BNL LHC PROGRAM

Brookhaven National Laboratory

Configurations of BNL-Built LHC Dipole Magnets

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Configurations of BNL-Built LHC Dipole Magnets

GENERAL: BNL will produce 26 ten meter long dipole magnets for the LHC Project, including spares. All the magnets are constructed using 8cm RHIC coils in their present, proven design configuration. The quantities of shippable magnets that BNL will produce is detailed below:

D1: 4 (+1 spare)
D2: 8 (+1 spare)
D3a: 2 (+1 spare)
D3b: 2 (+1 spare)
D4a: 2 (+1 spare)
D4b: 2 (+1 spare)

The construction of D2 and D4a/b are nearly alike. They use two collared coils in one steel yoke contained in a stainless steel shell (2-in-1 cold mass). The yoke is slightly wider than it is high, giving an oblate shape to the cold mass. There is one such cold mass in a cryostatted magnet assembly. Two required beam spacings for D4 magnets give rise to the "a" and "b" versions. The spacings are 232mm and 194mm respectively (at 4K). The D2 spacing is 188mm. The cryostat for D2 and D4 is 914mm (36 in) in diameter, a copy of the CERN cryostat cross section.

D1 and D3a/b are similar in construction yet have distinct differences. Both use 8cm RHIC 1-in-1 cold masses (but without sagitta), which employ the stressed yoke design as a collar rather than separate collared coils. The D3s are constructed using two such cold masses side by side on a common support cradle. The two D3 cold masses fit within the same 914mm cryostat as used for D2 and D4. As with D4, two required beam spacings for D3 magnets give rise to the "a" and "b" versions (420mm and 382mm respectively, at 4K). Magnet D1 on the other hand is a single cold mass in a smaller 610mm (24 in) cryostat, the identical design used for the RHIC arc dipoles. Figure 1 is a summary table of the preceding parameters, including some additional detail.

The following written descriptions are intended to be used in conjunction with the four LHC magnet cross sections for D1, D2, D3, and D4 (Figures 2 through 5) as well as with the longitudinal section sketches of the cold masses in their respective cryostats (Figures 6 through 11). The longitudinal sections show the piping required inside the cryostat for each magnet in each ring position, with the top of the cryostat removed in each case for clarity. Lower case letters are used to label the pipes and tubes that BNL has designed into the system, and these letters correspond (where applicable) to the header pipes labeled in upper case letters on the CERN cryogenic flow diagrams, to which the magnet piping eventually connects. These sections also show the tubing stubs protruding from the end volumes of the cold mass. Tubing stubs are needed to admit liquid helium, vent gaseous helium, and convey buses through liquid helium to the source of electrical power. The sizes of the various tubing stubs for each magnet type are shown in Figure 12.

Figures 13 through 16 are schematic diagrams. Labeling of the magnet terminals follows the convention specified in document LHC-DC-ES-0001.00 rev 1.1 dated 1999-04-27. Figures 14, 15, and 16 show how each magnet bore of the twin bore magnets (D2, D3, D4) will be powered and how the buswork must interface with the source of power for that particular magnet type. Since D1 is a single bore magnet, its

schematic is much simpler. While these schematics do not include the instrumentation that must interface to adjacent magnets or elements being constructed by CERN or others, they show the basic assumptions that drive the electro-mechanical design inside the end volumes of the BNL-built magnets.

A center tap is required on the D2, D3, and D4 magnets. In D2 magnets, this will allow up to a ~15% difference in field between the two apertures during injection. In D3 and D4 magnets, the center tap will be used to equalize the field in the two apertures. The two points of connection for each center tap are shown on the schematics.

<u>D1</u>**:** Four D1 magnets will be built, plus one spare. The installation locations are IP2L, IP2R, IP8L, and IP8R. As viewed from the lead end of the magnet, the construction of each of the five assemblies is identical regardless of location so that the spare magnet can be used in any of the four locations. The lead end of the cold mass always faces toward the IP and connects to the LBL-supplied DFBX. Since the piping within the cryostat is not symmetric left to right, each DFBX will be custom designed to mate properly with its D1 magnet assembly. D1 magnets operate at 1.9K using superfluid helium.

Coming out of the cold mass end volumes are four tubing stubs, two at each end, labeled c or m/c, and cy. Stubs labeled c and m/c are used to admit liquid helium into the cold mass. The c stubs are 1.00 inch outside diameter (OD) and the m/c stubs are 2.50 inch OD where they enter the face of the end volume. The D1 powering bus exits the end volume through the m/c stub shown at the lead end (m indicates magnet bus). The cy stubs represent the 1.9K heat exchanger tube and its internal tube which are used to further cool the helium in the magnet yoke down to operating temperature. The sizes of these are 28.6mm and 12mm respectively. Two heat exchanger tubes (with their internal tubes) are installed within the magnet yoke. They are brought together within the end volume. A single 2.00 inch OD tube exits the end volume to enter the phase separator.

Phase separators are shown outside each end volume. Only one is used in a particular installation; the other allows installation in any of the four needed locations. The phase separators will be physically located below the cold mass.

There will be two temperature sensors located within the cold mass on or near the outside of the yoke of D1 magnets. One of these is a redundant sensor. The wires for these are brought out the m/c stub along with the bus.

Shown within the cryostat are pipes labeled c, c' (c prime), cy, xb, e_1, and e_2. Pipe c is used to fill the cold mass with 4.5K helium, which is later cooled further via the heat exchanger tube. Pipe c' is used to supply helium to the beam screens which will be installed after the magnet is shipped to CERN. Pipe cy is used only in "right side of the IP" installations to supply 1.9K helium to the heat exchanger tube because the uphill end is not facing the DFBX at these locations. Pipe xb vents helium from the phase separator and is used only in "left side of the IP" installations because the downhill end is not facing the DFBX at these locations. Pipes c, cy, and xb are connected to the correspondingly labeled tubing stubs at the end volumes and phase separators, or remain unconnected, as indicated for each particular installation. The connection is made at CERN using "field-added" components (marked FA in the figures) supplied by BNL. The c and xb pipes are 2.875 inches OD. Where the sizes between the pipes and the tubing stubs differ, reducers will be used at the ends of these piping runs. Pipes e_1 and e_2 are the shield supply and return pipes. Helium at 55K enters through e_1 and exits through e_2. One pipe (not necessarily e_1) is thermally connected to the heat shield via aluminum sleeves. The other is thermally isolated from the heat shield. The thermally connected pipe is 2.375 OD; the isolated pipe is 2.875 OD. A 180 turn-around with reducer joins these two pipes at the non-lead end.

To install D1 magnets, connections between the DFBX and the magnet lead end will be made to the beam tube, the bus tube stub (m/c), its powering bus and instrumentation, the cold mass supply pipe (c), the beam screen pipe (c'), the heat shield supply and return pipes (e_1 and e_2), and the heat shield, multi-layer insulation (MLI) blankets, and cryostat. In addition, the 1.9K helium supply stub (cy) and the vent tube stub (xb) must either be connected or capped as indicated (shown by a T)at each end, and the 1.9K supply (cy) and vent pipes (xb) either connected or left open, depending on right or left side installation. Connections are done prior to ring installation once the specific location is known. A bus/flex joint assembly of BNL design will be used in the lead end volume for expansion/contraction of the powering bus connected to the DFBX. At the non-lead end the beam tube will be connected to a cold-to-warm transition (CWT) supplied by CERN. No other connections are known to be needed at the non-lead end, except to cap the heat shield, MLI blankets, and cryostat.

D2: There will be eight D2 magnets plus one spare built by BNL. The installation locations for these D2s are IP1L, IP1R, IP5L, IP5R, IP2L, IP2R, IP8L, and IP8R. As installed in the LHC ring, the configurations of the eight assemblies are similar in construction but not identical. The differences are a result of variations in tunnel slope direction and cryogenic connection to adjacent magnet Q4, which taken together form a cryogenic module. In order to be able to have one spare replace any of the D2 magnet assemblies, differences between the magnets must be slight and easily accommodated by minor modifications to the spare. This is accomplished through the use of some redundant piping within the cryostat and by specific field-added components (FA) which are added to the spare by CERN prior to tunnel installation. In addition, some of the magnet assemblies as manufactured at BNL will require these same minor modifications and FA components depending upon the installation location. Using this approach allows an economical manufacture of nine identical D2 units.

As shown in Figure 7, the lead end of the cold mass always faces away from the IP and connects to the CERN-supplied Q4 magnet. Each Q4 assembly can be the same and still mate properly with the D2 as a result of the field-added components mentioned above (however, Q4s may still be different based on other CERN requirements). D2 magnets operate at 4.5K in two-phase helium.

Coming out of the cold mass end volumes there are four tubing stubs, two at each end, labeled c_1, c_2, d, and m/c. There is also an additional stub at the lead end labeled t used only for cold testing at BNL. Stubs labeled c_1 or c_2 are used to admit liquid helium into the cold mass either in cooldown mode (c_1) or steady state mode (c_2); stubs labeled d are used as vents which return helium gas (which has collected in the top of the end volume) to the cryogenic system, sometimes via Q4. The m/c stub at the lead end provides a tube for the D2 powering bus and instrumentation leads to connect to Q4 as well as for the liquid helium in the two adjacent magnets to freely communicate during fill and steady state conditions. The size of the c stubs on the non-lead end is 1.00 inch OD. The size of the d stubs at the lead end is 1.50 inches OD, and at the non-lead end is 2.00 inches OD, based on the different venting requirements of the D2 magnet and the cryogenically connected Q4 magnet. The c and d stubs connect to the cylindrical portion of the end volume; this is indicated by showing the line representing them extending over the top of the cold mass. The m/c stub size is 2.50 inches and it emanates from the face of the end volume, near the bottom. This is indicated by showing the line representing it beginning at the end of the cold mass.

Shown in the figure are the field-added components for each installation location. Tubing caps are welded to unused d stubs to maintain cold mass integrity, and are shown as a T.

Level gauges to provide feedback for the helium fill valves are provided in the end volumes. At least one is required in the non-lead end volume. Two in this end volume provides redundancy; this is the current plan. There will also be a level gauge in the lead end volume for test stand use only. The wiring will come out the m/c stub at the lead end.

