PIP-II Non-Invasive Beam Profile Monitor System Technical Requirements Specification

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Document Approval

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Stakeholder Reviews performed off-line using TRS Metadata sheets	Dataset in TC

Revision History

Revision	Date of Release	Description of Change
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1. SCOPE

The scope of this technical requirements document is the PIP-II Non-Invasive Beam Profile Monitor (BProM) System, also known as the Laserwire.

Key cost, schedule, technical and programmatic assumptions are provided in PIP-II Project Assumptions [2].

Technical requirements are traceable to the following documents:

- PIP-II Global Requirements Document (GRD)[3]
- PIP-II Parameters Physics Requirements Document (PRD)[4]
- PIP-II Beam Instrumentation (BI) PRD[4]
- PIP-II Misalignment Tolerances PRD[6]
- PIP-II BI Functional Requirement Specification(FRS)[7]
- PIP-II BI Phase Reference Line FRS[8]
- PIP-II Vacuum Systems Technical Requirement Specification (TRS)[9]

Interface specifications between Noninvasive BProM systems and other PIP-II WBS[10] are elaborated in the PIP-II Noninvasive BProM Interface Specification Document (ISD)[11].

Counts and locations of units are provided in the PIP-II Parameters PRD[4].

2. ACRONYMS, TERMS, AND DEFINITIONS

BI	Beam Instrumentation
BProM	Beam Profile Monitor
BTL	Booster Transport Line
DAQ	Data Acquisition
DSP	Digital Signal Processing
FEM	Fermilab Engineering Manual
FESHM	Fermilab ES&H Manual
FNAL	Fermi National Accelerator Lab
FRCM	Fermilab Radiological Control Manual
FRS	Functional Requirements Specification
HV	High Voltage
ICD	Interface Control Document
ISD	Interface Specification Document
L2M	Level 2 Manager
L3M	Level 3 Manager
LEBT	Low Energy Beam Transport
LLRF	Low Level Radio Frequency
LV	Low Voltage
MEBT	Medium Energy Beam Transport
MPS	Machine Protection System
PIP-II	Proton Improvement Plan II Project
RF	Radio Frequency
SCL	Superconducting Linac
TRS	Technical Requirements Specification
WFE	Warm Front End

3. REFERENCED DOCUMENTS

#	Reference	Document #
1.	PIP-II Document Management and Control Procedure	PIPII- docDB 2946
2.	PIP-II Project Assumptions	PIPII-docDB 144
3.	PIP-II Global Requirements Document	ED0001222
4.	PIP-II Parameters Physics Requirement Document (PRD)	ED0010216
5.	PIP-II BI Physics Requirement Document (PRD)	ED0010230
6.	PIP-II Misalignment Tolerances PRD	ED0010231
7.	PIP-II BI Functional Requirements Specification (FRS)	ED0008303
8.	PIP-II BI Phase Reference Line FRS	ED0030105
9.	PIP-II Vacuum Systems Technical Requirement Specification (TRS)	ED0013681
10.	PIP-II WBS Dictionary	PIPII-docDB 599
11.	PIP-II BI Noninvasive BProM Interface Specification Document (ISD)	ED0016036
12.	PIP-II BI DAQ Electronics TRS	ED0013715
13.	PIP-II LLRF Master Oscillator and Precision Reference FRS	ED0005057
14.	PIP-II LLRF Master Oscillator and Precision Reference TRS	ED0005164
15.	PIP-II LLRF RF Distribution Block Diagram	ED0008050
16.	PIP-II BI Phase Reference Line TRS	ED0030047
17.	PIP-II Warm Unit Structures TRS	ED0008578
18.	PIP2 SCL Tunnel Envelope Drawings	F10104753, F10113422
19.	AD/Mechanical Support Department Procedure : Producing Very Low-Particulate UHV Components	ED0003571
20.	Fermilab Engineering Manual (FEM)	
21.	Fermilab Environmental Safety and Health Manual (FESHM)	
22.	Fermilab Radiological Control Manual (FRCM)	
23.	Fermilab FESHM 4260 – Lasers	
24.	American National Standard for the Safe Use of Lasers	ANSI Z136.1
25.	PIP-II 121.03 Accelerator Systems Quality Assurance (QA) Plan	PIPII- docDB 4805
26.	PIP-II Beam Instrumentation Quality Control (QC) Plan	PIPII- docDB 5520
27.	PIP-II Beam Instrumentation Installation Deliverables List	ED0011271
28.	PIP-II Accelerator Commissioning and Start-Up Plan	PIP-II docDB 5420

