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Functional Specification

INNER TRIPLET FEEDBOXES, DFBX

Abstract

This specification establishes the functional requirements for the eight inner triplet feedboxes (DFBX) that connect the superconducting magnets at interaction points (IP's) 1, 2, 5, and 8 to the LHC cryogenic, electrical, and vacuum systems. The equipment described in this specification performs the equivalent electrical distribution functions of the arc elements designated as DFB and the equivalent cryogenic distribution functions found in the Short Straight Sections.

There are two basic types of DFBX; the first at points 1 and 5 where there are resistive beam separation dipoles (D1) and the second at points 2 and 8 where the D1 are superconducting.

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History of Changes

Rev. No.	*Date*	*Pages*	*Description of Changes*
0.1-draft	1999-09-23	1-32	Initial Submittal
0.2-draft	1999-09-29	4-7,12,13,15, 31,32	Incorporate preliminary suggestions from FNAL and BNL
0.3-draft	1999-10-07	14	Correct error in Figure
		15	Correct error in schematic
		9, 10, 12, 14-18, 28, 30, 31	Miscellaneous corrections for reasons of grammar and clarification
0.4-draft	2000-01-14	5, 6	Corrected Figure 3.1-1 and Figure 3.2-1
		7	Added reference for slope and tilt
		8	Corrected Table 4.1-1. Used "high beta" optics and added MQXA and MQXB Equipment Code names in 4.2.
		9	Corrected Figure 4.2-1
		10	In Table 4.3.1-1 Changed HTS Lead Rating, 600 A lead count, and ≤ 180 lead type. Clarified insulation and jacket materials in 4.3.2.
		11	Clarified insulation material in 4.3.3.
		16	Clarified bore tube cleaning in 4.5.1.
		19	Clarified Operational Requirements in 4.7, added qualifier in Tunnel Constraints in 5.2.
		27	Revised Figure 5.3-1
		29	Added standardization in 6 and reference to LHC-PM-QA-100 in 7
		32	References are re-arranged and corrected as needed.
1.0	2000-02-07		First version released.

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1. SCOPE

This specification establishes the functional requirements for the eight inner triplet feedboxes (DFBX) that connect the superconducting magnets at interaction points (IP's) 1, 2, 5, and 8 to the LHC cryogenic, electrical, and vacuum systems. The equipment described in this specification performs the equivalent electrical distribution functions of the arc elements designated as DFB and the equivalent cryogenic distribution functions found in the Short Straight Sections.

There are two basic types of DFBX, the first at points 1 and 5 where there are resistive beam separation dipoles (D1) and the second type at points 2 and 8 where the D1 are superconducting.

2. EQUIPMENT CODE

Because each of the eight DFBX may have a unique design, we adopt the following equipment code in order to allow a straightforward application of the LHC documentation system to comply with the requirements in Section 10.3 of this Specification.

Location	IR1 Left	IR1 Right	IR2 Left	IR2 Right	IR5 Left	IR5 Right	IR8 Left	IR8 Right
Code	DFBXA	DFBXB	DFBXC	DFBXD	DFBXE	DFBXF	DFBXG	DFBXH

3. FUNCTIONAL OVERVIEW

3.1 FUNCTIONAL DIAGRAM FOR DFBX AT IP1 AND IP5

A functional diagram of the DFBX for IP's 1 and 5 is shown in Figure 3.1-1. The diagram depicts the main functions of providing cryogenic, electrical, and vacuum interconnections.

The cryogenic connections provide:

- distribution of cryogenic fluids for cooling and maintaining the MQX and corrector magnets in 1.9K, 1 bar superfluid helium,
- cooling for the internal radiation absorbers (TAS2 and TAS3) and magnet supports,
- cooling for current leads in the DFBX,
- thermal connections to the 50 – 75 K thermal shield,
- a means of venting the superconducting magnets and DFBX components in case of a magnet quench or other accident.

The electrical connections provide:

- current to the MQX magnets, with trimming as needed,
- current to the corrector magnets,
- signals from the magnet and bus bar quench sensors to the CERN control system,

- current to the quench protection heaters,
- signals to the CERN control system for monitoring and controlling cryogenic performance.

The vacuum connections provide:

- continuity of the beam tube vacuum from room temperature to 1.9 K,
- maintaining the insulating vacuum space common to the magnet cryostat,
- venting the insulating vacuum space in case of cryogenic line rupture.

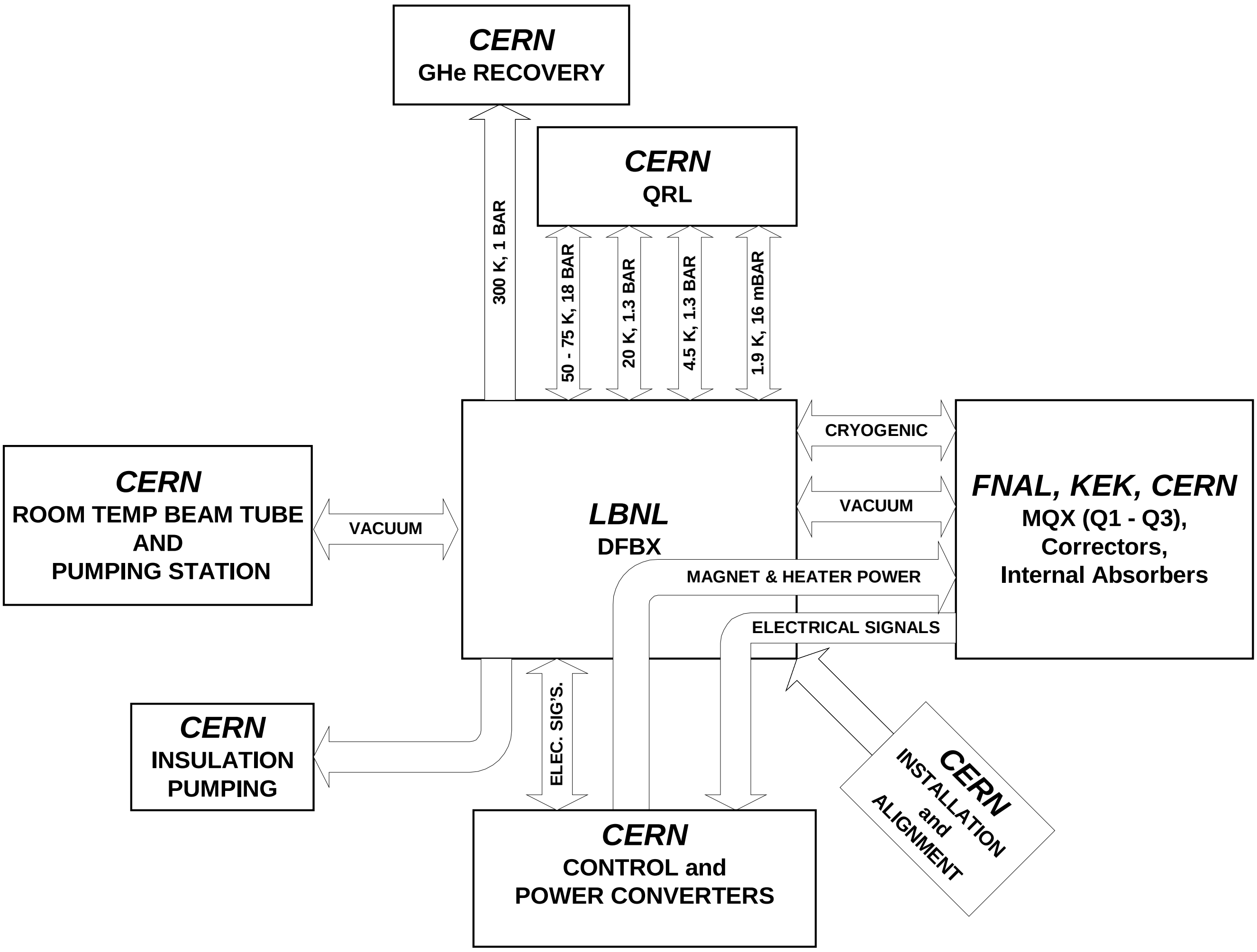

Figure 3.1-1 DFBX Functional Diagram (IP's 1 and 5)

3.2 FUNCTIONAL DIAGRAM FOR DFBX AT IP 2 AND IP8

A functional diagram of the DFBX for IP's 2 and 8, is shown in Figure 3.2-1. The diagram depicts the main functions of providing cryogenic, electrical, and vacuum interconnections.

This DFBX differs from the DFBX at IP's 1 and 5 in the following main points:

- It has additional cryogenic, vacuum, instrumentation and current leads to operate the superconducting D1 at 1.9 K, 1 bar superfluid helium.
- It has no warm to cold beam tube transition.
- It has provision for beam screen cooling connections.

