED0010906
PIP-II Building Infrastructure	ED0013928

Building Infrastructure interfaces refer to interfaces required for installation and operation of systems within the LINAC complex, including cable, cable penetrations, and relay racks as well as building utilities, such as AC power, ground, and LCW.

- ***2822-002 Space for Beam Instrumentation racks and equipment***
  - *CMPLX shall provide space for Beam Instrumentation racks and equipment.*
  - *BI shall define space requirements for beam instrumentation racks and equipment*
  - *CMPLX shall provide the required space for BI equipment*
  - *BLDGI and LI shall coordinate the required space and integrate the locations for BI equipment with CMPLX*
- ***2822-004 Support of laser optical transport line***
  - *BI will mount support structure to mechanically support the laser optical transport line to the ceiling*
  - *CMPLX shall verify load-bearing capacity and mounting onto the tunnel ceiling.*
  - *LI will provide installation support.*

9.1. Environmental

The gallery environment is specified in Table 9-2.

Table 9-2 : Gallery Environment Specifications

Radiation	Sensitive electronic components should not be exposed to ionizing radiations. Doses as small as 10^2 Gy may damage the MOS components used. Consequently, radiation sensitive electronic components should not be installed in the enclosure.
Thermal	Electronic components should withstand operating temperatures between -40ºC and 100ºC. The actual gallery temperature range should be much tighter than that.
Humidity	Electronic components should operate in non-condensing environments of the gallery.

9.2. Cable Penetration

- ***2822-003 BI Penetrations***
  - *BI shall define the distances/locations of the penetrations based on requirements on cable length, signal distortion and any other requirements pertaining to the properties of signal carried by the cables considered.*
  - *CMPLX shall provide the penetrations agreed upon with BI, taking into constraints and requirements from other sub-systems.*
  - *BLDGI shall coordinate the cable database and penetration usage.*

BI cables, which run between the pickup and electronics, should utilize from the penetrations nearest the pickup in the enclosure. In addition, cable start locations, end locations, and paths (i.e. penetrations used) shall be recorded and tracked in the PIP-II Cable Database.

The LV signal cables shall be installed in designated cable trays and conduits, shared by other LV cables and signal cables.

On the other hand, the HV signal cables shall be installed in designated cable trays and conduits, shared by other HV cables and signal cables. The HV cable insulation is rated higher than 5 kV (HV power supply).

Also, if the cable path is in a high RFI environment, cables should pass through metallic electrical conduits; aluminum conduits are appropriate to reject RFI. Additional common mode chokes shall be installed at cable segments, as needed.

9.3. Cable

Table 9-3 : PIP-II Documentation of Standard Cable

Documents	Number
PIP-II Standard Cable and Connectors	PIP-II docDB 2824
PIP-II Cable Pull and Documentation Plan	PIP-II docDB 2892
PIP-II Cable Criteria	PIP-II docDB 3054

- ***2796-004 Cables for BI systems***
  - *BI shall specify all cables required for BI systems. BLDGI shall supply any standard cables available in PIP-II cable stores. BI shall supply any non-standard cables.*
  - *BI shall define all the cables.*
  - *BLDGI shall deliver standard cables available in PIP-II stores. BI shall deliver any specialty cables.*
  - *LI shall perform all cable pulls.*

Cables shall connect the BI pickups in the enclosure to their corresponding electronics in the gallery. PIP-II cable stores shall provide standard cable types; non-standard cable types shall be procured as needed by BI. In addition, cable types, counts, and lengths shall be recorded and tracked.

9.3.1. Cable Selection

The Noninvasive BProM system will require one terminated, coaxial ¼” Superflex Heliax signal cable.

9.3.2. Common mode chokes

EMI coupling into electric circuits by way of ground loops can be reduced by using common-mode filters on both end of all cable segments. A cable segment is any cable between two points where the shield is grounded. For example, a cable between an oscilloscope and a grounded patch panel is a segment. An AC power cord between an instrument and an AC socket is a segment.

Simple common-mode filters can be made by passing the signal cable (twisted pair or coaxial) through a ferrite core. Passing the signal cable several times through the ferrite core increases the magnetic coupling -hence the common-mode noise rejection- by the square of the number of turns... until the capacitive coupling defeats the rejection. In practice, about 7 turns are optimum. The magnetic characteristics of the ferrite cores must correspond to the frequency spectrum of the noise to be rejected.