Connected to the non-lead end of D2 is a QQS Service Module. Helium is supplied to the D2/Q4 cryogenic module through the QQS. Although in detail the functionality of the left and right side modules are different, the internal plumbing will be configured the same for all so that complete interchangeability exists for all D2 magnets. This will require some pipes to be capped in specific installations. BNL is responsible for integrating the QQS into the construction of the D2 magnet, and shipping it as a unit. The D2 cryostat will therefore be somewhat different from the others in that the snout for the exiting QQS piping must be part of the cryostat design in order to keep the shipped length of the magnet below 40 feet. The cryostat in all other respects will look the same, with mechanical seals at its ends.

Shown within the cryostat are the pipes labeled e_1 and e_2. They are the shield supply pipes which are an integral part of the CERN-supplied heat shield extrusion. In cases where coolant flow is only passing through one pipe, it is simply labeled e. Because these pipes are integral to the aluminum extrusion, BNL is assuming that aluminum to stainless transitions will be required for the e pipes, and that CERN will specify an approved vendor.

To install D2 magnets, field added components are first attached by CERN as required for the appropriate destination in the ring. Lead end connections between Q4 and D2 consist of connecting the beam tube, the vent tube stub (d), the m/c tube stub and its powering bus and instrumentation within, installing the beam screen, connecting the heat shield supply and return pipes (e_1 and e_2), as well as the heat shield, MLI blankets, and cryostat. The t stub will be capped by BNL prior to shipping.

A bus/flex joint assembly of BNL design will be used in the lead end volume to accommodate expansion/contraction of the short powering bus connected to Q4. The electro-mechanical design inside the end volume will connect the two collared coils in series to the powering bus (see schematics). The circuit will also provide the center tap that allows trimming the current between the two collared coils.

Installation connections needed at the non-lead end are the beam tube, the helium supply and vent tube stubs (c_2 and d), the heat shield pipes (e_1, and e_2), and the heat shield, MLI blankets, QQS piping, and cryostat.

D3a: Two D3a magnets plus one spare will be built. The two D3a magnets are located in IP4L and IP4R. As installed in the LHC ring, the configurations of the two assemblies are similar in construction but not identical for the same reasons as created this condition for D2; tunnel slope and spare considerations. BNL will produce three identical units which operate at 4.5K. As shown in Figure 8, the lead end of each cold mass (two per D3a assembly) always faces away from the IP and connects to the BNL-built D3b magnet. The field-added components make feasible the universal installation and the necessity for only one spare assembly.

Since the two cold masses in each D3a assembly are identical, describing the details of one will suffice for both. Coming out of the cold mass end volumes there are four tubing stubs, two at each end, labeled c_1, c_2, c_3, or c_4; d, d_1, or d_2; and m/c. Subscripted c stubs all perform the same function as before, to admit liquid helium into the cold mass; the subscripts keep track of each stub. Similarly, stubs labeled d, d_1, or d_2 are used as vents. As before, the m/c stub at the lead end provides a connection tube for the powering bus, instrumentation leads, and liquid helium. The c stubs are 1.00 inch OD regardless of subscript. At the lead end the d stub is 1.50 inches OD; at the non-lead end the d_1 and d_2 stubs are 2.00 inches OD. The m/c stub size is 2.50 inches.

Level gauges to provide feedback for the helium fill valves are provided in the end volumes. At least one is required in each end volume to provide for interchangeability. Two in each end volume provides redundancy; this is the current plan. The wiring will come out the m/c stub at the lead end.

Shown within the cryostat are the pipes labeled c_1 and c_3, c' (c prime), and e. Each c_1 and c_3 pipe supplies helium to its own cold mass so that the fill level of each cold mass can be independently controlled. Pipe e is the shield supply pipe integral to the heat shield extrusion. Pipe c' is used to intercept heat at the support posts as well as to supply helium to the beam screens. Note that the beam screen is installed at CERN in every case, with turn-arounds connected to it in half the cases. The other field-added components shown, consisting of caps and 180 turn-arounds, are as previously described.

Connections at installation are as before: field added components are attached first, then lead end and non-lead end connections are made to the adjacent magnets.

A bus flex joint assembly will be used in each lead end volume to absorb the expansion and contraction of the powering buses within D3b, to which D3a is connected. Referring to the electrical schematic, note that the electro-mechanical design inside the end volume will connect the collared coil assembly in each bore to its respective bus from D3b. The series connection of the two bores in D3a is done within the DFBA. The center tap, which allows trimming the current between the two cold masses, is also within the DFBA and is therefore CERN-designed and supplied.

D3b: Two D3b magnets plus one spare will be built, located between the D3a and the DFBA in IP4L and IP4R. As with the other magnets, field-added components allow BNL to produce three identical units including the universal spare. As shown in Figure 9, the lead end of the cold mass always faces away from the IP and connects to the CERN-supplied DFBA. These magnets operate at 4.5K.

The arrangement, function, and sizing of the cold mass stubs is the same as for D3a. Two level gauges in each end volume will be provided. Their wiring will come out the m stub at the lead end.

The piping within the cryostat is the same as described before for D3a.
Connections at installation are as before: field added components are attached first, then lead end and non-lead end connections are made to the adjacent magnets.

A bus flex joint assembly will be used in each lead end volume to absorb the expansion/contraction of the leads powering D3b. Note that there is a bus provided in each D3b cold mass to supply power to D3a as mentioned above.

D4a: Because the D4 magnets carry the supply of 1.9K helium and electrical power to the LHC arcs, they have the most penetrations connecting to adjacent magnets of the four magnet types BNL will build.

Two D4a magnets plus one spare will be built, located between the D4b and the DFBA in IP4L and IP4R. As with the other magnets, symmetric construction allows BNL to produce three identical units including the universal spare. As shown in Figure 10, the lead end of the cold mass always faces toward the IP and connects to the CERN-supplied DFBA and the QQS Technical Service Module. D4 magnets operate at 1.9K.
At the lead end volume there are stubs labeled M_1, M_2, and M_3, 1.9K, and m/c. The stubs M_1, M_2, and M_3 are positioned exactly as on the LHC dipole end covers: 145mm above and below the horizontal midplane, and 140mm and 145mm to either side of the vertical midplane. These stubs are present to convey the two quadrupole buses (stubs M_1 and M_2) and the dipole bus (M_3) from the DFBA through the D4a (and D4b) to the Q7 magnet and beyond. In order to provide symmetry and allow a universal spare, a redundant second dipole bus slot is available in the yoke so that there are actually two M_3 tube stubs. One of these stubs will get capped off prior to installation of the magnet in the tunnel, and its bus is unused.

The stub labeled 1.9K represents the 1.9K heat exchanger tube assembly and is located on the vertical centerline 180mm above the horizontal midplane. The m/c stub functions as previously explained for D3a. The non-lead end stubs perform the same functions as given before on the other magnets.

The sizes of the stubs are: M_1, M_2, and M_3=80mm; 1.9K=58mm with 12mm OD tube within; m/c=2.50 inches.

There will be two temperature sensors located within the cold mass on or near the outside of the yoke of D4a magnets. One of these is a redundant sensor. The wires for these are brought out the m/c stub along with the bus.

Connected to the lead end of D4a is a QQS Service Module. Helium is supplied to the magnet system through the QQS module. The left and right side modules are different because 1.9K helium on the left side is supplied through the QQS into D4a, but on the right side 1.9K helium must enter at the extreme end of the standard LHC cell due to the tunnel slope. The D4a cryostat will employ mechanical seals at its ends; the QQS module will be attached to the one at the lead end by CERN personnel. The bus and cryogenic pipes will be supplied at lengths which still allow shipping within a standard 40 foot container. In some cases components might need to be extended upon magnet receipt.

The piping within the cryostat is labeled e, N, and c'. N is the pipe for the auxiliary bus, which is thermally and mechanically attached to the cold mass. Its size is 50mm. There are two pipes, to provide symmetry. The other two types of pipes (e and c') are as described for the other magnets.

There are no field-added components in the case of D4a, so connections to the adjacent magnets at installation are straightforward.

A flex joint will be provided at the lead end for the short bus that connects the D4a magnet coils to the power in the DFBA. In addition, to accommodate the motion of the LHC buses passing through D4a, flex joints will be located at the non-lead end of D4a on each LHC bus. The buses will have fixed points at the lead end.

<u>D4b:</u> Two D4b magnets plus one spare will be built, located between the D4a and the Q7 magnet in IP4L and IP4R. As with the other magnets, symmetric construction allows BNL to produce three identical units including the universal spare. As shown in Figure 11, the lead end of the cold mass always faces toward the IP and connects to D4a. The magnets operate at 1.9K.

The arrangement, function, and sizing of the cold mass stubs is the same as for D4a, with the following exceptions. At the non-lead end, the m/c stub is replaced by the c stub since the bus to power the D4 magnets is not present beyond this point in the cryogenic module.

The piping within the cryostat is the same as described for D4a before.

As in the previous case, there are no field-added components, so connections to the adjacent magnets at installation are straightforward.

Note that there is a bus provided in each D4a cold mass to supply power to D4b. There will be a flex joint provided in the lead end volume of D4b to absorb the expansion/contraction of this bus. In addition, to accommodate the motion of the LHC buses passing through D4a, flex joints will be located at the lead end of D4b. The buses will have fixed points at the lead end. D4b will also require flex joints at the non-lead end to provide flexibility when D4b is connected to Q7 on the right side of the IP.