4. ROLES AND RESPONSIBILITIES

4.1. Author(s)

Responsible for TRS preparation, including layout, proper format, requirement identification, requirement verification expectations, requirement 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 requirement(s). In some cases, the author can also have the role of the document Owner.

4.2. Owner

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

4.3. Reviewer

Technical Integration Office (TIO) reviewers are responsible for ensuring TRS 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 TRS document exists and is maintained within the framework of the project Document Management and Control Procedure[1]. A Reviewer is considered a “Checker” in the Teamcenter workflow release.

4.4. Approver

The L2M will evaluate the basis for requirements definition, ensure that requirements are properly articulated, and ensure that they align with higher level requirements specifications, as applicable. The L2M will ensure that Control Account Managers (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 Teamcenter workflow release.

4.5. Stakeholder

Each TRS includes a metadata sheet which lists each TRS requirement individually and assigns stakeholders to each. A stakeholder is a subject matter expert pertaining to the given requirement and/or has a direct stake in the requirement. Identified stakeholders are expected to be reviewers, ensuring accuracy and completeness, of requirements and content applicable to them and their associated scope of work. Stakeholder reviewers ensure a record of decision is made offline for accepting, rejecting, or modifying the requirement statement assigned to them within the TRS metadata sheet (included as a dataset in Teamcenter).

5. NON-INVASIVE BProM SYSTEM DEFINITION

5.1. Overview

Noninvasive BProM, also known as the Laserwire system, do not introduce material into the beam and produce negligible beam loss. This system provides longitudinal and transverse beam profiles in the WFE MEBT and only transverse profiles in the SCL.

5.2. High Level Operations Concepts/Scenarios

The Laserwire system consists of vacuum chambers, laser sources, laser transport, laser optics, optical enclosures, electron detection, deflection magnets, electronics, and software. It further includes the mechanical, vacuum, and electrical interfaces needed for installation as well as the information-passing interfaces between the BProM System and the PIP-II Controls System, Global Timing System, and LLRF.