Ferrite cores can be complemented advantageously by cores of amorphous cobalt alloy or nanocrystalline iron alloy cores next to the ferrite cores. MnZn tubes over the cables are effective against high frequencies >500 MHz. At low frequency down to 50Hz, iron-based nanocrystalline cores are effective. Cores with “soft” B-H loop (e.g., Hitachi Metals Finemet FT-3KL core annealing, Vacuumschmelze 500F field-annealed core) are preferred.

9.4. Relay Rack

Table 9-4 : PIP-II Documentation of Standard Relay Racks

Documents	Number
PIP-II Rack Bank Power	PIP-II docDB 5360
PIP-II Rack Specifications	PIP-II docDB 5363
LINAC Gallery Rack Allocation	PIP-II docDB 5390

- ***2796-001 Instrumentation racks (19" racks available for BI front-end electronics. Includes AC power.)***
  - *Rack requirements are defined by BI*
  - *BLDGI shall provide the racks, as well as layout of the racks for BI to populate*
  - *LI shall provide installation support to BI and BLDGI*

Electronic components shall be installed in the gallery and bolted into standard relay racks based on EIA-310. The chassis shall be 19" wide, and not exceed rack depth when including any rear protruding connectors.

Rack requirements are captured within the PIP-II Relay Rack Specification, and power requirements for each rack are captured in PIP-II Rack Bank Power.

In addition, relay racks for electronics should be located away from magnetic power supplies. Mapping within the LINAC Gallery is provided in the LINAC Gallery Rack Allocation .

Table 9-5 : Summary of BI Rack Allocation

Description of BI System	Rack Bank	Rack Count
BI systems installed in the WFE (before the shielding wall)	RB63	9
BI systems installed in the WFE (after the shielding wall), HWR, SSR1	RB74	6
BI systems installed in the SSR2	RB4	6
BI systems installed in the LB650	RB11	6
BI systems installed in the HB650	RB15	6
BI systems installed in the SCL (2kW) Dump, BTL Arc1	RB20	6
BI systems installed in BTL Straight, BAL, Arc2, 25kW Dump	F37	8

9.5. AC Power

- ***2796-002 Power (BLDGI shall provide power for Beam Instrumentation equipment.)***
    - *BI shall define power requirements for the Beam Instrumentation equipment*
    - *BLDGI shall design and procure the necessary hardware to extend the electrical service from the panel or disconnect to the beam instrumentation equipment*
    - *LI shall install the necessary hardware to connect the instrumentation equipment to the AC distribution.*

The power supplies for all electronic components require 120 V AC, 50/60 Hz power. BI low voltage power supplies (less than 20V) shall primarily be used for DAQ components. BI high voltage supplies shall be used for signal amplification or biasing.

9.6. Grounding

- ***2796-003 Grounding (BLDGI shall provide grounding of equipment.)***
    - *BI shall define any special grounding requirements for beam instrumentation equipment*
    - *BLDGI shall provide the grounding infrastructure required for BI equipment*
    - *LI shall provide installation support to BI*

Grounding is accomplished using trunk lines (500 mcm bare copper conductor), bonded to the ring ground system that encases the entire PIP-II complex, run via cable trays.

Within the enclosure, the cable tray system runs along the beam line at girder height or just below. Appropriate surfaces to connect the cable tray/trunk line to components shall be determined in the field, unless otherwise specified in the design of a component. These surfaces must be bare metal (e.g. not anodized) and accept a compression lug (provided by Building Infrastructure).

In addition, other electronic components are grounded to the AC mains ground by way of the power cord and outlet or rebar network. Additional filtering shall be used to remove line harmonics at the rack power supplies, as needed.