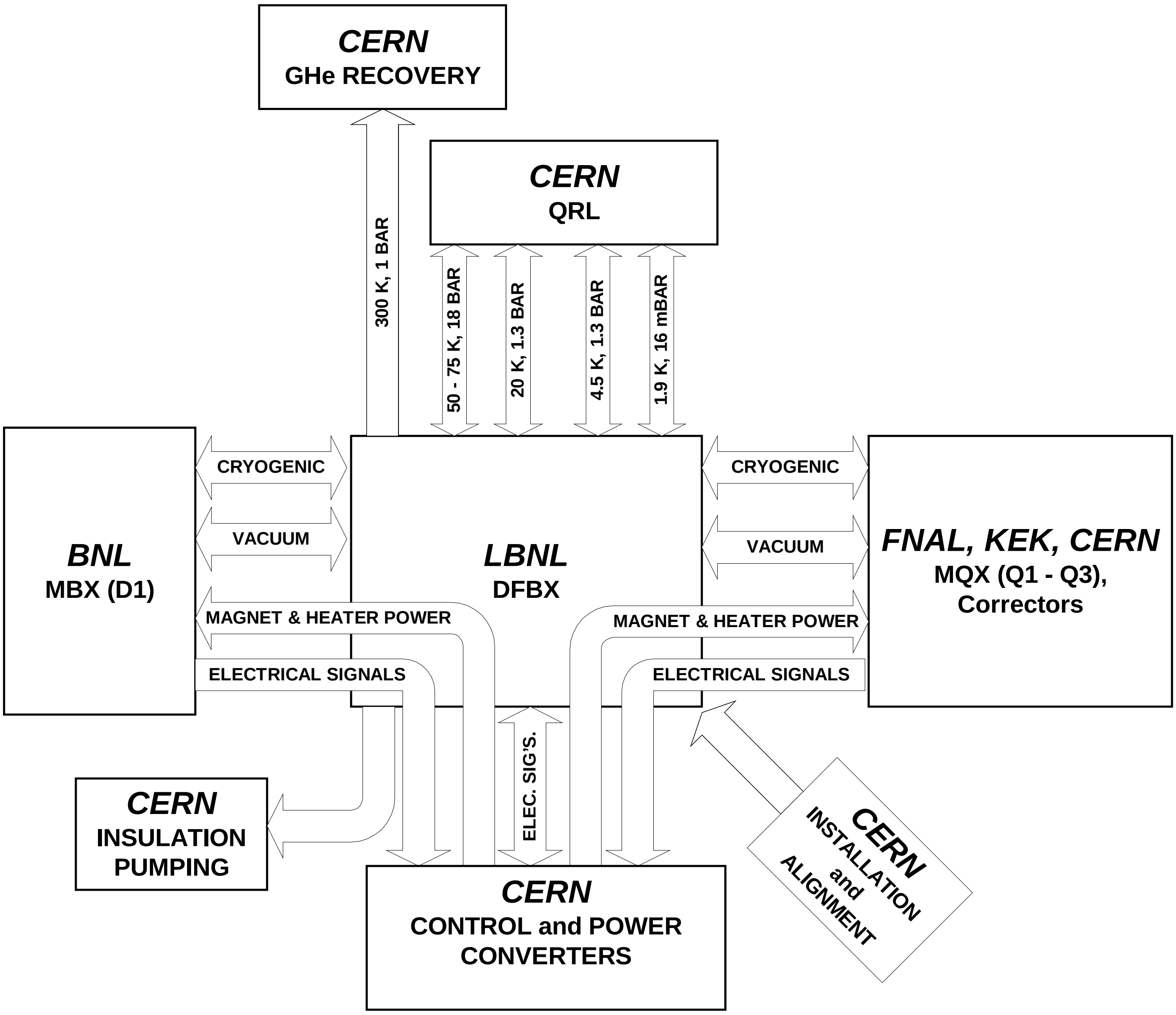

Figure 3.2-1 DFBX Functional Diagram (IP's 2 and 8)

3.3 INTERFACES

Table 3.3-1 gives a high-level listing of the interfaces between the DFBX and other equipment.

Table 3.3-1 DFBX Interface Summary

SYSTEM	LAB	INTERFACE	Location
CRYOGENICS	CERN	Connection to QRL	all
	FNAL	Connection to Q3	all
	BNL	Connection to D1	IP2, IP8
	CERN	Connection to GHe Recovery Line	all
MAGNET POWERING	CERN	Connection to Power Converters	all
	FNAL	(Q1-Q3) and Corrector Bus Bar Hook-up	all
	BNL	(D1) Bus Bar Hook-up	IP2, IP8
ELECTRICAL SIGNALS	FNAL	(Q1-Q3) Instrument Bus Connection	all
& HEATER POWER	BNL	(D1) Instrument Bus Connection	IP2, IP8
	CERN	DFBX Instrumentation	all
	CERN	Instrumentation Connectors	all
VACUUM	FNAL	Vacuum Closeout Sleeve to Q3	all
	BNL	Vacuum Closeout Sleeve to D1	IP2, IP8
	CERN	Vacuum Closeout Sleeves to QRL	all
	CERN, BNL, FNAL	Beam Tube Connections	all
	CERN	Connection to Beam Tube Pumping Station	IP1, IP5
	CERN	Connection to Insulation Vacuum Pumping	all
INSTALLATION	CERN	Tunnel Transport and Lifting Equipment	all
ALIGNMENT	CERN	Alignment Fiducial Locations	all

4. FUNCTIONAL REQUIREMENTS

4.1 OPTICS LAYOUT

The optics layout dictates the lattice spacing of the magnetic elements which leads to their physical spacing and the space allocated to service elements such as the DFBX.

We use optics study layout version 6.1 [1] as the basis for the DFBX position and size requirements. LHC Project Note 95, "Geometrie du LHC: Points caracteristiques, Formules de Transformation, 23 June 1997, gives the values of the longitudinal slope and transverse tilt of the LHC IP's. Table 4.1-1 lists the pertinent dimensions for the DFBX from these studies.

The slope along the beam line is important, since the 2-phase helium flow in the MQX and MBX magnet HeII heat exchangers must be downhill. The DFBX must be rotatable to match the local tilt of the LHC beam plane.

Table 4.1-1 DFBX Dimensional Parameters

Point	DFBX Midplane Location from IP (mm)	DFBX Length[b] (mm)	Longitudinal Slope (%)	Transverse Tilt (%)
IP1 - Left	56419	3106	+1.24%	+0.7 %
IP1 - Right	56419	3106	+1.24%	+0.7 %
IP2 - Left	56300	2869	+1.34%	-0.4 %
IP2 - Right	56300	2869	+1.34%	-0.4 %
IP5 - Left	56419	3106	-1.24%	-0.7 %
IP5 - Right	56419	3106	-1.24%	-0.7 %
IP8 - Left	67520[a]	2869	+0.42%	+1.3 %
IP8 - Right	45080[a]	2869	+0.42%	+1.3 %

a. Distance measured from center of UX 85; IP8 is shifted 11.22 m to the left of this point.

b. Length is defined as distance between midpoints of the interconnect regions for each DFBX.

4.2 MAGNET POWERING

Several arrangements of magnet powering are under consideration to allow operation in either standard or high beta optics without opening the cryostats to change the power leads to the inner triplet. The DFBX conceptual design must be flexible and responsive to CERN’s final selection.

The choice of mixing MQXB from FNAL (13 kA current) and MQXA from KEK (8 kA current) quadrupoles in the LHC inner triplets was adopted by the LHC Technical Committee [2], and we show this configuration in Figure 4.2-1.

Figure 4.2-1 shows the quadrupoles connected in series, with 4 current leads, which allows normal as well as high beta optics. All triplets are wired the same. Additional current leads for trimming are not required.

Note that corrector powering is not shown on Figure 4.2-1, but all corrector elements will be housed in the triplet cryostat and will require current leads and bus bars in the DFBX that are not shown. All current leads are identified in Section 4.3.1.

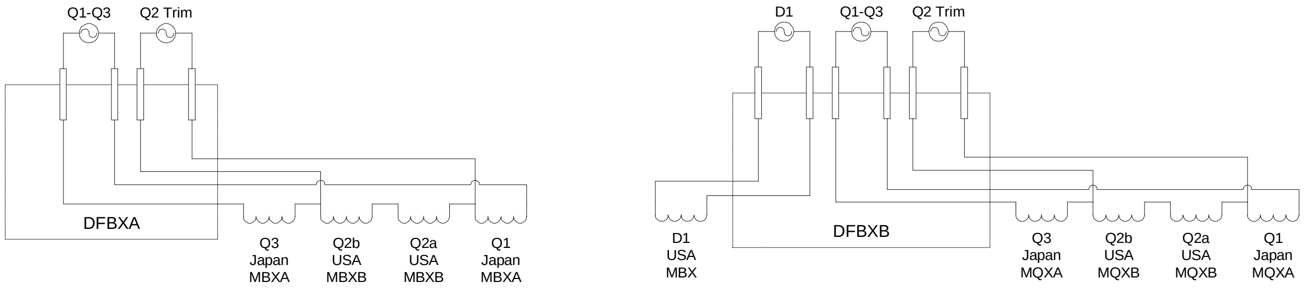

Figure 4.2-1 Main Magnet Powering Schematic for Mixed Quadrupoles

4.3 ELECTRICAL REQUIREMENTS

4.3.1 CURRENT LEADS

The current leads required to satisfy the magnet powering arrangement presented in Section 4.2 and the corrector magnet current lead recommendation of the CDR Panel [3], modified by the Workshop on LHC Interaction Region Correction Systems [4] are summarized in Table 4.3.1-1.

In the table,

1. The test voltage refers to the system test voltage to be applied at CERN[5].
2. An HTS type lead is one in which the lower portion of the lead is constructed of **H**igh **T**emperature **S**uperconductor to minimize the heat leak into the cryogenic system. The upper portion is a resistive lead cooled with helium gas at a maximum temperature of 20 K. The leads will be supplied with copper-stabilized Nb-Ti superconductor soldered to the HTS material to allow reliable connection to the DFBX bus bars.
3. A vapor-cooled lead is entirely resistive, in which the lower end is submerged in liquid helium and the cooling is provided by helium boiloff gas.
4. A conduction-cooled lead is designed to minimize the heat input to the cryogenic system by a proper choice of material, diameter, and length. There is no counterflow cooling with helium gas, but there may be a connection to the thermal shield at the proper position to reduce heat input to the 4 K bath. The thermal connection will provide electrical isolation to satisfy the test voltage in the table.

TABLE. 4.3.1-1 Current Leads in the DFBX

Element	Lead Rating	LHC Test Voltage	Type	Location	Number (each DFBX)
Q1-Q3	7.5 kA	1.2 kV	HTS	all	1 pr
Q2 Trim	7.5 kA	1.2 kV	HTS	all	1 pr
D1	7.5 kA	1.2 kV[a]	HTS	IP2, IP8	1 pr
Correctors	600 A	600 V	Vapor-cooled	all	7 pr
Correctors	≤180 A[b]	600 V[c]	To be Determined	all	8 pr

Notes:

(a) This value is not defined in [5]. We assume it to be the same as the quadrupoles.

(b) Exact values are not known at the present time; 180 A conduction leads assumed for heat leak calculations in section 4.6.1. Can be changed to suit the final requirements.

(c) This value is not defined in [5]. We assume it to be the same as the 600 A Correctors.

4.3.2 INSTRUMENTATION

The DFBX will serve as the interface point for the instrumentation wires needed for diagnostics and control of the IR superconducting magnets. The instrumentation is arranged into three sensor groups:

1. **Instrumentation from the liquid helium chamber:** these are from the sensors in the DFBX liquid helium chamber.
2. **Instrumentation from the superconducting magnets:** these are from the cold masses operated at 1 bar pressure, 1.9 K, and from the liquid collection volume located in the DFBX which is operated at 16 mbar, 1.9 K. A room temperature pressure tap will be provided on the connector housing to allow the magnet pressure to be monitored.
3. **Instrumentation from the DFBX vacuum space**: these originate from the DFBX and the end of Q3 and D1 nearest the DFBX.

These three groups will have separate connectors on the DFBX vacuum vessel.

All wires will be terminated in CERN-supplied or CERN-approved connectors. The wires in the DFBX will be insulated with heat-sealed polyimide (e.g. Kapton™) film or ML-type insulation and have a suitable jacket to prevent abrasion of the insulation.

Table 4.3.2-1 is a preliminary list of the instrumentation wires that will be terminated at the DFBX. Additions or deletions to the list can be accommodated as the requirements are finalized in the Interface Specification.