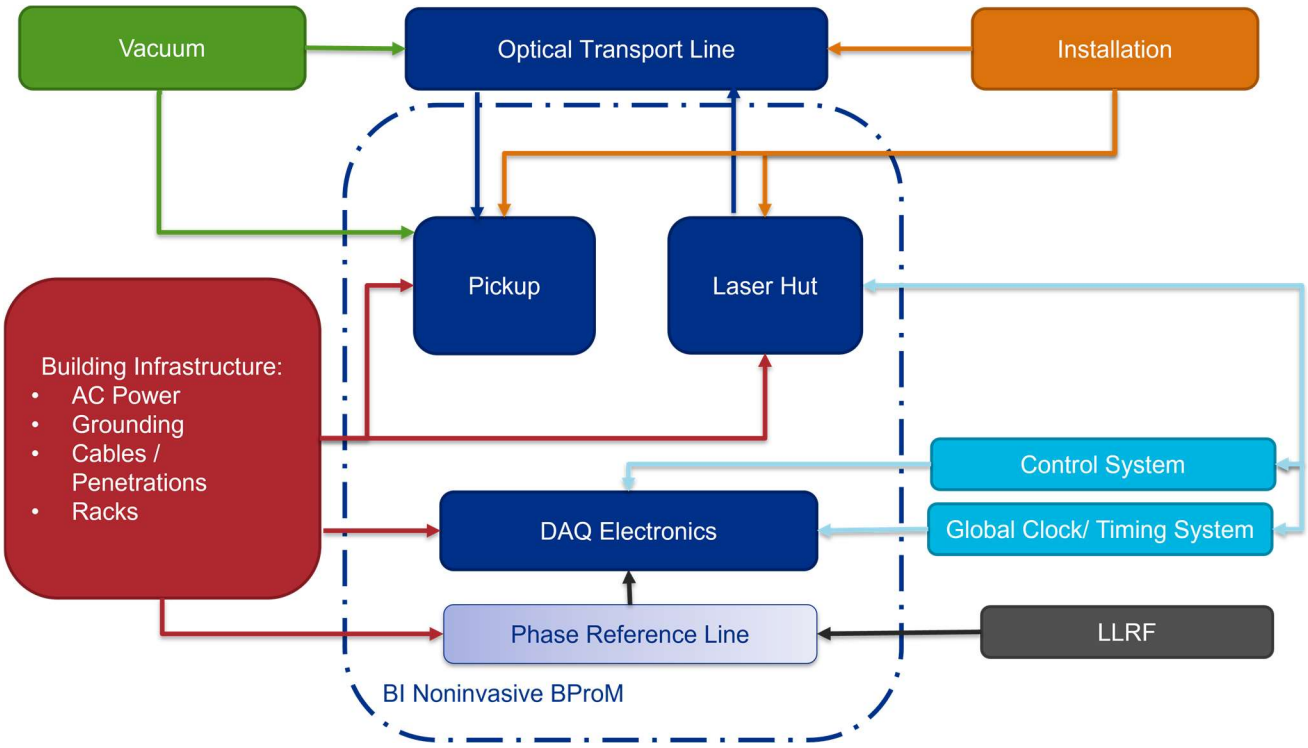


Figure 5-1 : Block Diagram of Noninvasive BProM System Architecture

5.3. General System Requirements

Table 5-1 : General Noninvasive BProM System Requirements

Requirement #	Requirement Statement
T-ED0013714-A001	Noninvasive BProM system shall meet function requirements, specified in PIP-II BI FRS. [7]
T-ED0013714-A002	Noninvasive BProM system shall meet the operational and performance requirements, specified in PIP-II BI PRD. [5]
T-ED0013714-A003	Noninvasive BProM signal cables should not share penetrations or cable trays with high power RF or high power pulsed signals.
T-ED0013714-A004	Noninvasive BProM system shall accept signals from the Global Clock and Timing system for event-based triggering and synchronization.
T-ED0013714-A005	Noninvasive BProM system components shall have no electrical connections normally exposed to employee contact.

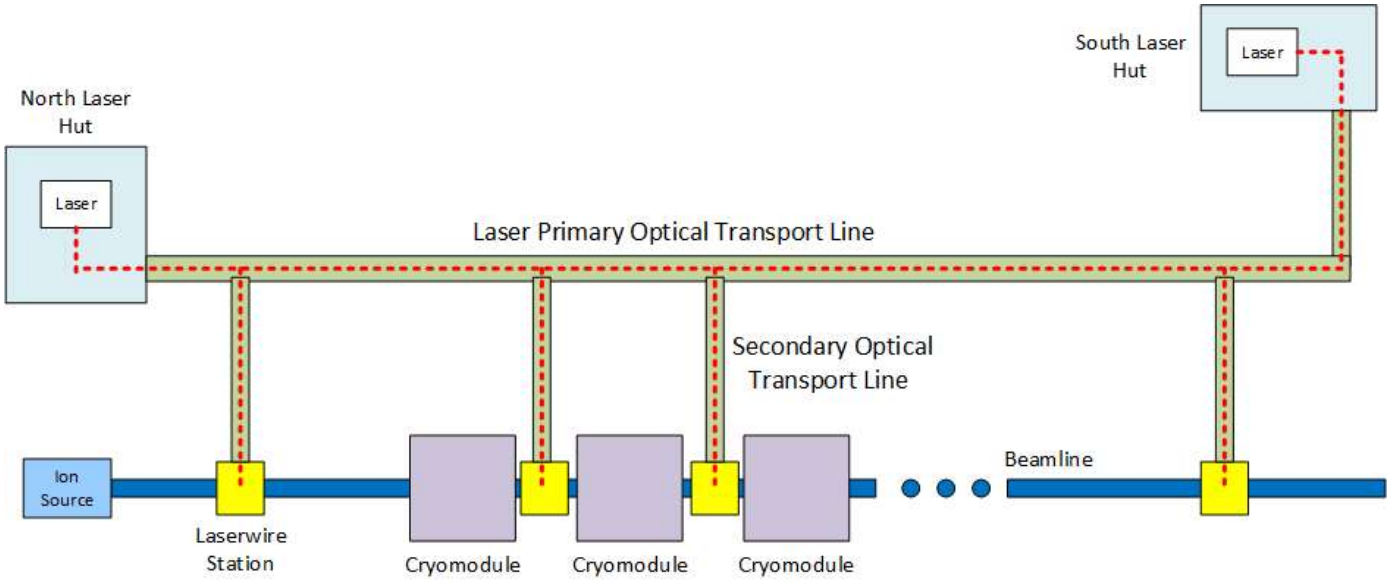
Detail requirements for the Noninvasive BProM electronics are found the PIP-II BI DAQ Electronics TRS[12].