9.7. LCW

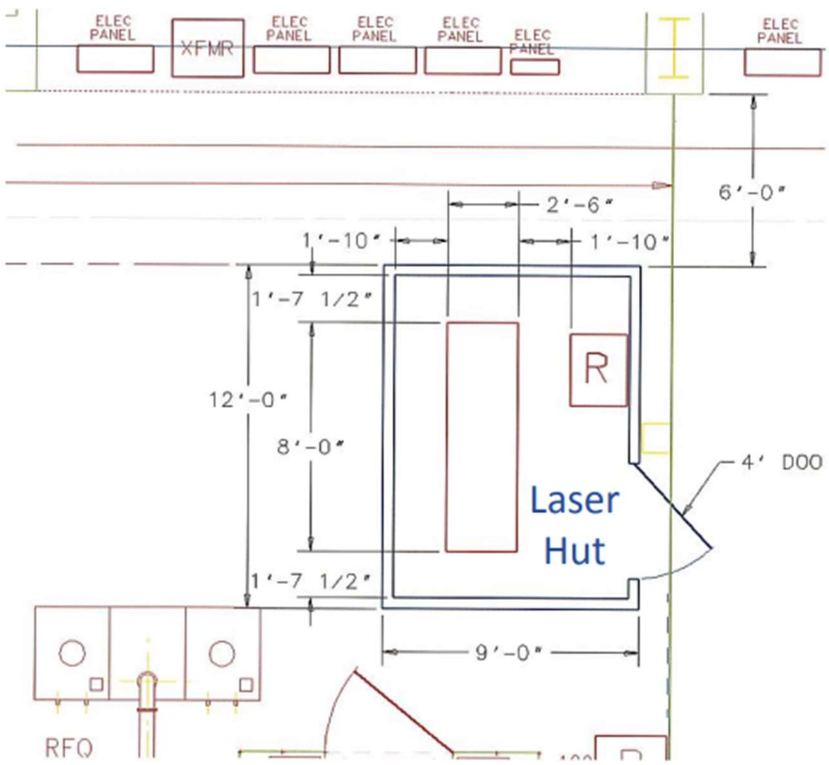
Not Applicable.

9.8. Laser Room

- ***2822-001 Laser Room***
  - *The Linac Complex will house the Laser Room*
  - *CMPLX and BI will determine spatial and infrastructure requirements for the Laser Room*
  - *CMPLX shall design and construct the conventional portion of the Laser Room enclosure*
  - *BI shall design, procure and install the technical equipment for the Laser Room*

The PIP-II Laser Room, also known as the Laser Hut, shall based on the PIP2IT Laser Room() and must meet beneficial occupancy requirements. In addition, it's design should follow the Laser Laboratory Design Guide (Table 13-1) as well as ergonomics best practiced.

Figure 9-1 : Diagram of PIP2IT Laser Hut



Physical dimensions of the Laser Room shall accommodate an optical table, the Class3B and Class 4 laser system, and laser opticals components. In addition, the laser room must have connections to AC Power (Section 9.5), Ground (Section 9.6), Controls global clock and timing system (Section 12.2), and Ethernet (Section 12.1).

10. LLRF Interfaces

The Noninvasive BProM system has no direct interface to LLRF.

Instead, the LLRF system supplies a single reference RF of 162.5Mhz to BI BPM system, which shall distribute a copy to Noninvasive BProM Laser Rooms. Details are elaborated in PIP-II BI Phase Reference Line FRS and TRS (Table 10-1) as well as PIP-II BI DAQ Electronics TRS[10].

Table 10-1 : PIP-II Documentation for Phase Reference Line Interface

Documents	Number
PIP-II LLRF FRS, Master Oscillator and Precision Reference Line	ED0005057
PIP-II LLRF TRS, RF Distribution	ED0005164
PIP-II, LLRF, RF Distribution Block Diagram	ED0008050
PIP-II LLRF TRS, Master Oscillator and Precision Reference Line	ED0014024
PIP-II BI Phase Reference Line TRS	ED0030047
PIP-II BI Phase Reference Line FRS	ED0030105

11. MPS Interfaces

Not Applicable.

12. Control System Interfaces

Table 12-1 : PIP-II Documentation for Control System Interface

Documents	Number
PIP-II ACC Controls DAQ PiRM TRS	ED0013500
PIP-II ACC Controls Front End Interface TRS	ED0013504
PIP-II ACC Controls Application Software TRS	ED0013505
PIP-II ACC Controls Console/Server Software & Hardware TRS	ED0013506
PIP-II ACC Controls ISD	ED0016515

