Polarity control of the HL-LHC circuits

Mirko Pojer

CERN TE-MPE-MP

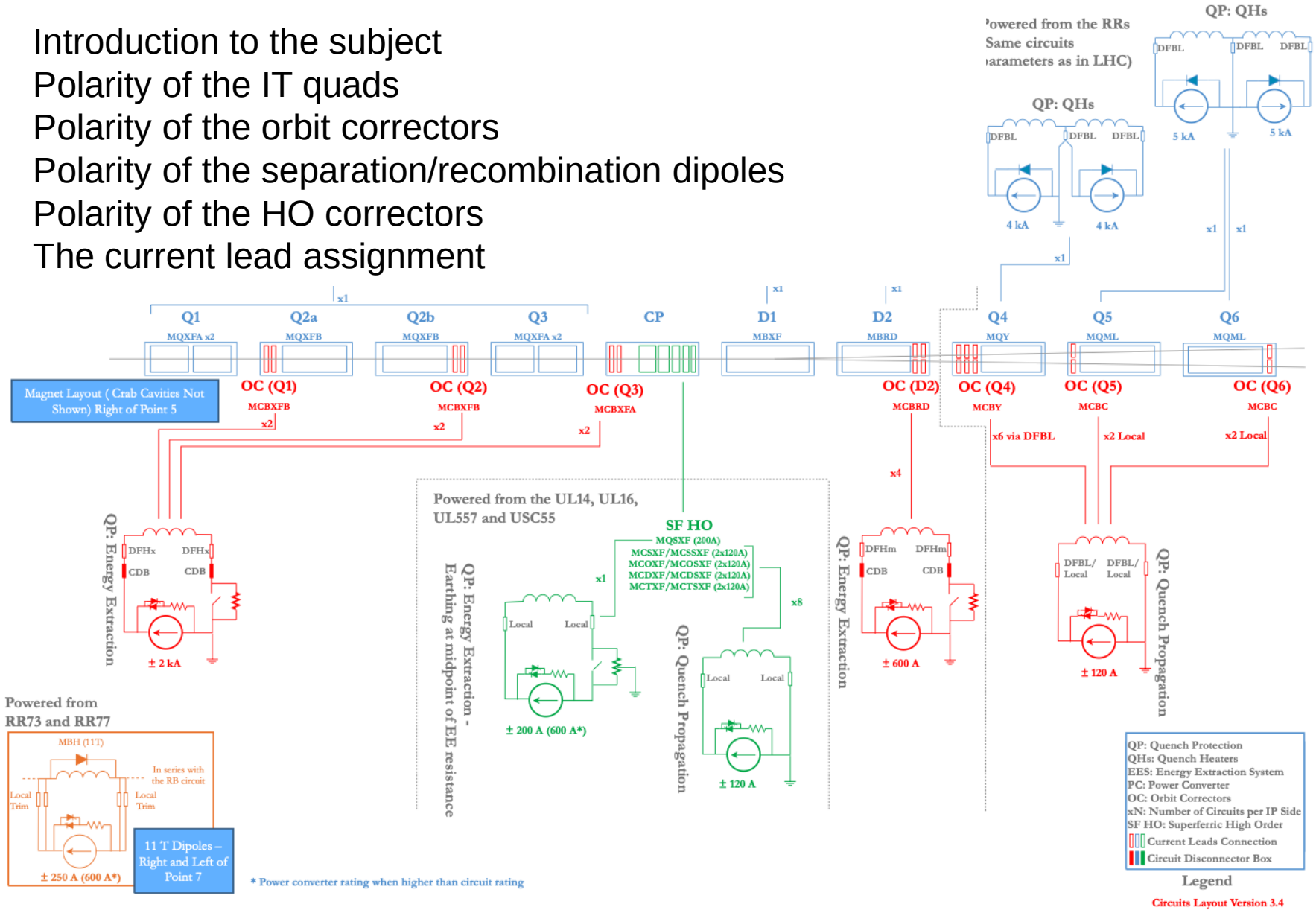
with contributions from Herve Prin and Samer Yammine

MCF session – September 21, 2022

HL-LHC circuits layout

From the MCF web page

- Introduction to the subject
- Polarity of the IT quads
- Polarity of the orbit correctors
- Polarity of the separation/recombination dipoles
- Polarity of the HO correctors
- The current lead assignment



Polarities for the HL-LHC magnets

- "…define clear conventions (based on LHC experience) and perform the required verifications in order to ascertain the defined circuit polarities to be coherent with the optics layouts and operation with beams. This will be done in close collaboration with the concerned WP leaders … covering the relevant aspects ranging from the design and manufacturing of circuit components to the assembly of the circuits during construction, tests and hardware commissioning. This applies to **both cold powering components and warm parts** of electrical circuits."