Figure 1

BNL LHC MAGNET PARAMETERS MAGPARAM.XLS 1 Sep 99	D1	D2	D3a, b	D4a, b	PROTOTYPE
QUANTITY + (SPARES)	4 + (1)	8 + (1)	2 + (1), 2 + (1)	2 + (1), 2 + (1)	2
OPERATING TEMP	1.9K	4.5K	4.5K	1.9K	4.5K TEST
BEAM TUBE OD / ID	78 / 74mm (flared end IR2)	73 / 69mm	73 / 69mm	73 / 69mm	73 / 69mm
BEAM DYNAMIC HEAT LOAD	screen (partial IR2)	screen	screen	screen	N/A
COIL PRESTRESSED BY... (7kpsi)	yoke	collar	yoke	collar	collar
COLD MASS DESIGN	1 / 1	2 / 1	1 / 1	2 / 1	2 / 1
BORE SPACING(S), COLD	N/A	188mm	420, 382mm	232, 194mm	194mm
YOKE SIZE	267mm (10.5 in)	550mm x 625mm	267mm (10.5 in)	550mm x 625mm	550mm x 625mm
SHELL THICKNESS	4.8mm (.188 in)	9.5mm (.375 in)	4.8mm (.188 in)	9.5mm (.375 in)	9.5mm (.375 in)
END PLATE THICKNESS	32mm (1.25 in)	70mm (2.75 in)	32mm (1.25 in)	70mm (2.75 in)	70mm (2.75 in)
C. M. LENGTH OVER END PLATES	9.72m (382.7 in)	9.80m (385.8 in)	9.72m (382.7 in)	9.80m (385.8 in)	3.32m (130.6 in)
C. M. LENGTH OVER END VOLUMES	10.23m (402.8 in)	10.35m (407.5 in)	10.23m (402.8 in)	10.35m (407.5 in)	N/A
COLD MASSES PER CRYOSTAT	1	1	2	1	N/A
CRYOSTAT LENGTH	9.65m (379.75 in)	9.77m (384.5 in)	9.65m (379.75 in)	9.77m (384.5 in)	N/A
CRYOSTAT DIA	610mm (24 in)	914mm (36 in)	914mm (36 in)	914mm (36 in)	N/A

Figure 2

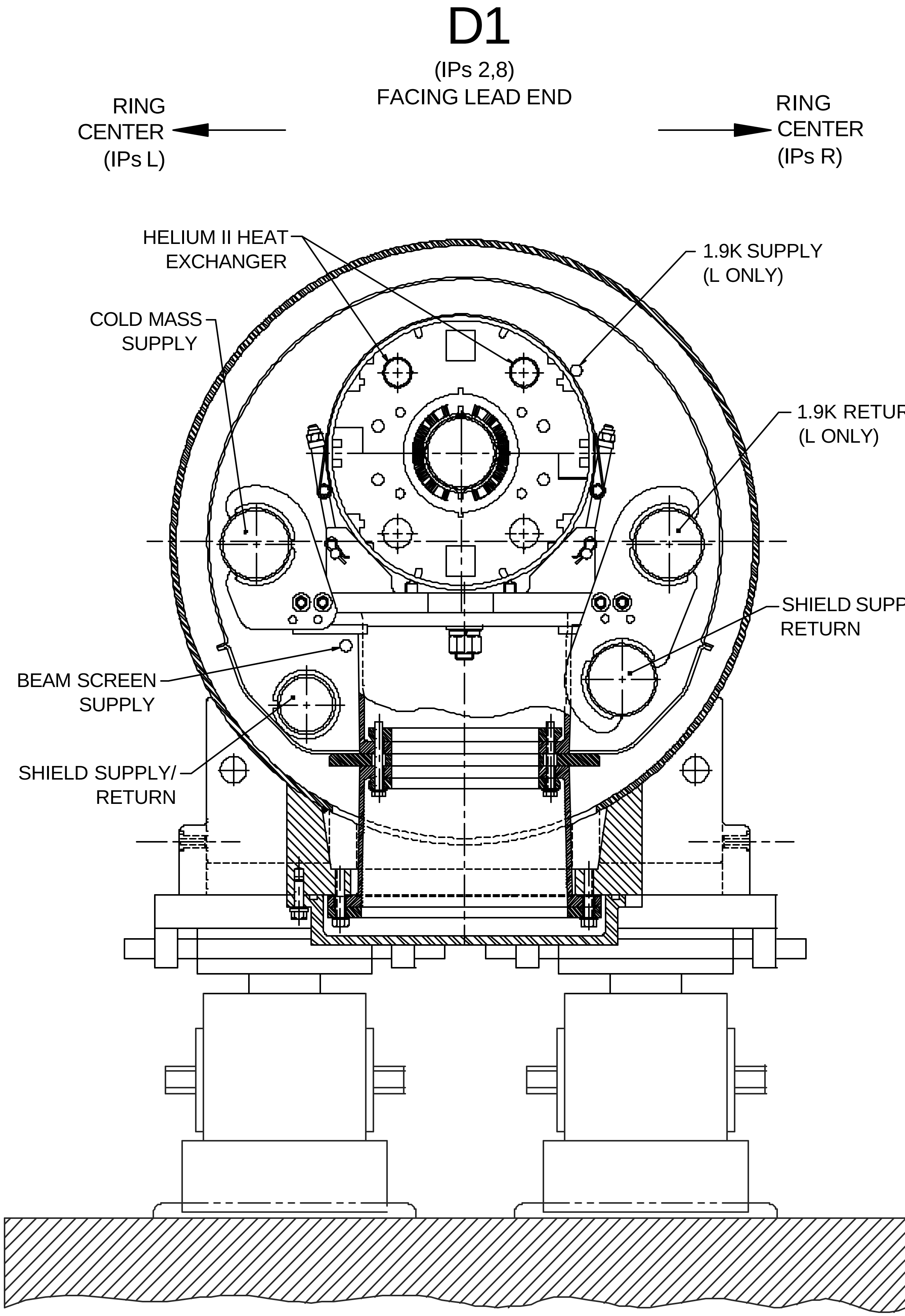
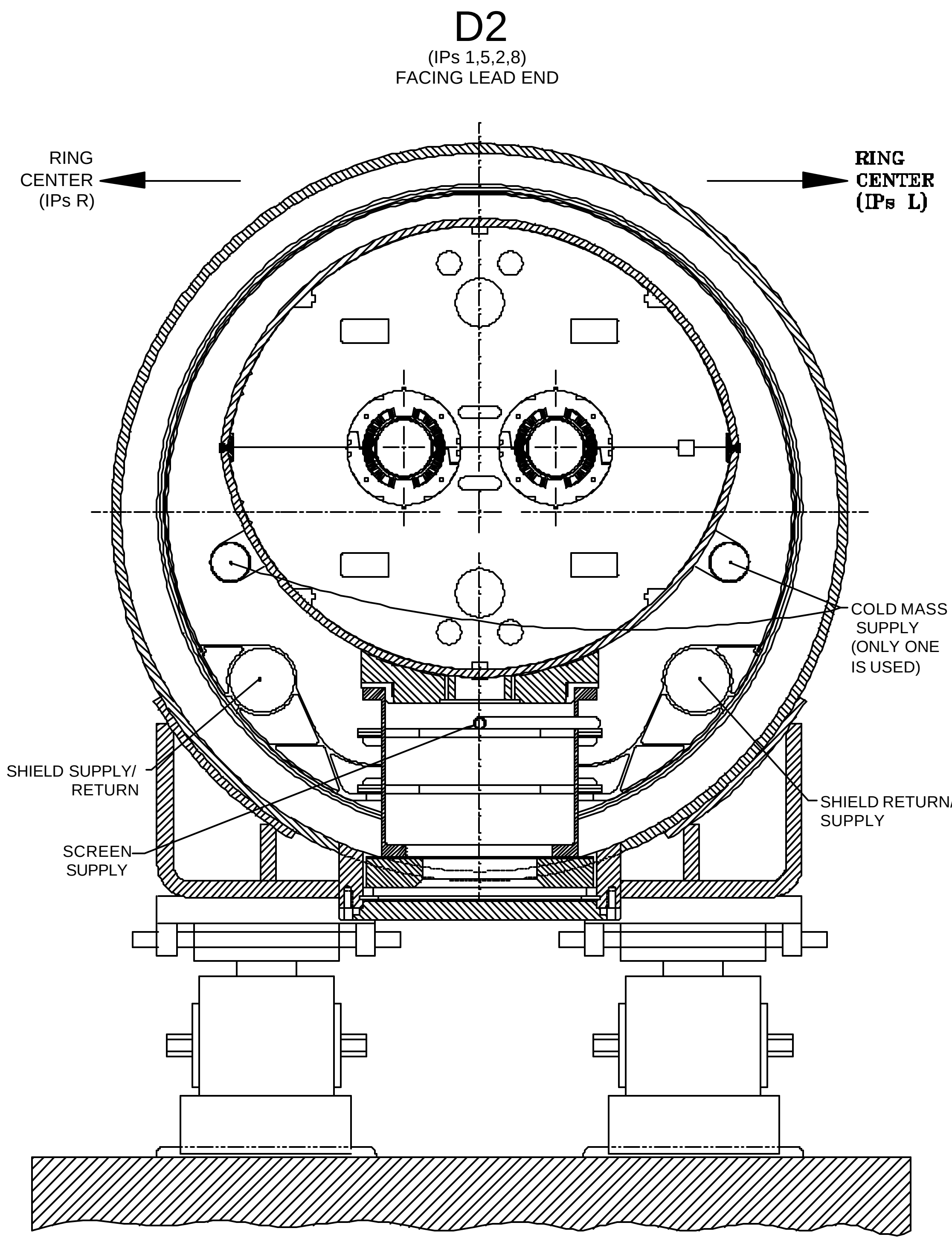
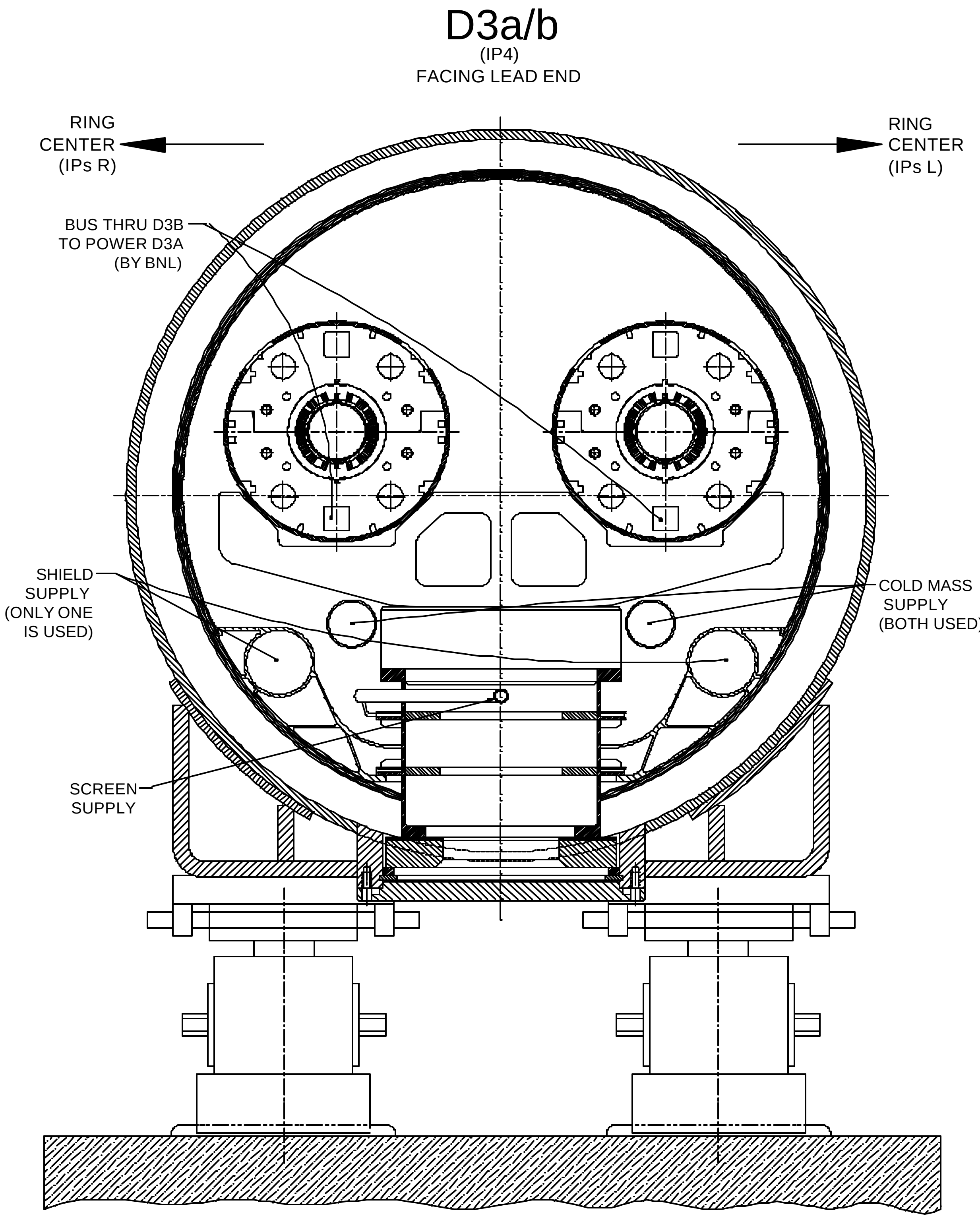