Table 4.3.2-1 Preliminary DFBX Wire List

Sensor	Cable Type	Number of Cables
Quadrupole Diagnostics		
Quench Voltage	2-wire	8
Quench Heaters	2-wire	16
Temperature Sensors	4-wire	4
Liquid Collector Heaters	2-wire	2
Liquid Collector Level Sensor	4-wire	2
Spare/Uncommitted Cables	2-wire	8
Spare/Uncommitted Cables	4-wire	4
Dipole Diagnostics		
Quench Voltage	1-wire	6
Quench Heaters	2-wire	4
Spare/Uncommitted Cables	2-wire	2
Spare/Uncommitted Cables	4-wire	4
DFBX Diagnostics		
HTS Lead Voltage Taps	3-wire	12
Other Lead Voltage Taps	2-wire	20
HTS Temperature Sensors	4-wire	12
Cryogenic Temp. Sensors	4-wire	6
Level Sensors	4-wire	2
Bath Heaters	2-wire	2
Spare/Uncommitted Cables	4-wire	4

4.3.3 SUPERCONDUCTING BUS BARS

The superconducting bus bars in the DFBX will be the same as used in the inner triplet.

The bus bars are electrically insulated by a suitable wrapping of polyimide (e.g. Kapton™) film to allow voltage testing to the levels listed in Sections 4.3.1 above. Mechanical support of the bus bars in the helium chamber and the ducts leading to the magnet volumes will be made using spacers which are electrically insulating, and with a radiation tolerance equivalent to G11-CR.

4.4 CRYOGENIC CONNECTIONS

The cryogenic connections required for DFBXB and DFBXC are shown in the cryogenic schematics in Figures 4.4-1 and 4.4-2, respectively. All superconducting magnets connected to the DFBX are operated at 1.9 K, 1 bar helium. These figures are representative of the two types of DFBX.

The main cryogenic components are discussed below. The underlined quantities represent present design estimates for operation, with contingency, at a nominal luminosity of 10^{34} $cm^{-2}s^{-1}$. The details will be finalized in the applicable Interface Specifications.

Thermal Shield Cooling: The US-supplied IR system will require approximately 12 g/sec of thermal shield gas flow to intercept heat flow from ambient due to thermal radiation and conduction. The flow will be supplied from Header E and discharged into Header F. CERN will maintain a minimum pressure differential of 0.4 bar [6] between Headers E and F to sustain this flow. A temperature-controlled cryogenic valve in the CERN QRLS will regulate the flow rate.

Liquid Helium Chamber: The DFBX will contain a liquid helium chamber which provides cooling for the required current leads (see Section 4.3.1), and for the superconducting bus bars that provide current to the superconducting magnets. The bus bars exit through an insulating barrier called a lambda plate, which separates the chamber liquid helium from the magnet superfluid helium.

The chamber contains about 120 liters of LHe; the liquid is provided by a J-T valve in the QRLS connected to Header C. The liquid level is monitored by a superconducting liquid helium level sensor, which provides feedback to the J-T valve controller.

Boiloff gas provides cooling for the resistive portion of the HTS current leads and the vapor cooled leads; excess is sent to Header D.

A heater is provided for trim control of the liquid level.

The helium chamber is protected from overpressure by a relief valve (CERN-supplied) connected to the room temperature helium recovery header.

HTS Lead Cooling: The HTS (lower) portion of the lead is cooled by boiloff generated by heating in the HTS portion itself, which is a feature of the HTS lead construction. The upper (resistive) portions of the leads are cooled by the vapor generated by liquid boiloff in the liquid helium chamber as described above, augmented with flow from Header D as needed. The gas connection to the resistive section will provide the required electrical isolation described in Section 4.3 above.

The HTS leads are protected from excessive pressure in Header D by a pair of valves in the QRLS on the connection to Header D; the valves can be closed automatically in case of magnet quench or manually for pressure testing. A relief valve connected to the room temperature helium recovery header provides additional protection against overpressure. All valves are provided by CERN.

Magnet Cooling: The MQX, D1 (at IP2 and IP8), and corrector magnets are operated in a bath of pressurized superfluid helium at 1.9K and 1 bar.

They are cooled to 4.5 K and filled from the low end of the magnet string with helium from Header C fed through a J-T valve. Temperature and pressure sensors on or in the cold masses provide valve control feedback. At IP2 and IP8, the Quadrupoles and D1 are cooled in series by means of a connecting pipe in the DFBX.

Cooling to the superfluid state and providing the refrigeration needed to maintain the temperature is accomplished by heat transfer to a heat exchanger tube containing saturated liquid helium at 16 mbar. (The heat exchanger tube is an integral part of the magnet system.)

The 16 mbar pressure in the tube is maintained by connection to Header B (the pumping line), and the tube is supplied with saturated liquid helium from a J-T valve connected to Header C. At IP2 and IP8 the quadrupole and dipole magnet heat exchangers are pumped in parallel by means of a tee connection in the DFBX.

A heat exchanger in the QRLS that cools the supply stream prior to the J-T valve increases the fraction of liquid phase supplied to the magnet heat exchangers. At IP2 and IP8 separate J-T valves in the QRLS supply the quadrupole and dipole magnet heat exchangers; the J-T valves are connected in parallel to a single J-T heat exchanger.

The magnet heat exchanger at IP1 and IP5 will be required to remove up to 250 W at nominal luminosity for which a helium mass flow rate of 12 g/sec is needed. At IP 2 and IP8, the heat removal requirement is significantly less, so the mass flow rate through the heat exchanger is on the order of 7 g/sec.

A lambda plate separates the 1.9 K superfluid helium bath from the 4.5 K liquid helium bath in the DFBX. Electrical bus bars that provide current to the triplets and correctors pass through this plate.

Note: Heaters mounted on the MQX for control of the step function heat input to the inner triplet LHeII bath from collisions are not shown on the DFBX schematics.

Liquid Collector: Each DFBX located at the low end of the inner triplet will contain a liquid collector.

The function of the liquid collector is to ensure that the pumping line to Header B remains unobstructed. It provides a volume for liquid to drop out of the pumping line in the event that a quench or other event causes a large volume of liquid to be ejected out of the heat exchanger tube.

The liquid collector shall contain a level sensor capable of operating in vacuum as well as a heater for vaporizing any liquid that may collect. The instrumentation exiting the subatmospheric helium volume shall be equipped with a room temperature helium guard to prevent contamination of the helium system with air.

Magnet Pressure Safety: The magnet string shall be connected to Header D with CERN-supplied pressure safety relief valves to provide for venting in case of a magnet quench. At IP1 and IP5, two relief valves are required for redundancy. At IP2 and IP8, three relief valves are required, one on each end of the magnet string and a third connected to the common cooldown line in the DFBX. The valves can also be electrically opened as required for cooldown and other operational considerations.

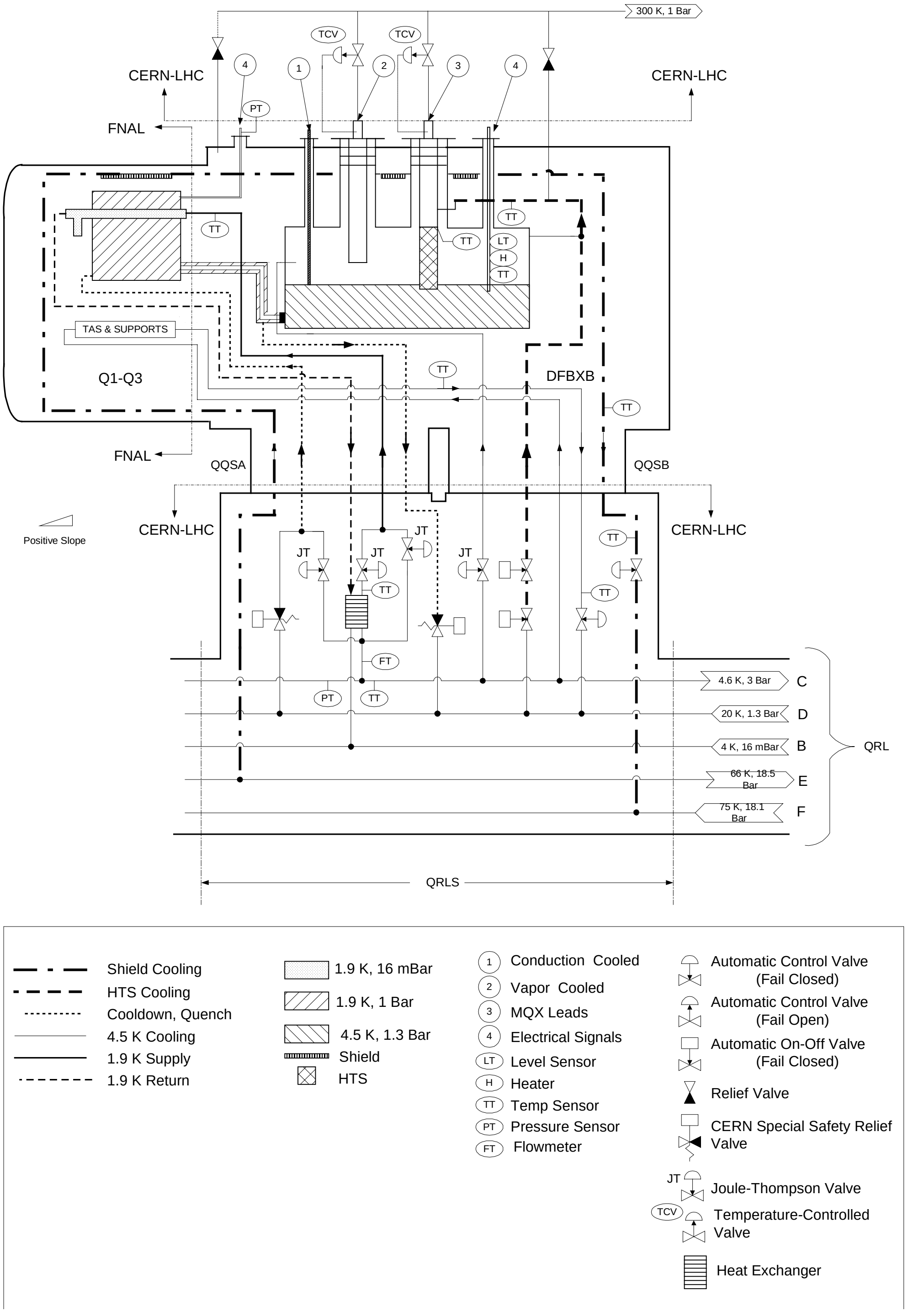

Figure 4.4-1 Cryogenic Schematic for DFBXB (IR1 Right)