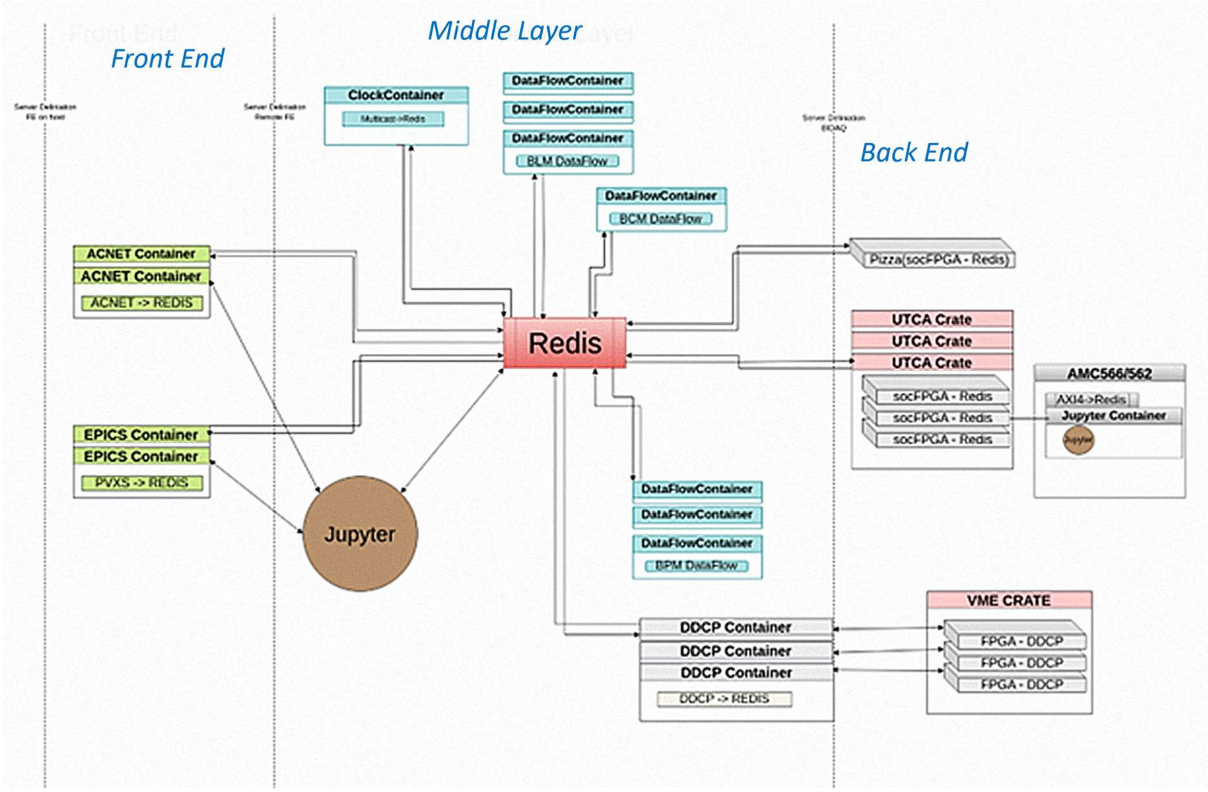
Control interfaces refer to any signal or data interfaces, providing control inputs to or readback outputs from the Control system. This includes interfaces related to signal pathways for the global clock and timing system.

- ***2695-001 Beam Instrumentation Control System Interface (Hardware interface and communication protocol if appropriate to controls front ends.)***
  - *CNTRL with input from BI shall specify the communication protocol for instrumentation devices to attach to the control system.*
  - *BI shall provide crates that house instrumentation, processors that interface with the control system, and the associated front-end software. CNTRL shall provide required network connections.*
  - *CNTRL and BI shall provide integration and testing for all relevant BI devices.*
- ***2695-006 General DAQ for Beam Instrumentation (Sample and hold readouts and DAC channels)***
  - *Number of channels sampling requirements, and locations will be defined by BI.*
  - *Controls provides the readouts into the general control system. Controls will provide the readout hardware as well.*
  - *Controls will provide installation support and demonstrate operation.*

Noninvasive BProM measurements shall be provided through Controls Sample & Hold DAQ electronics. . Details are elaborated in PIP-II BI DAQ Electronics TRS [10].

Other control and readout devices will be presented through PIP-II BI DAQ architecture (Figure 12-1). Details are elaborated in PIP-II BI Server Software Requirements Specifications[12].

Figure 12-1 : Block Diagram of BI DAQ Architecture



12.1. Ethernet Network

- ***2695-004 Network interface***
  - *Laser diagnostics room connections to accelerator controls network. Usually an ethernet connection.*
  - *CNTRL defines networks connections. BI makes the network request.*
  - *CNTRL shall provide the connection to the controls network*
  - *CNTRL and BI shall provide integration and testing of the laser room connection*

Use of copper or optical fiber cables shall be determined based on the criticality of the unit, data rate requirement to operations, and the electronics' location relative to the nearest switch. For connections requiring 10Gbps Ethernet, the cable shall be single-mode optical fiber; otherwise, the cable shall be industry standard Cat6A.