D1
(IPs 2,8)
FACING LEAD END
RING
CENTER
(IPs L)
RING
CENTER
(IPs R)
HELIUM II HEAT
EXCHANGER
1.9K SUPPLY
(L ONLY)
COLD MASS
SUPPLY
1.9K RETURN
(L ONLY)
SHIELD SUPPLY/
RETURN
BEAM SCREEN
SUPPLY
SHIELD SUPPLY/
RETURN

Figure 3


D2
(IPs 1,5,2,8)
FACING LEAD END
RING
CENTER
(IPs R)
RING
CENTER
(IPs L)
COLD MASS
SUPPLY
(ONLY ONE
IS USED)
SHIELD SUPPLY/
RETURN
SHIELD RETURN/
SUPPLY
SCREEN
SUPPLY

-

Figure 4



D3a/b
(IP4)
FACING LEAD END
RING
CENTER
(IPs R)
RING
CENTER
(IPs L)
BUS THRU D3B
TO POWER D3A
(BY BNL)
SHIELD
SUPPLY
(ONLY ONE
IS USED)
COLD MASS
SUPPLY
(BOTH USED)
SCREEN
SUPPLY

Figure 5

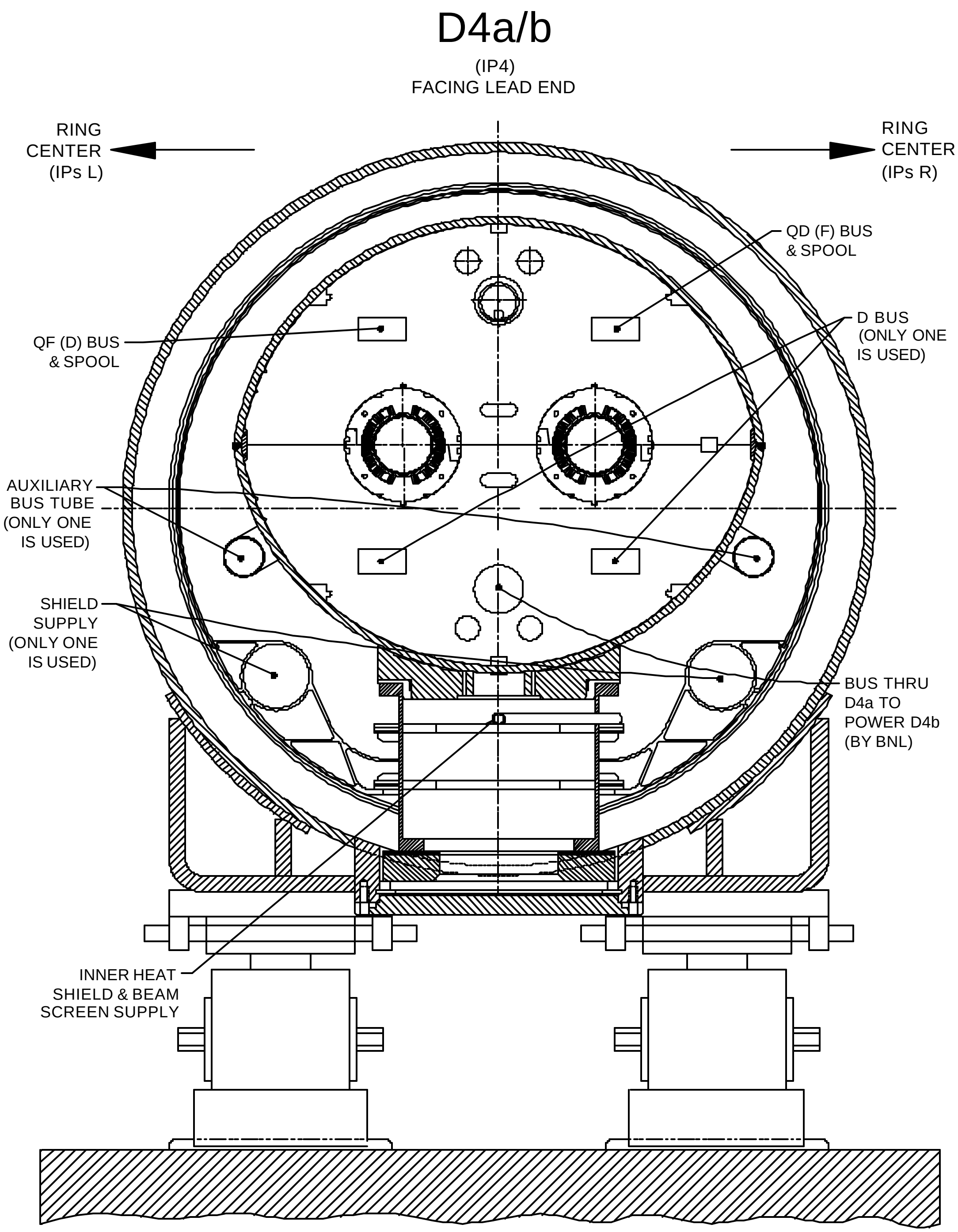

D4a/b
(IP4)
FACING LEAD END
RING CENTER (IPs L)
RING CENTER (IPs R)
QD (F) BUS & SPOOL
D BUS (ONLY ONE IS USED)
QF (D) BUS & SPOOL
AUXILIARY BUS TUBE (ONLY ONE IS USED)
SHIELD SUPPLY (ONLY ONE IS USED)
BUS THRU D4a TO POWER D4b (BY BNL)
INNER HEAT SHIELD & BEAM SCREEN SUPPLY