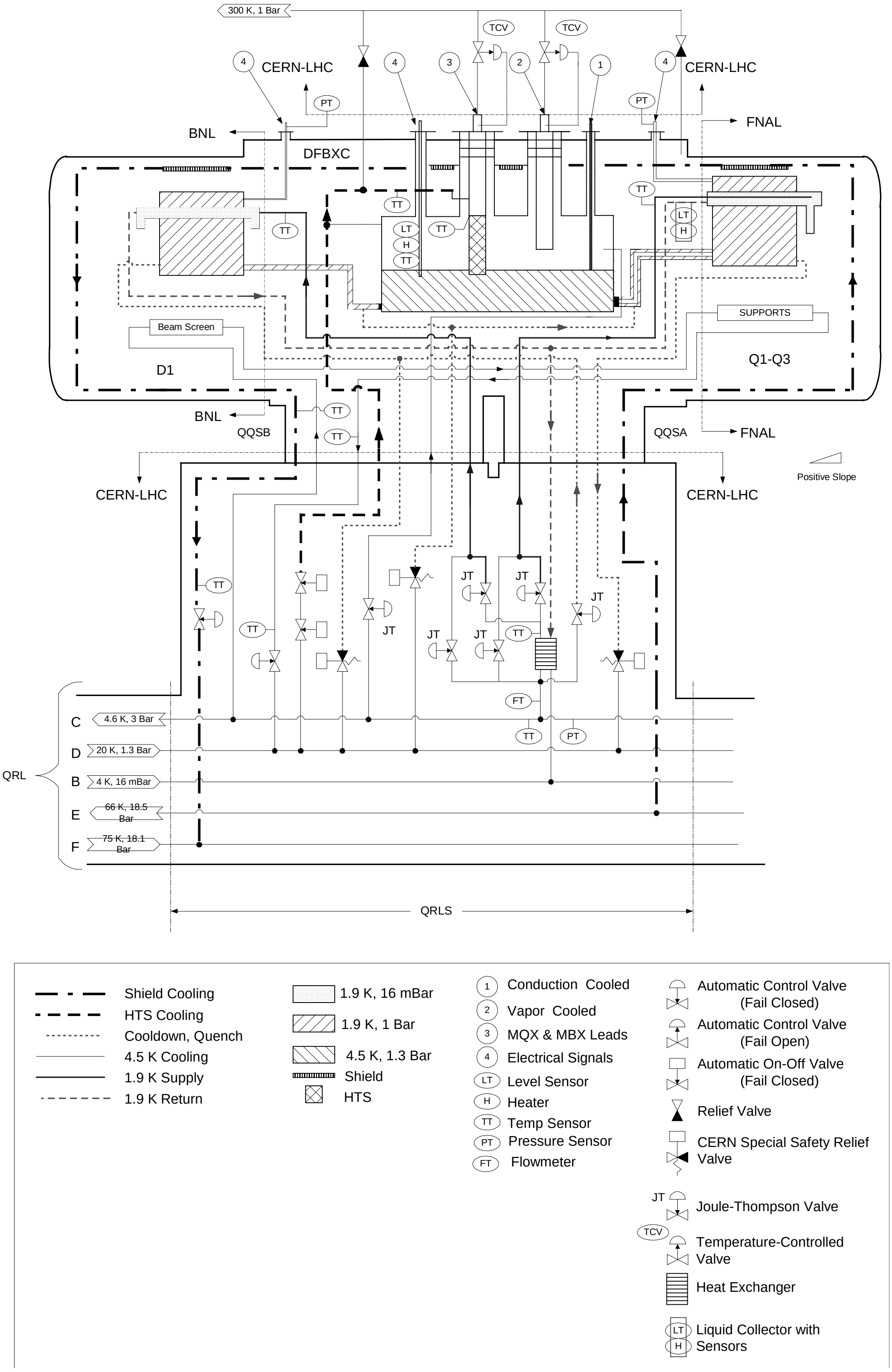

Figure 4.4-2 Cryogenic Schematic for DFBXC (IR2 Left)

4.5 VACUUM AND PRESSURE REQUIREMENTS

4.5.1 BORE TUBE

The DFBX bore tube is a 316LN stainless steel chamber that provides a vacuum-tight enclosure for the LHC particle beams. A CERN-supplied beam screen or liner that provides the conducting path for the beam return current and beam vacuum pumping features will be inserted into the DFBX beam tube at installation.

At IP's 1 and 5 the DFBX bore tube will contain a warm to cold transition on the resistive D1 end.

At IP's 2 and 8 the bore tube temperature will be approximately 1.9 K because it is connected at each end to superconducting magnets operated at 1.9 K.

To accommodate thermal contraction of the bore tube, bellows will be used. The CERN-supplied beam screen will have a sliding RF joint to accommodate the thermal contraction.

The bore tube material will be supplied to LBNL after final cleaning [7]. After fabrication at LBNL, the tubes will be cleaned per procedures to be written, backfilled with dry Nitrogen, and capped with blank flanges. The blank flanges will be equipped with pressure gauges and valves for repressurizing if the backfill gas is accidentally vented. The bore tube flanges will allow the bore tubes to be capped and mechanically sealed for delivery and storage at CERN. Welded connections for permanent installation in the LHC ring will be possible for cryogenic sections.

4.5.2 INSULATING VACUUM

The DFBX thermal insulation vacuum is common with the insulating vacuum of the US-cryostatted magnets. A vacuum barrier close to the QRL is provided by CERN to separate the magnet system insulating vacuum from the QRL insulating vacuum.

In order to provide suitable protection against excessive thermal heat load due to residual gas conduction, the pressure in the DFBX space will be 1×10^{-5} Torr or less.

Due to the differential area of the DFBX vacuum system that will be loaded by atmospheric pressure, the DFBX will experience a significant axial load. This load will be accommodated by the DFBX vessel support system.

4.5.3 PRESSURE RATING

The pressure ratings of the DFBX components are determined by the pressure rating of the QRL piping to which they are connected [8,9], as summarized in Table 4.5.3-1

Table 4.5.3-1 Pressure ratings of DFBX Components

	Nominal Pressure (bar)	Design Pressure (bar)	Test Pressure (bar)
Pumping Connections to Header B	0.016	4	5
Magnet Connections to Header C	3.6	20	25
Magnet Piping Connected to Header D	1.3	20	25
Thermal Shield Piping Connected to Headers E and F	19.5	22	27.5
LHe Chamber and Connections to HTS Leads	1.3	2.5	3.2

Thrust loads on the pressurized piping will be reacted via low heat leak supports to the vacuum vessel.

Appropriate means, such as internal liners or external sleeves to prevent bellows squirm will be provided.

4.6 THERMAL DESIGN

4.6.1 HEAT LOAD BUDGET

The estimated heat load budgeted for the DFBX is given in Table 4.6.1-1.

The major assumptions used in preparing the estimates in these Tables are:

- Current leads per Table 4.3.1-1,
- A 316LN cold bore tube,78/74 mm, with thermal anchors at 50 K and 4 K for the DFBX at Points 1 and 5,
- 304L lead chimneys, 150/146 mm,
- Instrumentation wiring per Table 4.3.2-1, Preliminary DFBX Wire List,
- Heating due to longitudinal impedance and image currents are 1/3 of Yellow Book [10] value for MB magnet (rough scaling by length),

- Heat deposition due to collision products per [11],
- Thermal radiation values per QRL specification [8]; 1W/m^2 to thermal shield for 30 layers MLI and 0.05 W/m^2 to 4 K surface for 10 layers MLI,
- Contingency of 25% on heat loads, no contingency on mass flows,
- No estimate of heat flow due to CERN-supplied beam screen is included, and
- No estimate of heating due to electron cloud effects is included.

Detailed heat load calculations can be found in [12].

The Table shows that more cold helium gas will be generated by the DFBX at Points 1 and 5 than required for lead cooling. We estimate about 1.5 g/sec will flow back to Header D. In the case of the DFBX at Points 2 and 8, in standby about 1 g/sec will flow to Header D but in operation all boiloff will be required for current lead cooling.

Table 4.6.1-1 Heat Load Budget for A Single DFBX

	Heat Load, Watts to 50 K	Heat Load, Watts to 4.5 K	Heat Load, Watts to 1.9 K	Required HTS Lead Flow, g/sec	Required V.C. Lead Flow, g/sec	Excess Boiloff, g/sec
DFBX at IP1 or IP5 (Standby)	400	81	5	1.3	0.2	1.7
DFBX at IP1 or IP5 (Operation)	400	103	9	2.2	0.3	1.6
DFBX at IP2 or IP8 (Standby)	396	81	7	1.9	0.2	1.1
DFBX at IP2 or IP8 (Operation)	396	91	10	3.2	0.3	0.0

4.6.2 THERMAL MOTION

The DFBX design shall accommodate thermal expansion of the components and hold the component stresses to safe levels. Bellows and expansion loops in piping and bus bars will be required to accommodate the thermal contraction in a safe manner.

The center of the helium chamber will be fixed to the vacuum vessel with structural members having low thermal conductivity.

Table 4.6.2-1 lists the temperature ranges to be considered. Thermal motion from neighboring cryogenic elements and how the motion is to be accommodated shall be developed and agreed upon in the Interface Specifications.

Table 4.6.2-1 Operating Temperature Ranges

Element	Operation
Vacuum vessel	288 K to 298 K
Thermal shields	60 K to 75 K
Helium Chamber	4.5 K
D1 Piping	1.9 K
MQX Piping	1.9 K
Beam Tube	1.9 K at Q3 end 1.9 K at D1 end in IR2 & IR8 293 K at D1 end in IR1 & IR5

4.7 OPERATIONAL REQUIREMENTS

The following DFBX operational requirements are consistent with LHC machine parameters [13] and QRL requirements [8].

- The design operating lifetime of the DFBX is 20 years.
- The number of thermal cycles between room and operating temperature is 50.
- The guaranteed fatigue life of bellows must be 1000 cycles.

5. DESIGN CONSTRAINTS

5.1 MAGNET COMMONALITY

The DFBX design shall allow the use of a common IR magnet design, such that any triplet or superconducting D1 can be positioned at any interaction region location without extensive rework to the magnet or the DFBX.

5.2 TUNNEL CONSTRAINTS

CERN layout drawings were used to create Figures 5.2-1 through 5.2-7, which show the position and tunnel environment of the DFBX. Note that these figures are based on optics version 5.0 and are being reviewed for optics version 6.1; no significant change is expected for the 6.1 optics.

The most restrictive location is for IP5, where the DFBX is partially located in the 3.8-m diameter tunnel adjacent to RZ54 on the left-hand side and UJ56 on the right hand side. The next most restrictive location is for IP8 where the DFBX on the left side is located entirely in a 4.4-m diameter tunnel. The remaining DFBX locations are in large diameter galleries.