5.4. Laser Hut Requirements

Table 5-2 : Laser Hut Technical Requirements

Requirement #	Requirement Statement
T-ED0013714-B001	The laser huts shall be designed to prevent the uncontrolled release of laser light.
T-ED0013714-B002	The laser huts shall be under interlocked control to prevent the uncontrolled release of laser light.
T-ED0013714-B003	The laser huts shall fit into the volumes defined by conventional facilities.
T-ED0013714-B004	The laser huts shall be temperature controlled to 75°F +/- 3°F and maximum relative humidity of 55%.

Figure 5-2 : Connections Between Optical Transport Line to Laserwire Components

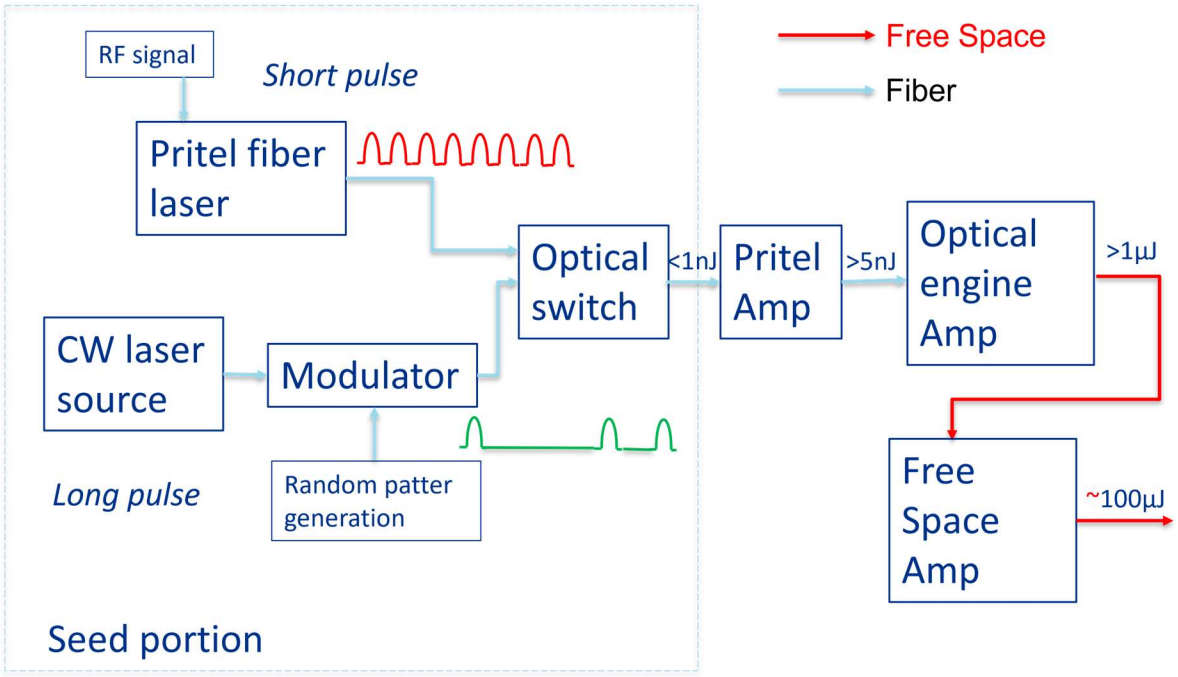


5.5. Laser Requirements

Table 5-3 : Laser Technical Requirements

Requirement #	Requirement Statement
T-ED0013714-C001	The laser wavelength shall be between 1030 and 1070 nm.
T-ED0013714-C002	The laser shall be pulsed and locked to the accelerator RF of 162.5 MHz from the BI Phase Reference Line. [16]
T-ED0013714-C003	LLRF shall generated a single 162.5MHz RF reference clock signal for beam instrumentation. [13][14][15] Beam instrumentation shall be responsible for distributing this signal to all necessary beam instrumentation electronics including the BProM laser huts. [16]