- Close collaboration with magnet experts, Mr Circuit and MCF

EDMS No. 2316942

Mandate for the Verification of Polarities of the HL-LHC Magnet System

(Polarity Controller)

In the context of the HL-LHC project, a number of magnets and of magnetic circuits will be profoundly modified. The main modifications are:

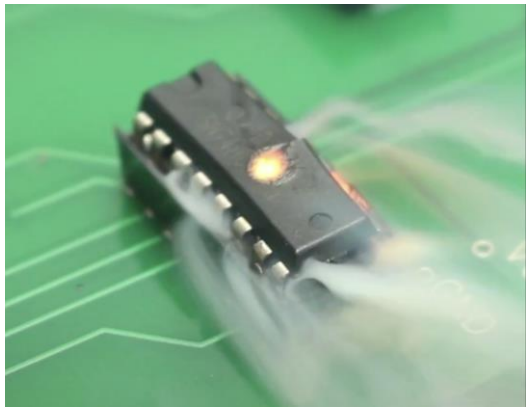
1. Q1-Q2-Q3 (Inner Triplet) in IR (Interaction Region) 1 and IR5
2. D1 and D2 (Separation/Recombination dipole pair) in IR1 and IR5
3. All corrector magnets of the Inner Triplets in IP1 and IR5
4. The 11 T dipoles in the DS (Dispersion Suppressor) right and left of IP (Interaction Point) 7.
5. Small modifications may involve other magnets in IR6
6. Hollow e-lens in IR4
7. Any new equipment with magnet circuits that may be added to the baseline as, inter alia, LRBB (long-range beam-beam) compensating electrical wires, etc…

The mandated person (Polarity Controller) will define clear conventions (based on LHC experience) and perform the required verifications in order to ascertain the defined circuit polarities to be coherent with the optics layouts and operation with beams. This will be done in close collaboration with the concerned WP leaders (WP2 - Accelerator Physics and Performance, WP3 - IR Magnets, WP6A-B - Cold-Warm Powering, WP7 - Machine Protection, WP9 - Cryogenics, WP 11 - 11T dipole, WP15 - Integration and Installation, and any other relevant WPs), Operation's representatives and the Magnet Circuits Expert, covering the relevant aspects ranging from the design and manufacturing of circuit components to the assembly of the circuits during construction, tests and hardware commissioning. This applies to both cold powering components and warm parts of electrical circuits.

To this end, a revision of the existing reference documentation should be performed, and modifications applied if required. A plan should be prepared in order to have a consistent set of documents (notes, drawings with electrical schemes, etc).

The mandate of the Polarity Controller is established within the framework of the responsibility of the Magnet Circuits Expert and includes a regular report to the HL-LHC Magnet Circuit Forum (MCF). When necessary, the Polarity Controller will report to the TCC and to the HL-LHC Project Leader.

Why it's important to check the polarities?



In an accelerator, the wrong polarity of a circuit might lead to (orbit or optics) perturbation, which might be difficult to identify and could also be tricky to fix (e.g. cable length and rigidity).