Figure 6

D1

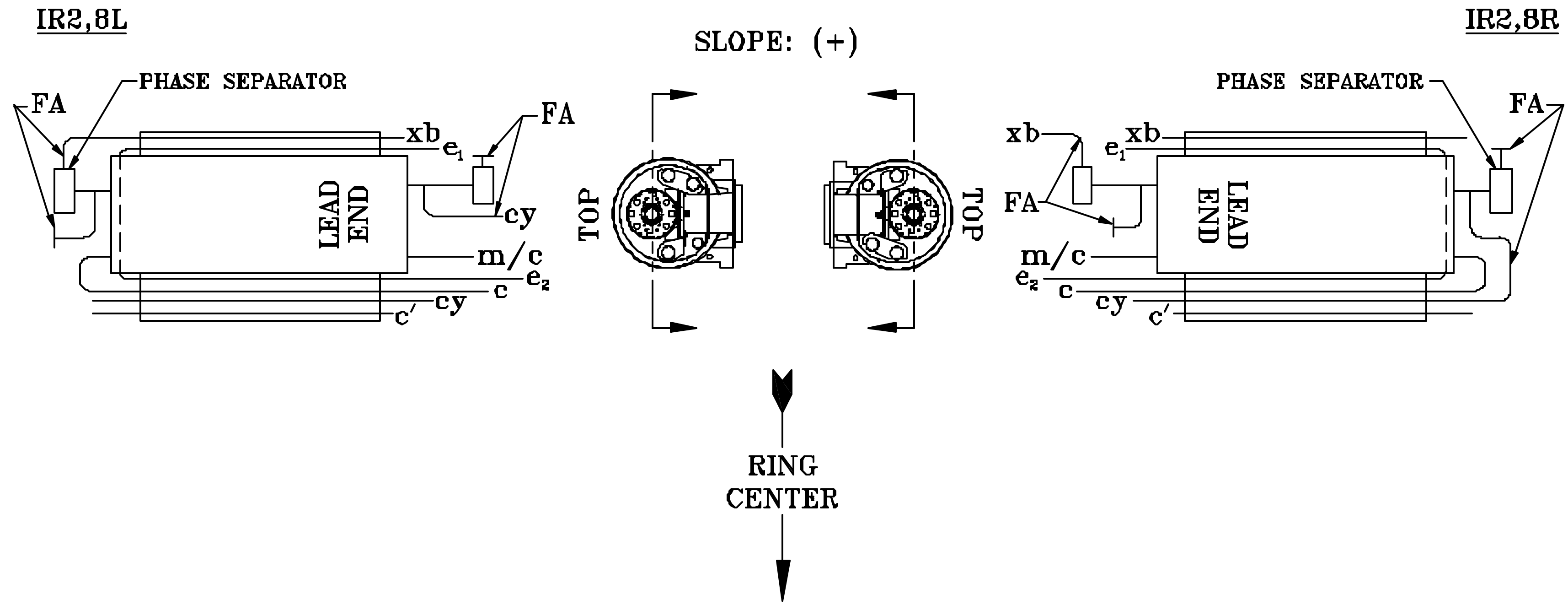

IR2,8L
SLOPE: (+)
IR2,8R
PHASE SEPARATOR
FA
xb
e1
cy
LEAD END
m/c
e2
c
c′
TOP
RING CENTER

Figure 7

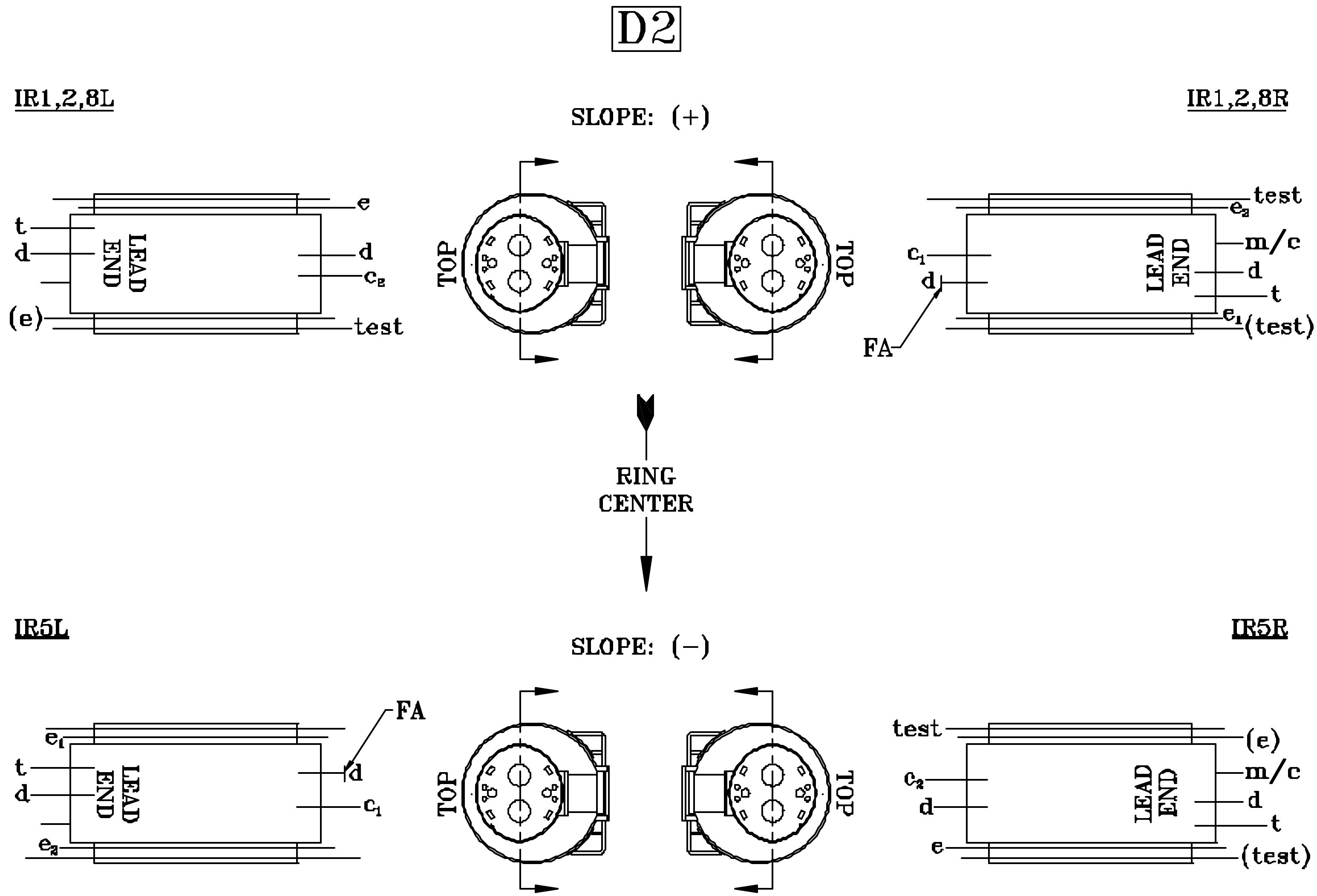

D2
IR1,2,8L
SLOPE: (+)
IR1,2,8R
LEAD END
TOP
e
t
d
d
c_2
(e)
test
test
e_2
c_1
m/c
d
t
e_1
(test)
FA
RING CENTER
IR5L
SLOPE: (−)
IR5R
FA
e_1
t
d
d
c_1
e_2
test
(e)
c_2
m/c
d
t
e
(test)

Figure 8

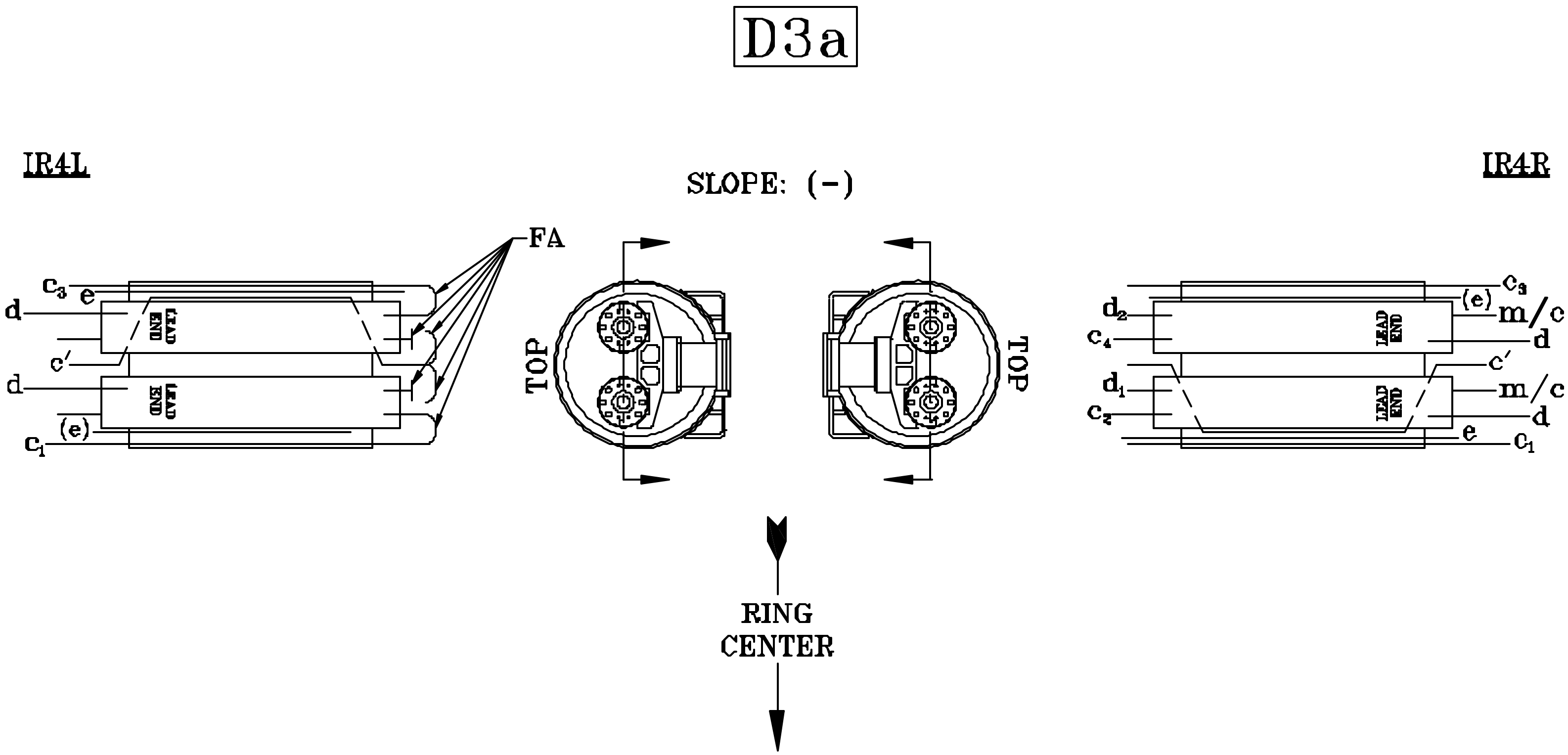
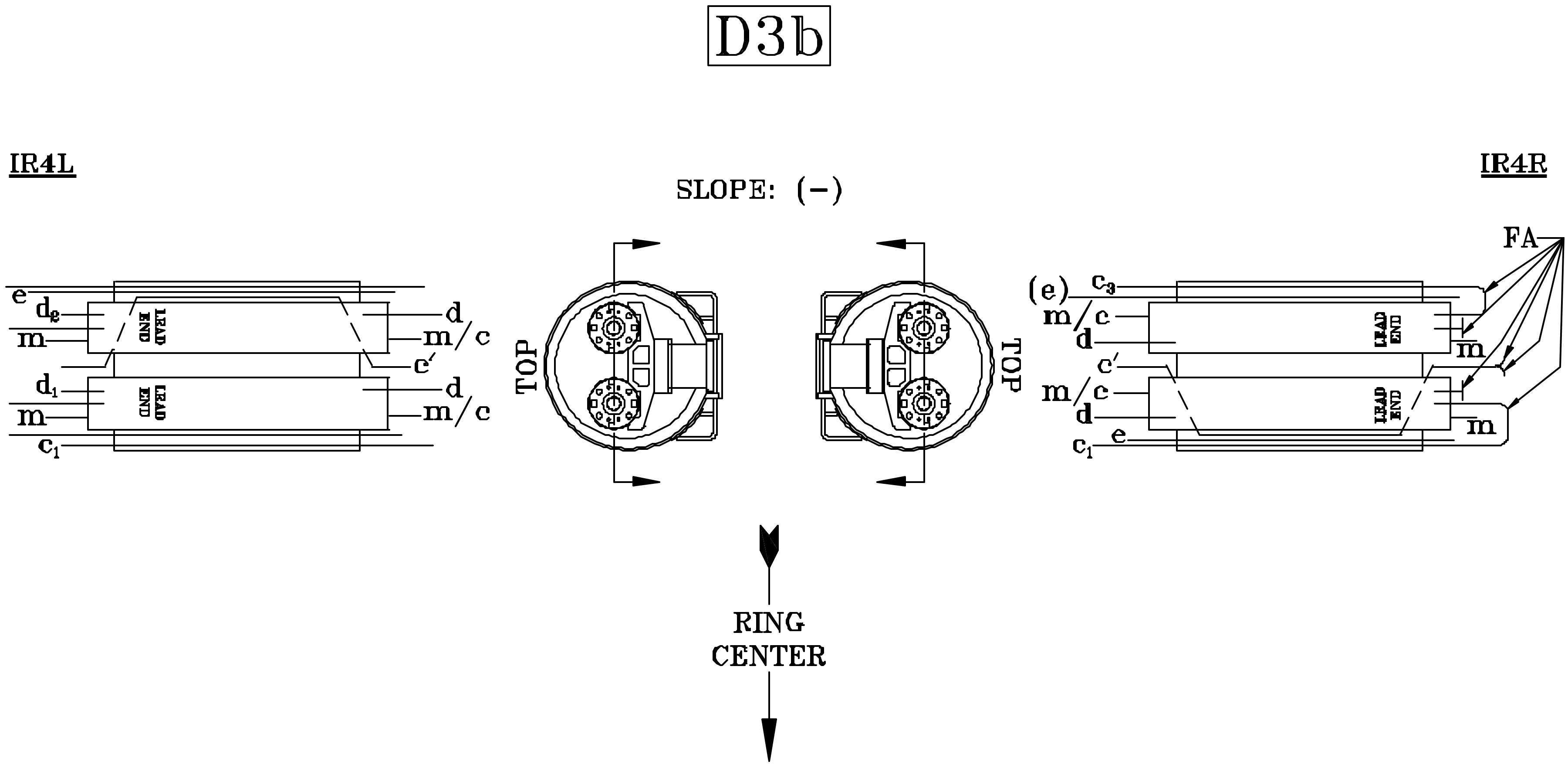