Figure 5-3 : Block Diagram of Fiber laser-free space laser hybrid system

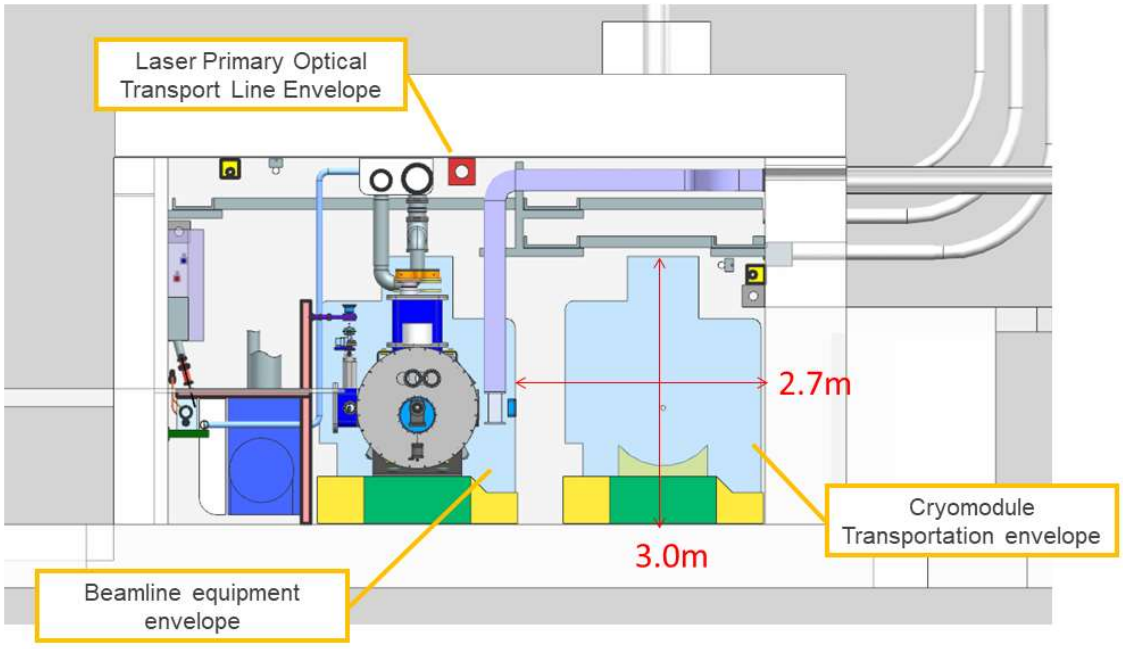


5.6. Optical Transport Line Requirements

Table 5-4 : Optical Transport Line Technical Requirements

Requirement #	Requirement Statement
T-ED0013714-D001	The optical transport lines shall be designed to prevent the uncontrolled release of laser light.
T-ED0013714-D002	The optical transport lines shall be under interlocked control to prevent the uncontrolled release of laser light.
T-ED0013714-D003	The optical transport lines shall fit into the volumes defined by conventional facilities.[18]
T-ED0013714-D004	The primary optical transport line center line shall not deviate by more than 5 mm from optically straight.
T-ED0013714-D005	Access to the optical transport lines shall be provided at every primary to secondary optical transport line intersection.
T-ED0013714-D006	The primary optical transport line shall have an optically straight clear aperture of >90 mm.
T-ED0013714-D007	The laser optical transport line shall be capable of being under low vacuum of no more than 250 mTorr.

Figure 5-4 : Cross-sectional View of SCL tunnel enclosure and the location of the laser primary optical transport line envelope