Details are elaborated in BI Ethernet Networking Requirements [11].

12.2. Clock & Timing System Interface

- ***2695-002 Beam Instrumentation Timing Interface (Interface to the LCLK timing distribution system. Instrumentation requirements of the timing system)***
  - *CNTRL with the input of BI shall specify the interface to the timing system. BI shall provide BI specific requirements.*
  - CNTRL shall provide the timing signals and interface boards and/or FPGA logic for the interface.
  - *CNTRL and BI shall provide integration and testing of the timing interface*
- ***2695-003 Timing and control signals***
  - *CNTRL and BI shall both define clocks signals for instrumentation in the laser room.*
  - *CNTRL shall provide the timing signals and interface boards, timing decoding, triggers, and/or FPGA logic for the interface*
  - *CNTRL and BI shall provide integration and testing of the timing interface.*

BI electronics shall be able to receive and decode global LCLK clock signals to track events in the timeline and machine states.

Table 12-2 : PIP-II Documentation for Global Clock System Interfaces

Documents	Number
PIP-II Controls LCLK-II TRS	ED0013498
PIP-II Controls ACLK TRS	ED0013499
PIP-II Timing Systems (ACLK and LCLK) ISD	ED0016516
LCLK-II Clock Generator Docs	PIP-II docDB 4959
ACLK/LCLK Fiber Fanout Unit Docs	PIP-II docDB 4962
ACLK/LCLK Local Fanout Unit Docs	PIP-II docDB 4965

Additionally, BI electronics shall be able to receive delayable event-based digital signals from standard timing modules, provided by Controls. These signals drive the trigger mechanism and timing logic to align both firmware and software modules with accelerator operations. This is critical for proper signal digitization, signal processing, and data acquisition.

Table 12-3 : PIP-II Documentation for Timing System Interfaces

Documents	Number
LCLK-II MFTU Docs	PIP-II docDB 4956
PIP-II Timing System Assorted Documents	PIP-II docDB 5927

Details are elaborated in PIP-II BI DAQ Electronics TRS [10].

12.3. Motion Control Interfaces

Not Applicable.

13. Safety Systems Interface

Safety System interfaces refers to interfaces and requirements needed for monitoring and interlocking components that impact E&SH limits.:

- ***2740-001 BI's Linac Laser Lab Interface to SS's Linac LSS.***
    - *BI shall interlock its Linac laser lab enclosure with SS's LSS enclosure hardware.*
    - *BI's laser lab enclosure will be equipped with SS's LSS enclosure personnel protection interlock equipment (gates, switches, control boxes, sirens, strobes, etc.).*
    - *BI owns the Laser Lab Enclosure Interface. BI provides the laser lab enclosure.*
    - *SS supplies interlock permits. Supplies enclosure personnel protection equipment (gates, switches, control boxes, sirens, strobes, etc.) and their wiring.*
    - *SS will install the LSS enclosure hardware into the laser lab.*

The operation of a Class IV laser requires personnel safety measures, which interlock the Laser Rooms. Laserwire safety is controlled by interlock system. The primary monitored components of interlock system included laser room door switches, optical transport line vacuum switch, beamline laserwire station switches, and beamline vacuum switch.

By making the laser transport line a vacuum system, a vacuum safety interlock switch shall be utilized to cut power to the laser when vacuum is let up to atmosphere. This shall require that the roughing valve is a gate valve that can shut off the laser when closed, maintaining laser safety. Control release of laser light from laser hut is done via closing optical shutter or dropping of laser interlocks.

In addition, all safety procedures shall be based on the PIP2IT Laserwire Interlock System (Table 13-1) and shall be listed in the BI QC Plan [18].

Table 13-1 : ESH Documentation for PIP2IT Laser Lab

Documents	Number
Laser Laboratory Design Guide	ESH docDB 2098
Laser ID #334	ESH docDB 4151
Laser ID# 335	ESH docDB 4154
PIP2 IT CMTF Laser Room Key Record	ESH docDB 7330
Fermilab Class 3B/4 Laser Standard Operating Procedure In CMTF Laser Room for GQuEST	ESH docDB 7454
PIP2 IT Laser Lab Interlock Operation Manual	ESH docDB 7524

Figure 13-1 : PIP2IT Laserwire Interlock System