D3a
IR4L
SLOPE: (-)
IR4R
FA
TOP
TOP
c3
e
d
c'
d
(e)
c1
LEAD END
LEAD END
d2
c4
d1
c2
c3
(e)
m/c
d
c'
m/c
d
e
c1
RING
CENTER

Figure 9



D3b
IR4L
SLOPE: (-)
IR4R
FA
e
d2
m
d1
m
c1
d
m/c
c'
d
m/c
LEAD END
LEAD END
TOP
TOP
(e)
c3
m/c
d
c'
m/c
d
e
c1
m
m
LEAD END
LEAD END
RING CENTER

Figure 10

D4a

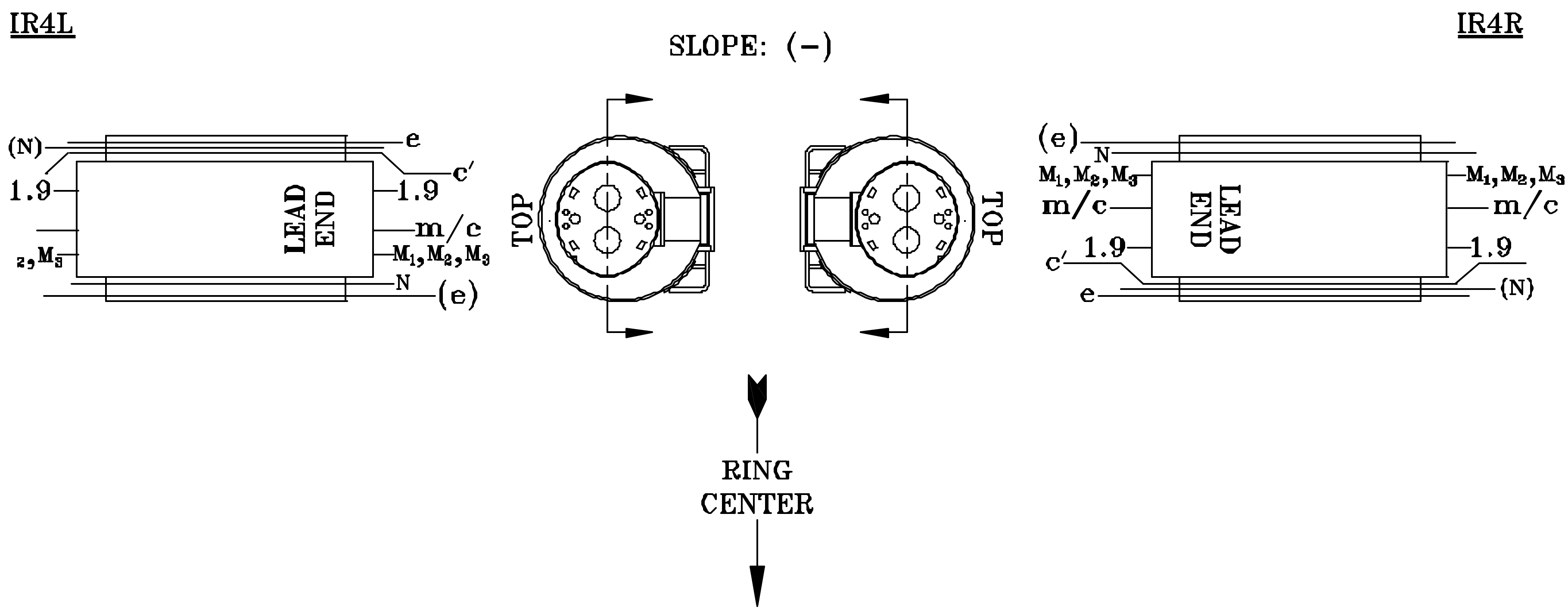


Figure 11