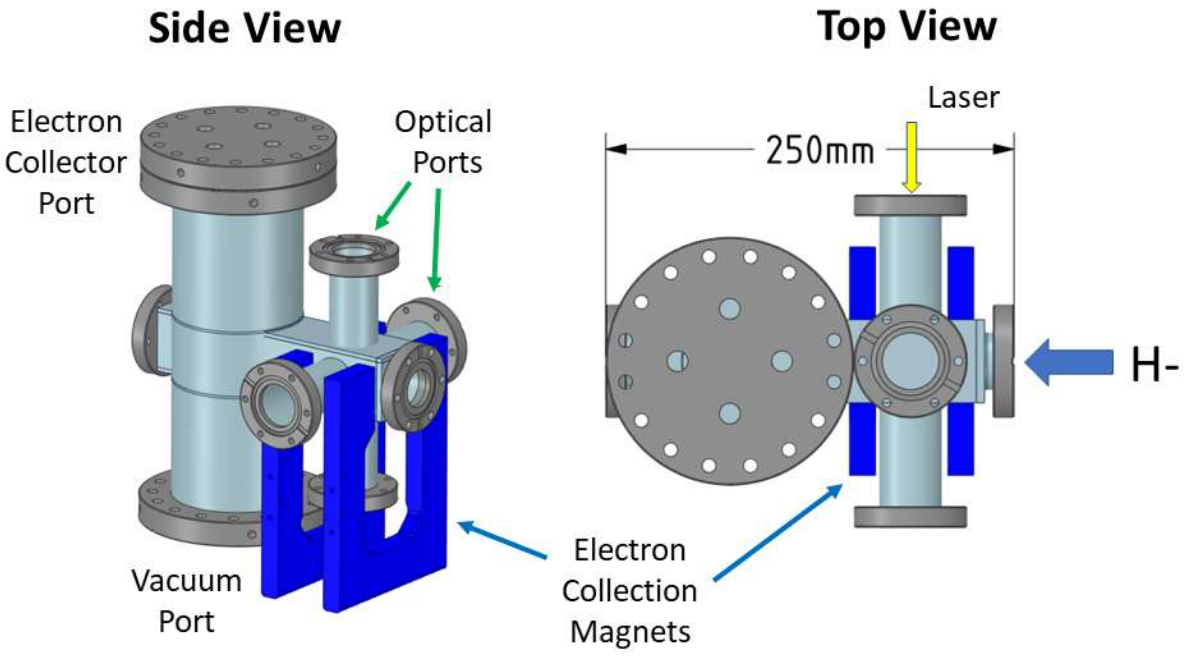


5.7. Laserwire Station Requirements

Table 5-5 : Laserwire Station Technical Requirements

Requirement #	Requirement Statement
T-ED0013714-E001	Each laser station shall be designed to prevent the uncontrolled release of laser light.
T-ED0013714-E002	Each SCL laserwire station shall fit into the volumes defined by warm unit specifications. [17]
T-ED0013714-E003	The laserwire stations shall not be a beamline aperture restriction and shall not have inner diameters less than the beam pipe apertures specified in each location.
T-ED0013714-E004	The free-space optics at each laserwire station shall keep the maximum average optical energy density on the vacuum viewports to less than 150 mJ/cm2 in 10μs and less than 3 J/cm2 in 1s.
T-ED0013714-E005	Each laserwire station laser dump shall have a photodiode to indicate the presence of laser light.
T-ED0013714-E006	Each laserwire station shall not be baked or operated at temperatures exceeding 100°C (212°F).
T-ED0013714-E007	A magnetic field downstream of the laser interaction point shall be used to produce a vertical transverse deflect the photoionized electrons into an electron collector. The magnets should be capable of supplying a field up to 800 Gauss.
T-ED0013714-E008	All laserwire vacuum components shall meet PIP-II particle-free requirements and operate under ultra-high vacuum conditions.[19]
T-ED0013714-E009	The laser optics boxes shall be removeable for repair and maintenance and access the beamline. Individual optics boxes shall be designed to allow removal without disturbing each warm unit assembly.
T-ED0013714-E010	Each laserwire station vacuum chamber shall have a port for a beamline vacuum pumping system.
T-ED0013714-E011	The material used to make components for any BI systems, located at enclosure locations subjected to radiation, shall be selected to be as radiation resistant as possible.
T-ED0013714-E012	Optical components of the laserwire profile monitor (including lenses, mirrors, vacuum viewports, and optical fibers) may require periodic replacements due to darkening from radiation exposure. Design of the laserwire system shall allow for these periodic replacements.

Figure 5-5 : Side view and top view of a generic block diagram of a beamline laserwire vacuum chamber.



6. TRANSPORTABILITY

Applicable travelers and relevant procedures for transport and shipping is elaborated in PIP-II BI QC Plan [26] and PIP-II Beam Instrumentation Installation Deliverables List[27].