Note that the CERN drawings indicate fictitious DFBX cryostats; the drawings will be updated to reflect the actual DFBX cryostats in the Interface Specification.

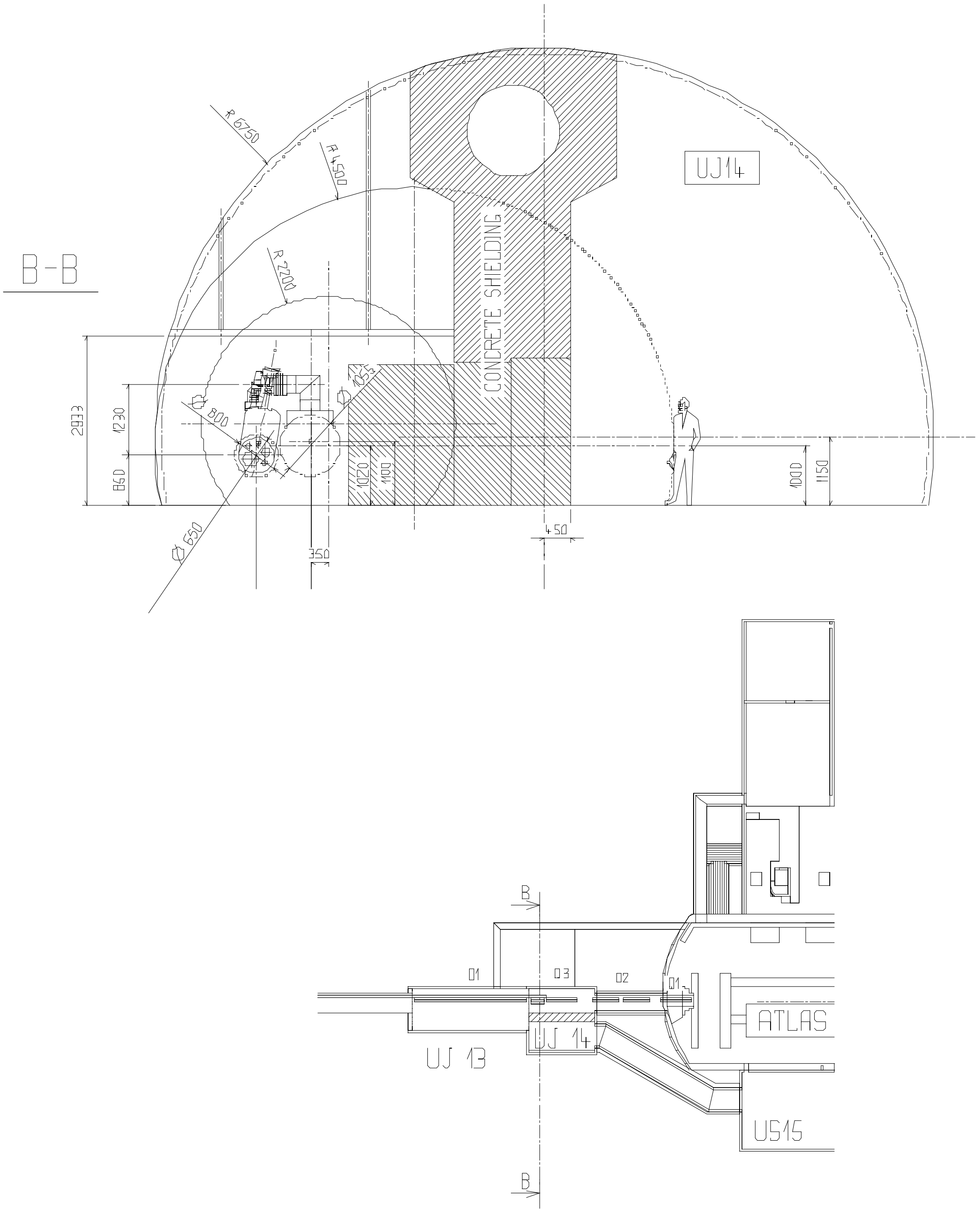

Figure 5.2-1, DFBX location at Point 1 – Left (from [14])

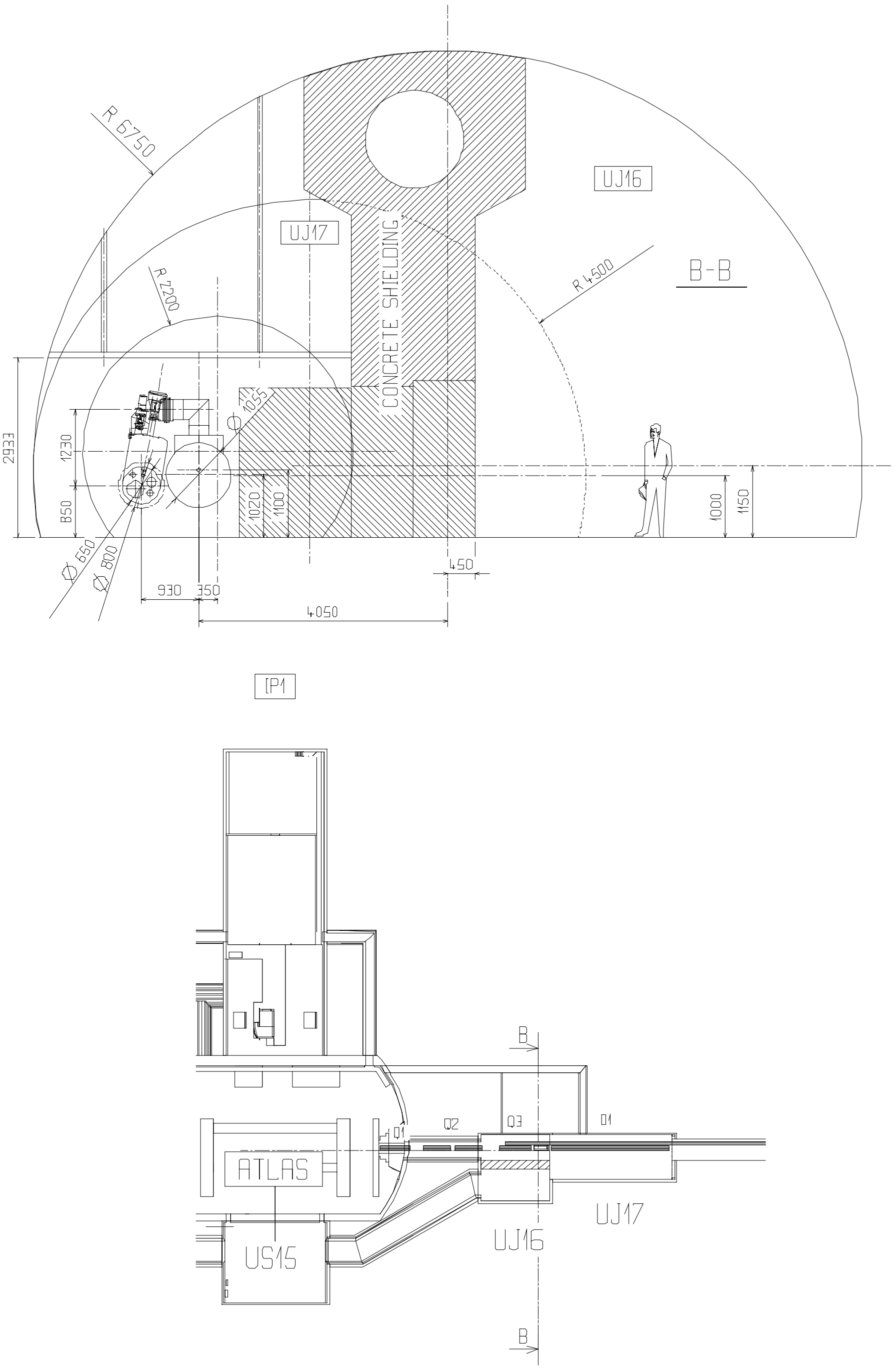

Figure 5.2-2, DFBX location at Point 1 – Right (from [15])

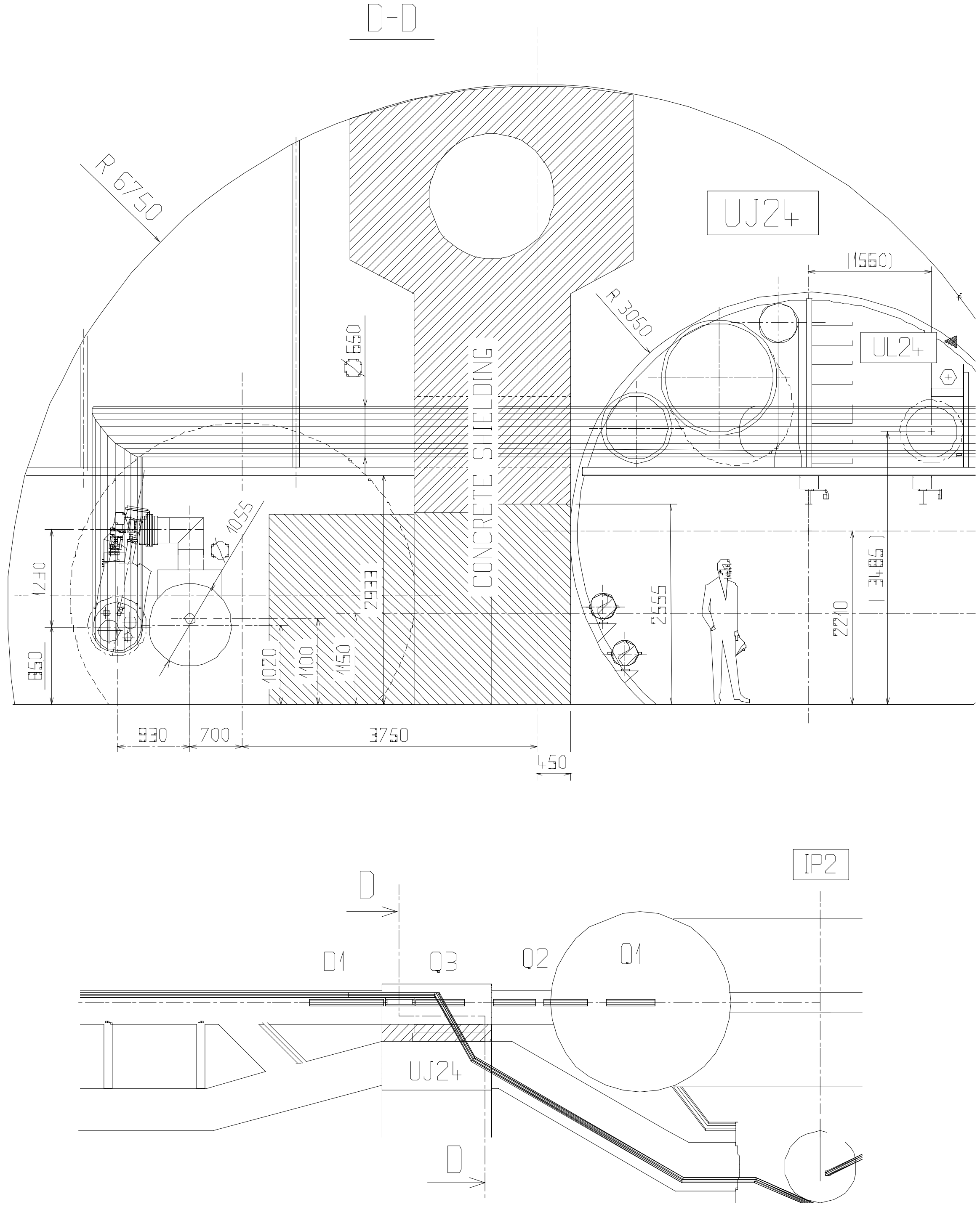

Figure 5.2-3, DFBX location at Point 2 – Left (from [16])