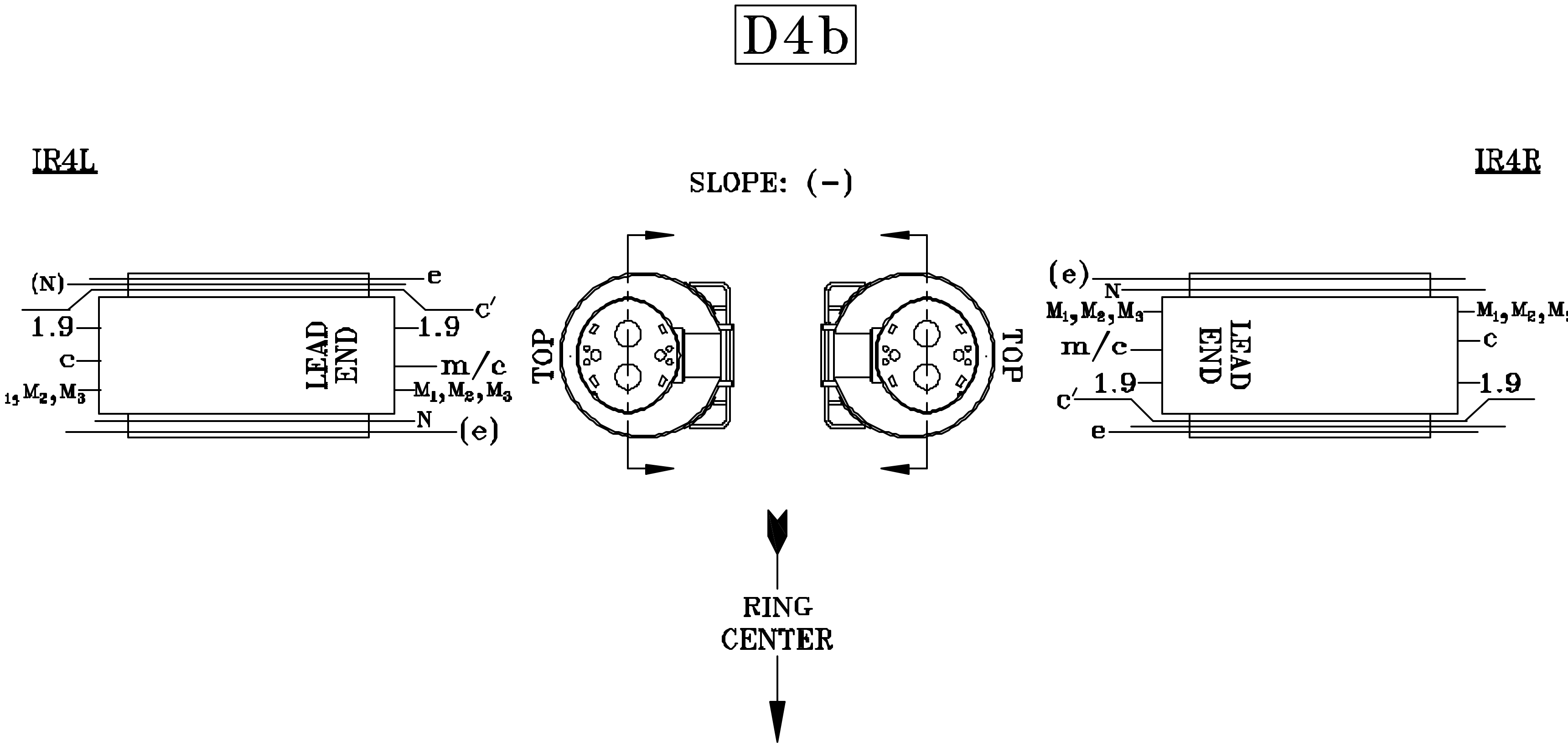
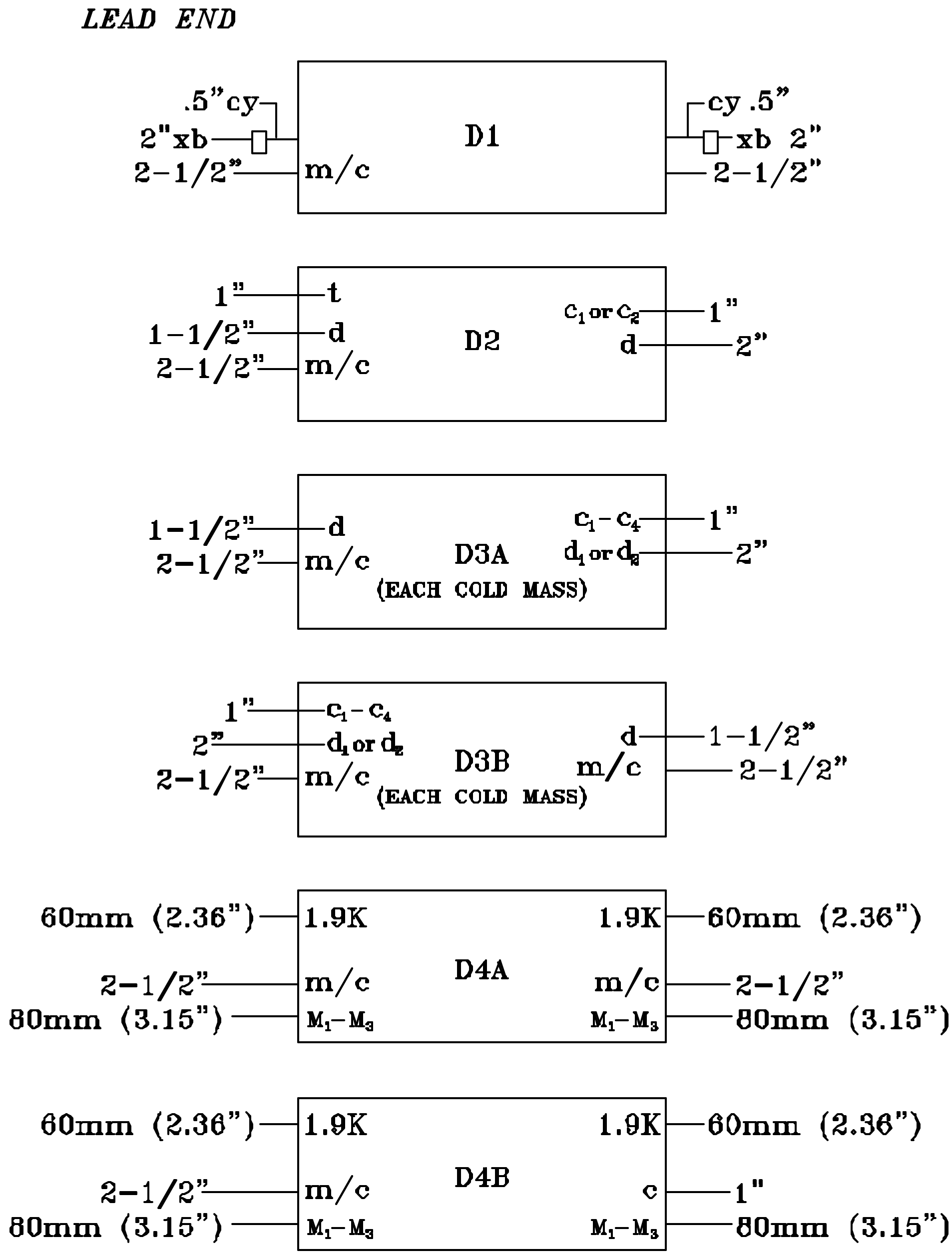

D4b
IR4L
IR4R
SLOPE: (–)
(N)
e
c′
1.9
c
m/c
M1, M2, M3
N
(e)
LEAD END
TOP
RING CENTER

Figure 12

END VOLUME PIPING/TUBING SIZES



NOTE: m CONTAINS BNL BUS FOR MAGNET POWER

Figure 13

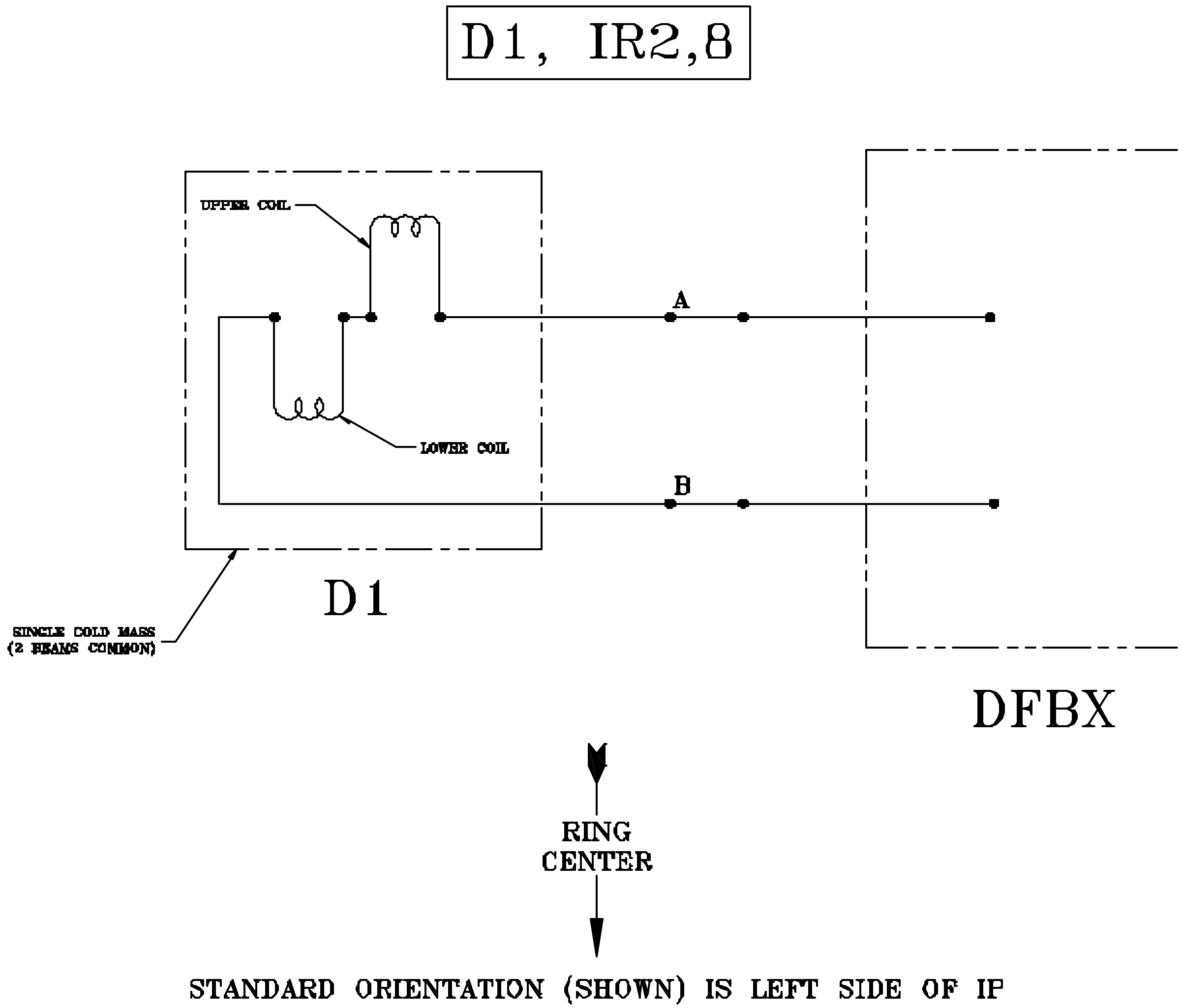
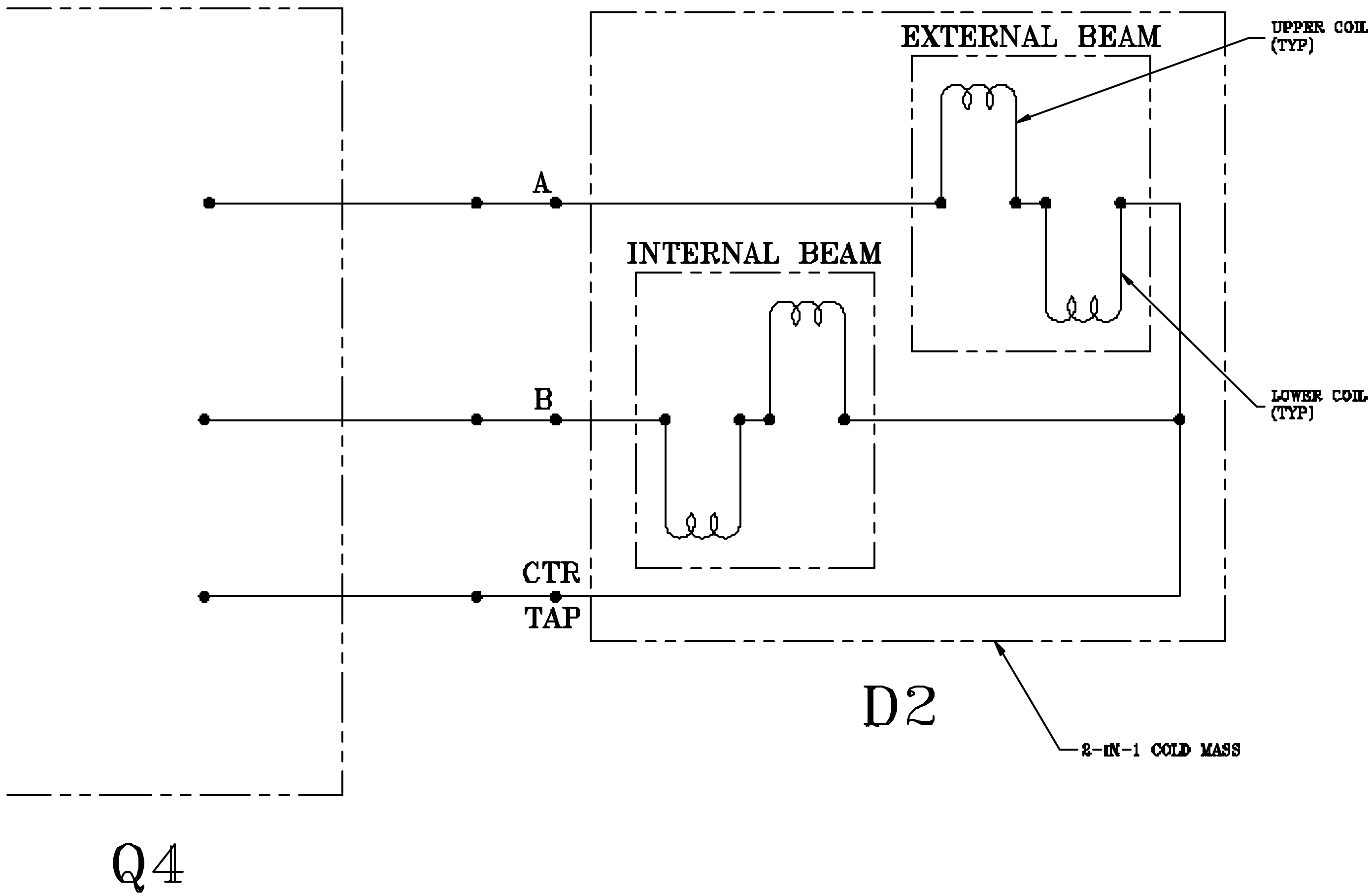