Responsibility of oversight of transportability is shared between the L3M and L4M.

7. TESTING, VALIDATION, ACCEPTANCE

The following procedures are elaborated in the PIP-II BI QC Plan[26]:

- Acceptance Criteria & Testing
- Hardware Acceptance Testing
- Software Acceptance Testing
- System Acceptance Testing
- In-Process Monitoring and Measurement Activities
- Verification Plans: Methods & Activities
- Travelers, Procedures, and Checklists
- Deliverable Documentation and Records

Responsibility of addressing testing, validation, and acceptance concerns is shared between the L3M and L4M.

8. RELIABILITY, MAINTAINABILITY, AND AVAILABILITY

All BProM systems shall be designed for a minimum service lifetime consistent with that of the PIP-II project. Testing and calibrations shall be planned for at least annually, or more frequently, after system repairs, component replacement, or for system upgrades. Applicable travelers, relevant procedures, and associated equipment shall be listed in PIP-II BI QC Plan[26].

Responsibility of addressing reliability, maintainability, and availability concerns is shared between the L3M and L4M.

9. SAFETY

All BProM systems shall follow the FESHM[21] and FRCM[22] requirements, listed in the PIP-II BI FRS[7]. Additionally, the Laserwire System shall follow laser safety requirements defined in Fermilab FESHM 4260 [23] and American National Standard for the Safe Use of Lasers [24].

Any changes in the applicability or adherence to these requirements require the approval and authorization of the PIP-II Technical Director or designee.

Responsibility of oversight and compliance of safety requirements is shared between the L3M and L4M.

10. DESIGN & CONSTRUCTION STANDARDS

The design and construction of all BProM systems shall follow the codes and standards, listed in the PIP-II BI FRS[7] as well as the guidelines for best practices outlined in the FEM[20].

Responsibility of satisfying design and construction standards during system assembly and development is shared between the L3M and L4M.

11. QUALITY CONTROL PROVISIONS

All BProM systems shall adhere to the PIP-II BI QC Plan[26], which complies with the PIP-II 121.03 Accelerator Systems QA Plan[25] as well as addresses control of nonconformances.

Responsibility of oversight and implementation of QC provisions is shared between the L3M and L4M.