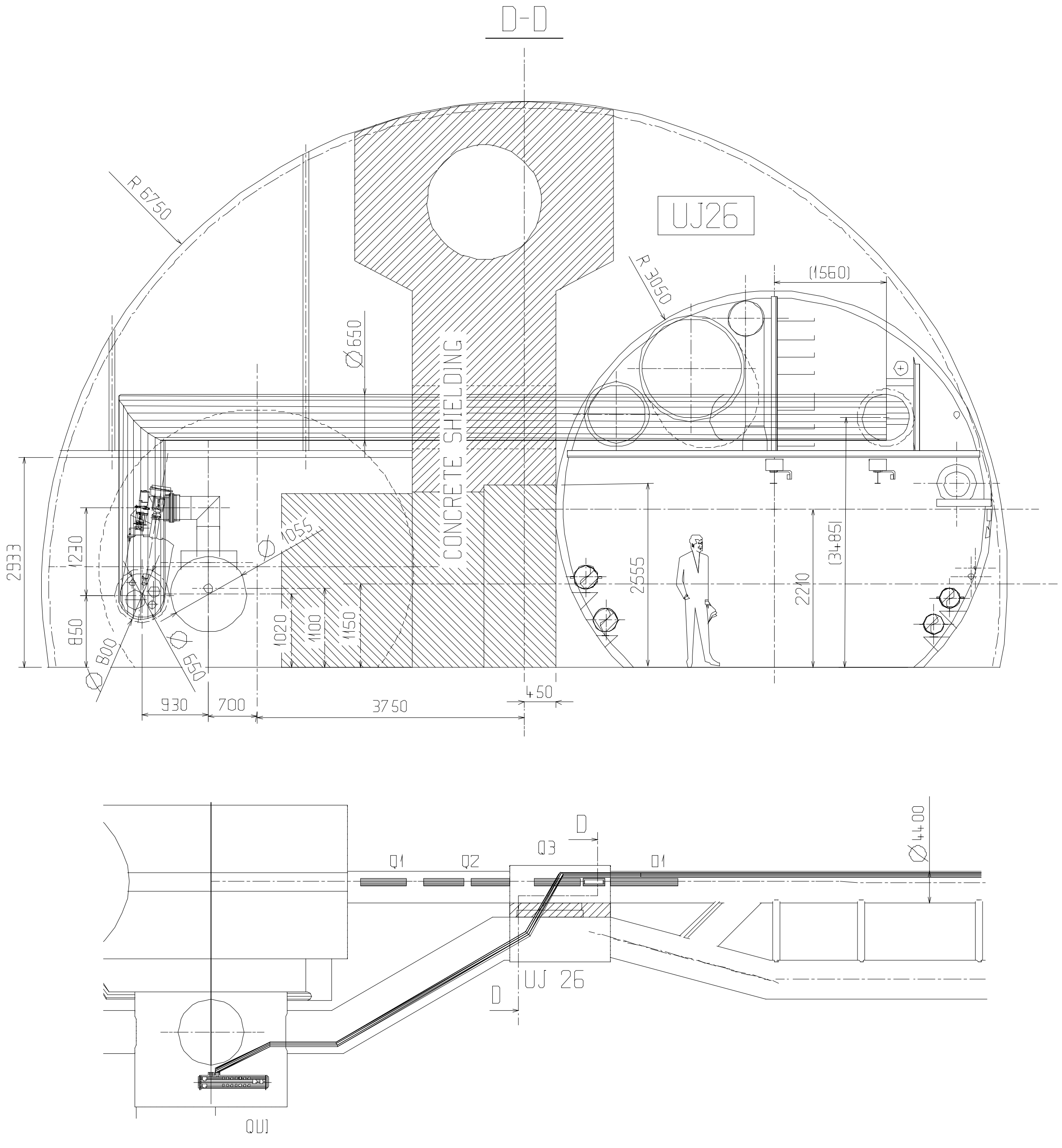

Figure 5.2-4, DFBX location at Point 2 – Right (from [17])

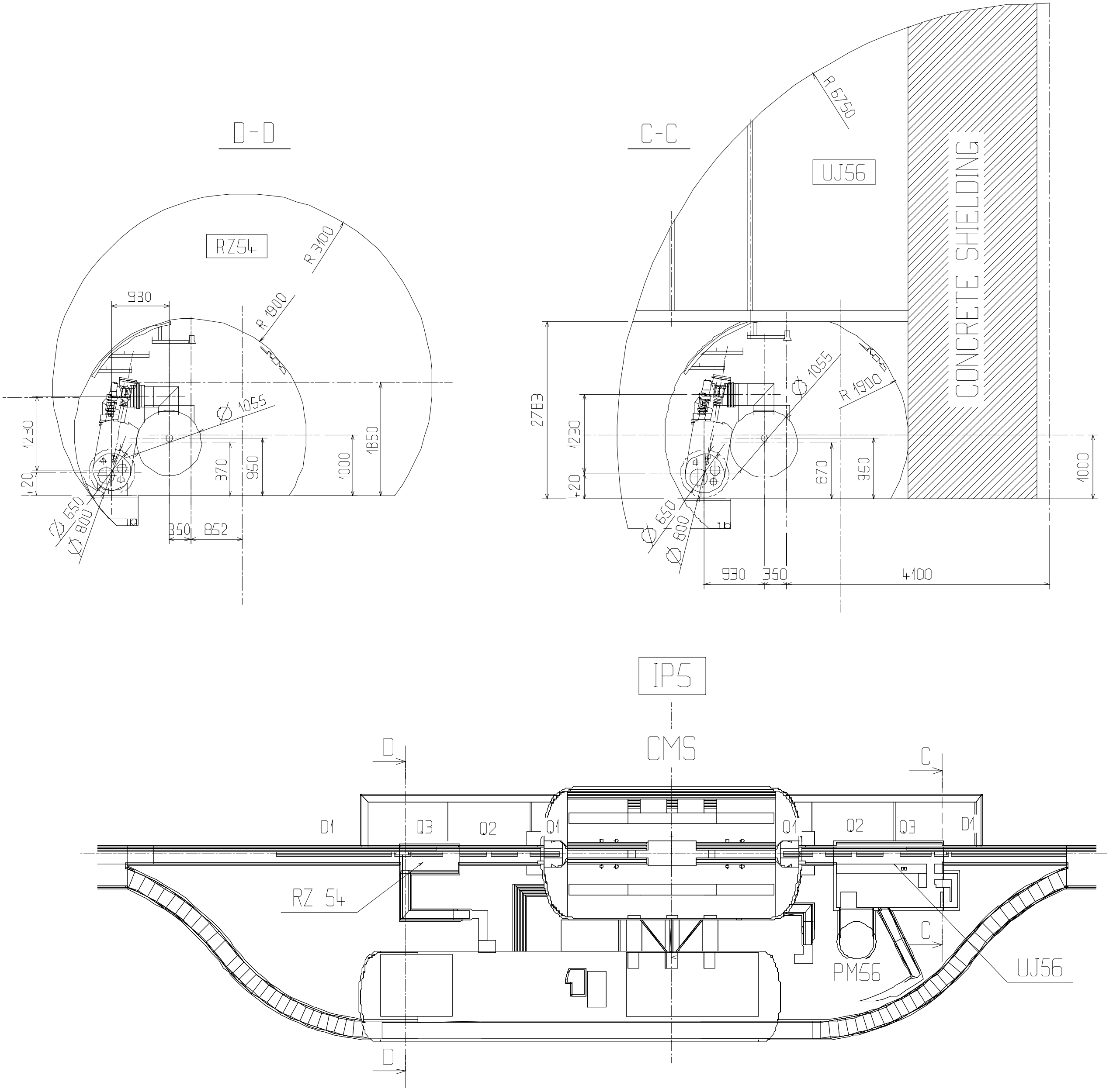

Figure 5.2-5, DFBX location at Point 5 (from [18(right), 19(left)])