D1, IR2,8
UPPER COIL
LOWER COIL
A
B
SINGLE COLD MASS
(2 BEAMS COMMON)
D1
DFBX
RING
CENTER
STANDARD ORIENTATION (SHOWN) IS LEFT SIDE OF IP

Figure 14

D2, IR1,2,5,8



STANDARD ORIENTATION (SHOWN) IS LEFT SIDE OF IP

Figure 15

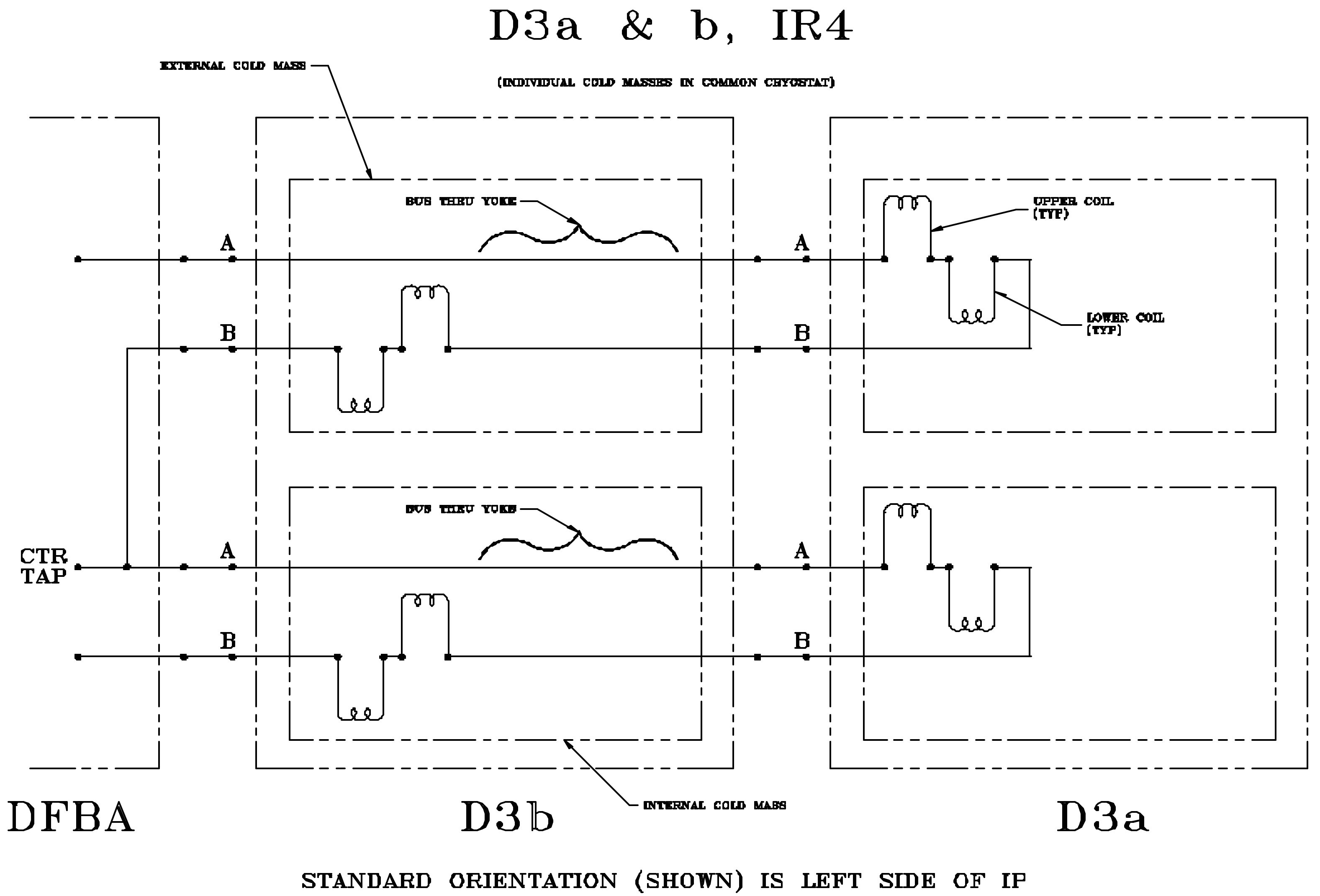
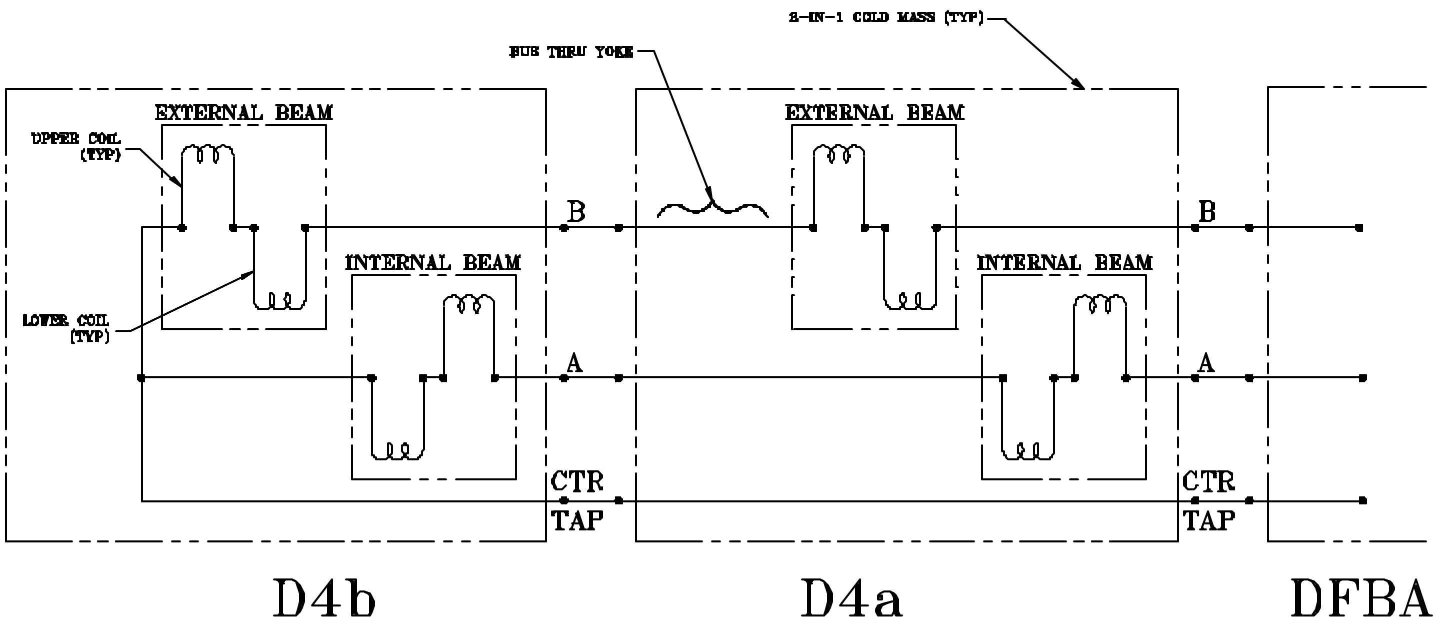

D3a & b, IR4
EXTERNAL COLD MASS
(INDIVIDUAL COLD MASSES IN COMMON CRYOSTAT)
BUS THRU YOKE
UPPER COIL (TYP)
LOWER COIL (TYP)
A
B
CTR TAP
INTERNAL COLD MASS
DFBA
D3b
D3a
STANDARD ORIENTATION (SHOWN) IS LEFT SIDE OF IP

Figure 16

D4a & b, IR4



STANDARD ORIENTATION (SHOWN) IS LEFT SIDE OF IP