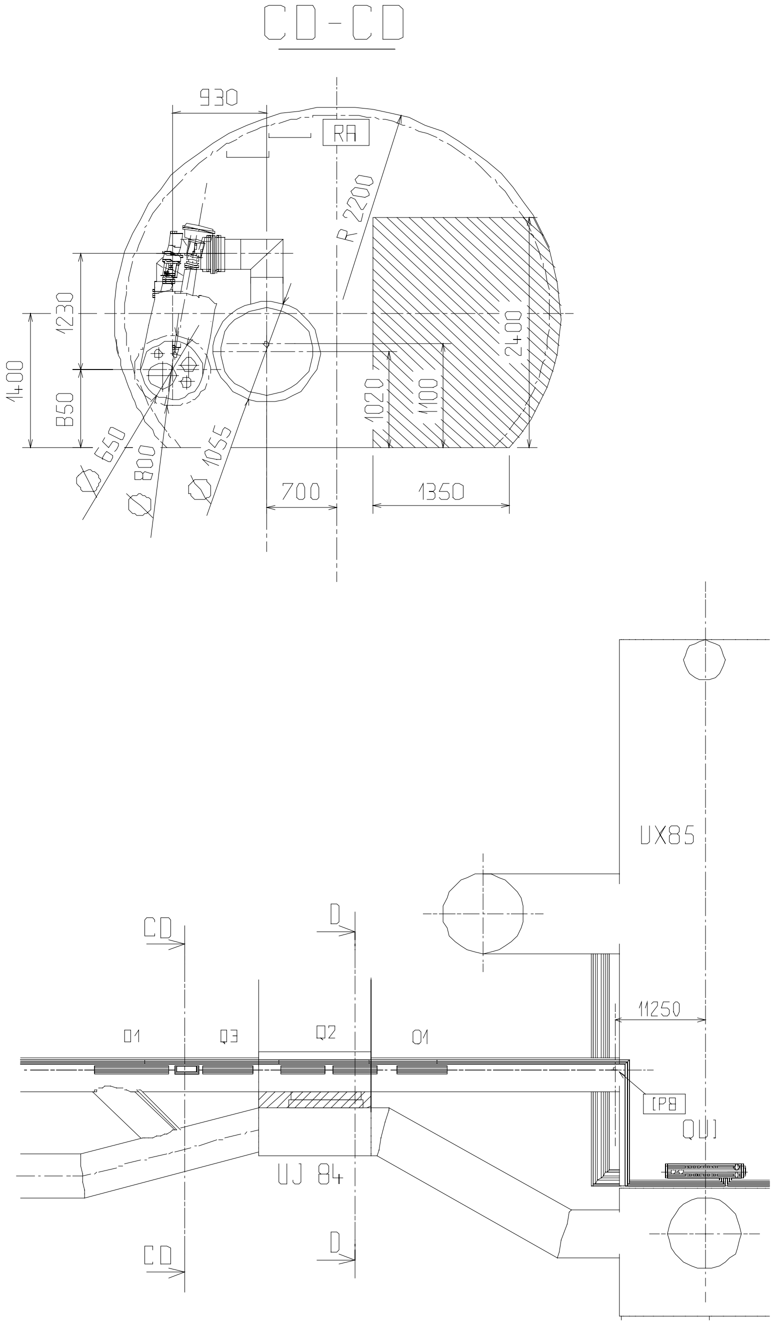

Figure 5.2-6, DFBX position at Point 8 – Left (from [20])

Note: The view CD-CD was created from [20] for this Functional Specification.

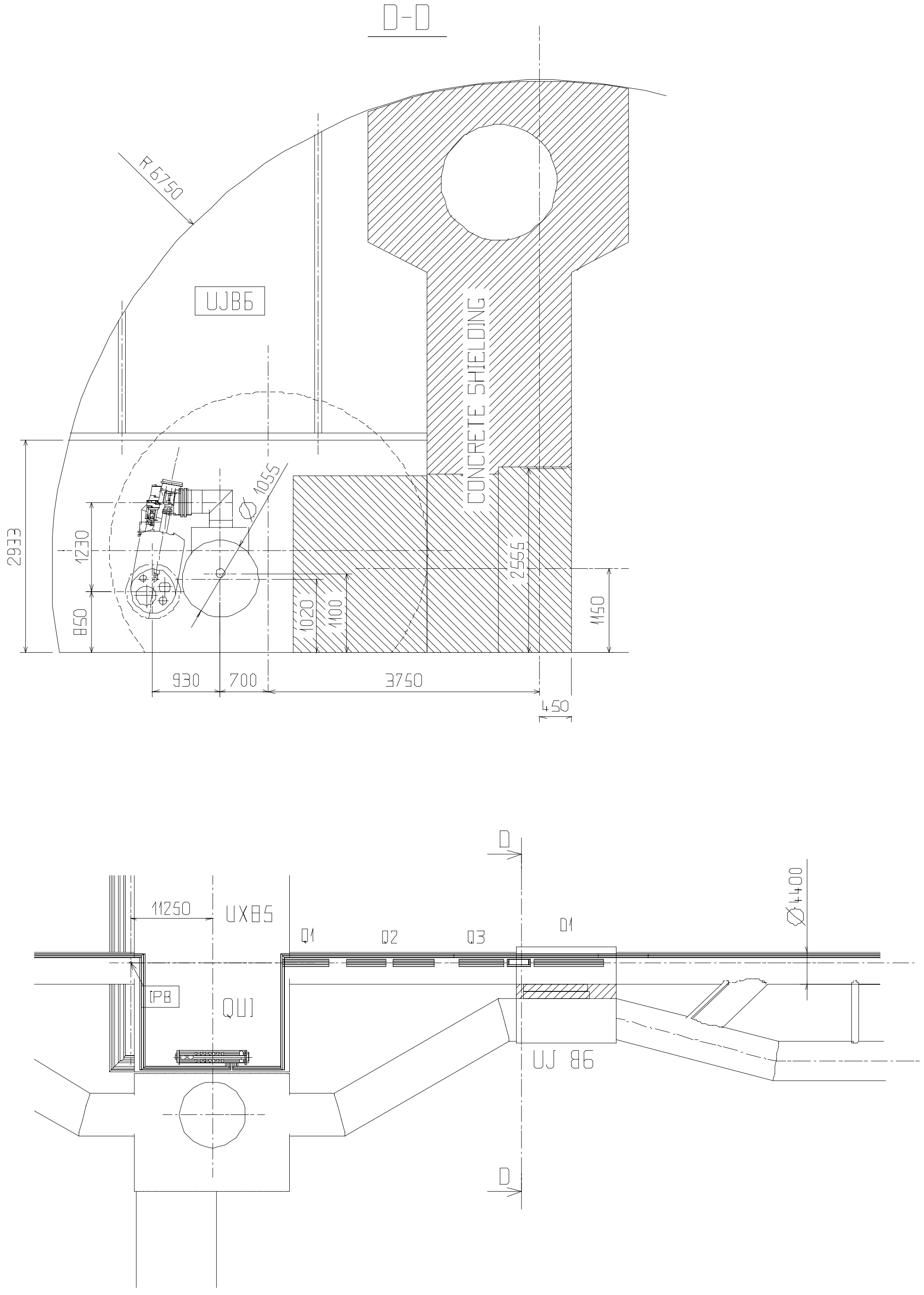

Figure 5.2-7, DFBX position at Point 8 – Right (from [21])

5.3 INSTALLATION

Because of limited access, the DFBX for IP5 left and right must be transported along the machine tunnel from access shafts at the neighboring IP’s [22]. Therefore, the DFBX must pass within the zone allocated for transport shown on Figure 5.3-1.

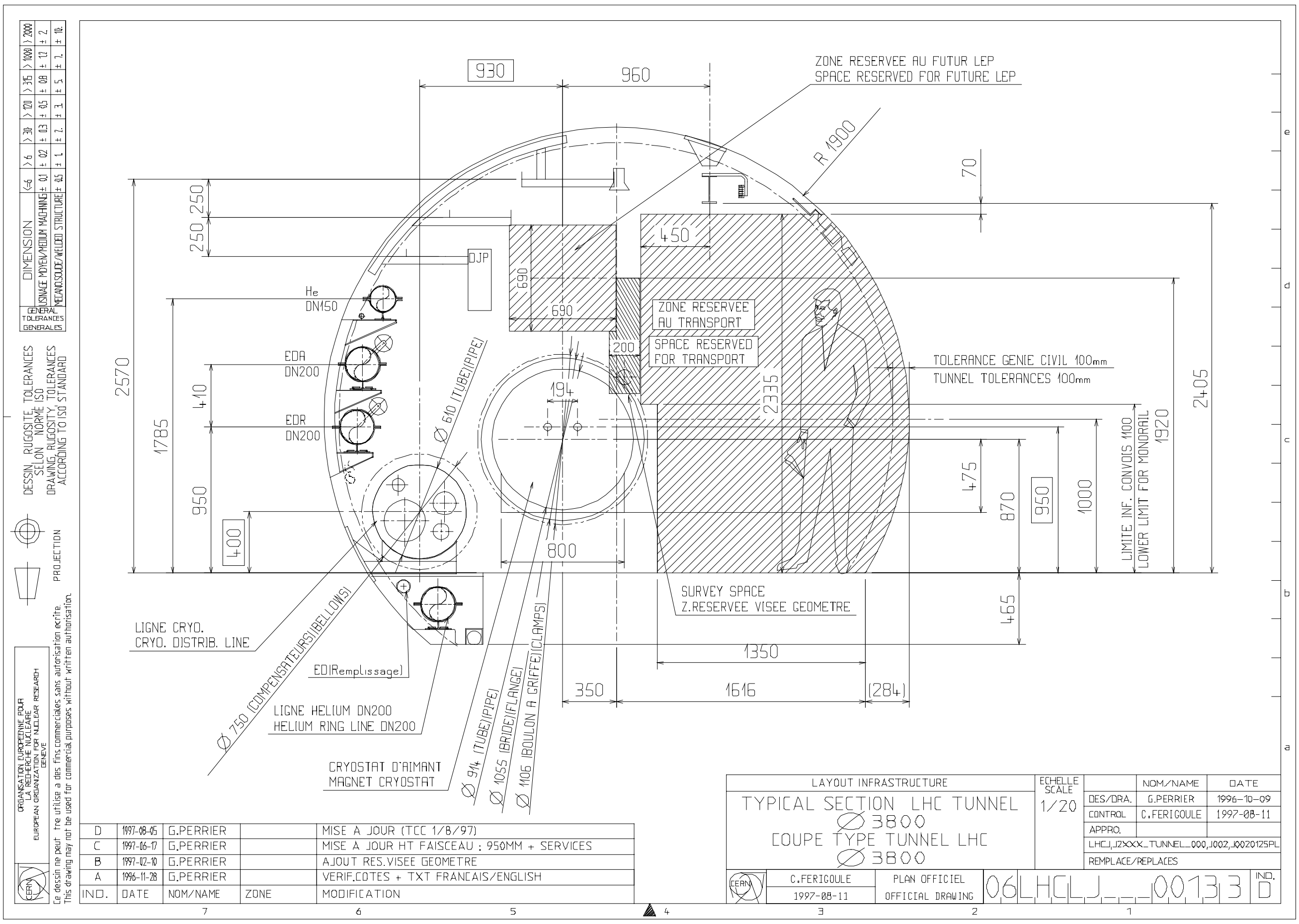

Figure 5.3-1, LHC Tunnel Section (LHCLJ__0013 rev D)

The DFBX must have features to allow safe installation by CERN personnel. This includes: lifting points for movement by a crane, protective covers over components that could be damaged during installation, attachment points or features for CERN rollers and connection features to allow CERN tractors to be utilized.

The DFBX must be supplied with all components needed for tunnel installation, such as bellows, flanges, seals, pipe and tube sections, etc.

5.4 CONNECTION TO THE CRYOGENIC DISTRIBUTION LINE

The connection of the DFBX cryogenic piping to the QRL shall be carried out using two jumpers, designated as QQSA and QQSB, having an appropriate outer diameter.

The center to center distance between the two jumpers shall be 1700 mm [8].

Each jumper shall contain a CERN-supplied vacuum barrier at the QRL, which separates the QRL insulating vacuum from that of the US-supplied hardware.

The exact arrangement and diameters of the piping in the jumpers will be arranged with CERN and specified in the Interface specification.

5.5 ALIGNMENT

The DFBX vacuum vessel will have features to allow installation of CERN-type holders for Taylor-Hobson spherical targets [23] and other CERN-required devices such as electronic levels. These features and their locations will be finalized in the Interface Specification.

The DFBX range of motion for alignment will be on the order of +/- 10 mm horizontal and vertical, as allowed by ISR jacks provided by CERN. A 3-point support will be used.

The beam tube supports, internal to the DFBX, will allow the beam tube to be supported at room temperature to allow connection to be made to the neighboring elements in a straightforward manner.

These supports will also incorporate compliant features that will allow the beam tube to readjust position transverse to the beam axis to follow the movement of the neighboring elements due to thermal motion or realignment without damage.

5.6 RADIATION

The effects of radiation on the DFBX at Points 1 and 5 have been calculated [11], with the following preliminary conclusions:

- The radiation dose rate at the DFBX vacuum vessel at Points 1 and 5 is expected to be 1.5 mGy/sec when the LHC is operated at the baseline luminosity of 10^{34} cm^{-2} s^{-1}. This places restrictions on the choice of polymeric and elastomeric materials for insulators and vacuum seals.

- The heat deposited into the DFBX beam tube at Points 1 and 5 is about 14 Watts when LHC is operated at the baseline luminosity of 10^{34} cm^{-2} s^{-1}. We assume that 75% of this will be deposited into the liquid helium chamber and the remainder into the 1.9 K magnet bath.

- The activation of the DFBX helium chamber and vacuum vessel is expected to be very slight and should not prevent *in situ* repairs on the DFBX which require cutting and welding.

5.7 HARDWARE

Only metric fasteners shall be used in the DFBX. Standard procedures for eliminating counterfeit materials will be employed.

6. RELIABILTY, AVAILABILITY, AND MAINTAINABILITY

The DFBX is critical to the operation of the LHC, since a failure of the DFBX will cause the inner triplet magnets at IP's 1,2,5, and 8 to shutdown, which in turn causes a shutdown of the LHC machine. The DFBX design is intended to offer continuous operation over the intended 20-year lifetime.

In order to allow the use of common-design magnets, Section 5.1, the eight DFBX are by and large unique and it is therefore not feasible to maintain spare DFBX's in inventory.

However, if unforeseen conditions require components to be repaired or replaced before the normal end of life, the design of the DFBX will allow this work to proceed in an expeditious manner.

The liquid helium level sensors, heaters, and thermometers in the DFBX 4.5 K liquid helium bath can be removed and replaced by simply pulling the defective ones out and putting new ones in. The elements will be machine-standard as far as possible.

For small, inexpensive items such as temperature sensors, heaters, etc that are accessible only with significant intervention, redundant elements with signal wires accessible at the vacuum vessel will be installed in order to cope rapidly with failures.

For larger, expensive items such as current leads, having redundant parts pre-installed in place are not possible and if a failure occurs, a major effort will be needed to correct the problem. In this case, the design will generally allow for removal and replacement without taking the DFBX out of the beamline.

For certain other items, such as bus bars and lambda plates a failure may require that the DFBX be moved out of the beamline and into a shop where the repairs can be made. Under conditions such as these, the DFBX can be moved out of the beamline using similar techniques and requiring about the same time and system disruption as removing one of the main ring dipoles.

7. SAFETY AND REGULATORY REQUIREMENTS

The DFBX must meet the safety guidelines put forward by the CERN Technical Inspection and Safety Commission (TIS). TIS have issued safety documents in compliance with LHC-PM-QA-100 rev1.1, and the guidelines in these documents will be incorporated into the DFBX design. For the DFBX, the relevant TIS safety documents are:

7.1 PRESSURE SAFETY

The DFBX design, fabrication, and test will comply with the Memorandum of Understanding between the US-LHC Accelerator Project and CERN [24].

7.2 LIFTING

The DFBX design, fabrication, and test will comply with the Memorandum of Understanding between the US-LHC Accelerator Project and CERN [24].

7.3 FIRE SAFETY AND RADIATION RESISTANCE

The DFBX will comply with CERN Safety Instruction IS 41, “The Use of Plastic and other Non-Metallic Materials at CERN with respect to Fire Safety and Radiation Resistance”, March 1995.

8. DESIGN CALCULATIONS

The following calculations will be carried out during the design of the DFBX.

1. Finite element calculations to verify integrity of the DFBX outer vacuum vessel.
2. MARS calculations of radiation effects such as dose, energy deposition, and activation of DFBX components.
3. Calculations to verify pressure safety of the DFBX piping, bellows and helium chamber.
4. Finite element calculations to verify pressure integrity of the lambda plate.
5. Calculations to predict heat loads due to the DFBX.
6. Prediction of the effect of loads due to transportation g-forces.

9. TEST AND QA

9.1 COMPONENT TESTING

Tests shall be carried out on certain prototype components to verify the design is suitable for use in the DFBX. The list of components and purpose of the test include:

Component	Purpose of Test
Lambda Plate	Thermal cycling, pressure capability
Conduction cooled leads	Thermal Cycling, Heat Load to 50 K, Hi-Pot Test

9.2 IN-PROCESS TESTING

Tests shall be carried out on fabricated components to verify proper fabrication. The list of tests and their purpose include:

Test	Purpose
Material Testing	Check properties for low temperature use
Weld/Welder Qualification Tests	Make sure weld processes, materials, and personnel are suitable
Electrical & Mechanical Tests	Make sure fabrication and assembly is proceeding properly

9.3 FINAL TESTING

The DFBX will undergo final tests at LBNL before they are shipped to CERN. The tests will verify that they are properly fabricated and can be installed into the LHC. The testing will include:

Electrical continuity of instrumentation wires and bus bars
High potential tests to ground,
Leak-tightness of the insulating vacuum,
Pressure testing of the internal components at room temperature,
LHe boiloff rates of the helium chambers,
Full-current tests of the current leads

10. MARKING, SHIPPING, AND DOCUMENTATION

10.1 MARKING

Each DFBX will be marked with its intended position in the LHC machine. The current leads will be clearly labeled with the element to which they connect, and the instrumentation receptacles will be labeled to correlate with the electrical schematics.

10.2 SHIPPING

The DFBX will be shipped as complete, tested units to CERN. Shipment dates will be co-ordinated with CERN. The DFBX will be packaged for safe shipment to CERN, including protective bracing to prevent fatigue damage, seals on exposed tubes and pipes, protective covers on electrical connectors, and other methods to ensure an undamaged delivery.

10.3 DOCUMENTATION

Each DFBX will have a separate documentation package containing:

- Assembly and detail part drawings (in hard version and HPGL)
- Mechanical interface drawings (in hard version and HPGL)
- Electrical and cryogenic schematics (in hard version and HPGL)
- Fabrication and Test Documentation (in hard version and electronic)
- Certificate of Compliance (in hard version and electronic)

11. REFERENCES

1. The following Study Drawings of the Insertion Region Working Group were used:
"IR1 Left, Cells C1.L1 to C7.L1", LHC Drawing LHCLSX_0001 rev. B,
"IR1 Right, Cells C1.R1 to C7.R1", LHC Drawing LHCLSX_0002 rev. B,
"IR2 Left, Cells C1.L2 to C7.L2", LHC Drawing LHCLSX_0003 rev. B,
"IR2 Right, Cells C1.R2 to C7.R2", LHC Drawing LHCLSX_0004 rev. B,
"IR5 Left, Cells C1.L5 to C7.L5", LHC Drawing LHCLSX_0009 rev. B,
"IR5 Right, Cells C1.R5 to C7.R5", LHC Drawing LHCLSX_0010 rev. B,
"IR8 Left, Cells C1.L8 to C7.L8", LHC Drawing LHCLSX_0015 rev.B, and
"IR8 Right, Cells C1.R8 to C7.R8", LHC Drawing LHCLSX_0016 rev. B

2. Minutes of the LHC Technical Committee, 4 May 1999.

3. "Report of DFBX-Conceptual Design Review Conducted on 2 December 1998", issued by US-LHC Accelerator Project Office on 21 January 1999.

4. Jie Wie, "Summary View Graphs of Workshop on LHC Interaction Region Correction Systems", 7 May 1999.

5. LHC Engineering Specification, "Voltage Withstand Levels for Electrical Insulation Tests on Components and Bus Bar Cross Sections for the Different LHC Machine Circuits", LHC-PM-ES-0001.00 rev. 1.0, 17 May, 1999.

6. R. VanWeelderen, e-mail message dated 5 February 1998.

7. Brookhaven National Laboratory Specification, "LHC D1 Dipole Magnet Beam Tube Material", LHC-MAG-M-1016.

8. LHC Technical Specification, "Technical Specification for a Compound Cryogenic Helium Distribution Line for the Large Hadron Collider (LHC)", IT-2399/LHC/LHC, December 1997.

9. LHC Eng Spec, "Dimensions, Pressures, Temperatures, and Sizing of Valves and Piping in the LHC Machine Cryostat and Cryogenic Distribution Line", LHC-Q-ES-0001.00 rev 1.0.

10. "The Large Hadron Collider – Conceptual Design", CERN/AC/95-05, October 1995.

11. Nikolai Mokhov, work in progress, preliminary information received on 14 January 1999.

12. LBNL Engineering Note, "Heat Loads in LHC IR Feedboxes", in preparation.

13. LHC Eng Spec, "General Parameters For Equipment Installed in the LHC", LHC-PM-ES-0002.

14. "QRL Schematic Layout Point 1_Left Side", LHC Drawing LHCLJ1GQ0001 rev. B.

15. "QRL Schematic Layout Point 1_Right Side", LHC Drawing LHCLJ1GQ0002 rev. B.

16. "QRL Schematic Layout Point 2_Left Side", LHC Drawing LHCLJ2GQ0001 rev. B.

17. "QRL Schematic Layout Point 2_Right Side", LHC Drawing LHCLJ2GQ0002 rev. B.

18. "QRL Schematic Layout Point 5_Left Side", LHC Drawing LHCLJ5GQ0001 rev. B.

19. "QRL Schematic Layout Point 5_Right Side", LHC Drawing LHCLJ5GQ0002 rev. B.

20. "QRL Schematic Layout Point 8_Left Side", LHC Drawing LHCLJ8GQ0001 rev. B.

21. "QRL Schematic Layout Point 8_Right Side", LHC Drawing LHCLJ8GQ0002 rev. B.

22. Claude Ferigoule, private communication, 1 September 1998.

23. "Reference Socket Assembly", LHC Drawing LHCGIMSA0001 rev. A

24. CERN/LHC-US/LHC MOU on Accelerator Mechanical Safety, TIS-TE-MB-98-74, 14 December 1998.