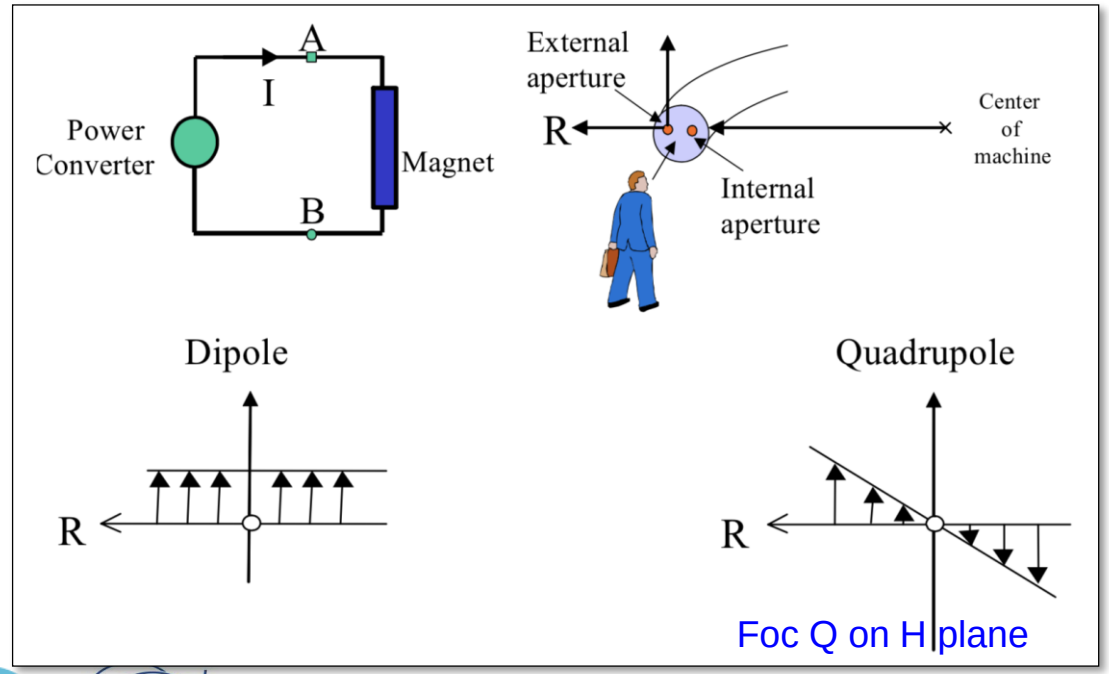
October 20, 2021 – Beam test after LS2: Unexpectedly large beta-beat observed ► traced to a B1-B2 swap of RQTL7.R3.B1 with RQTL7.R3.B2.

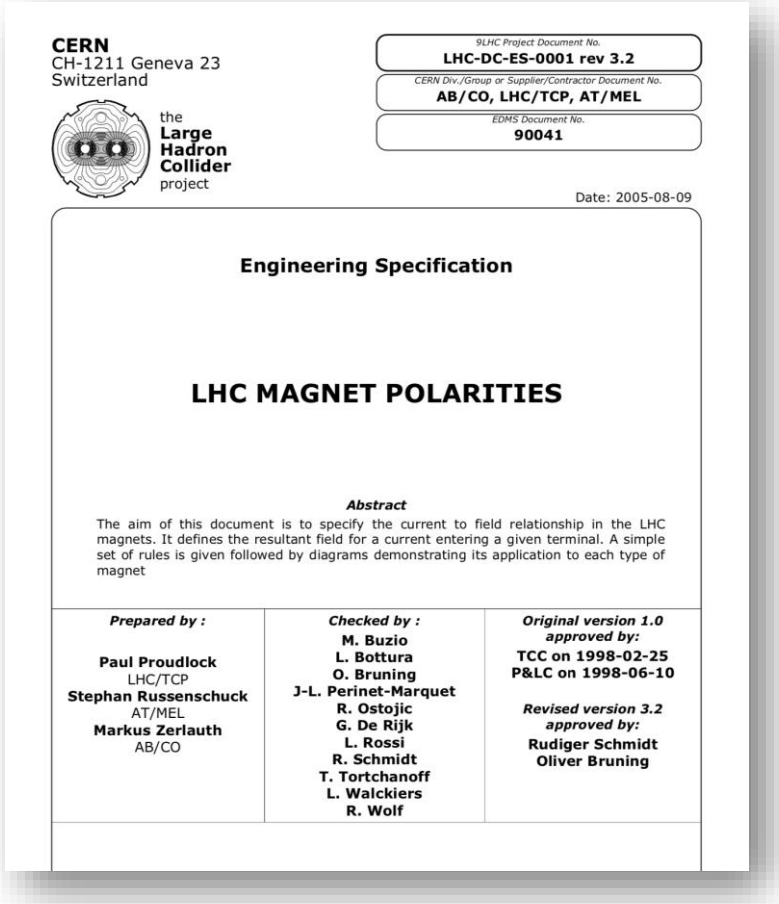
In 2009, after the incident in S34, the two circuits were found swapped at the level of the N line connection (EDMS 985231); the two converters were inverted. In LS2, the corresponding magnet was changed and the circuits connected correctly, but the swap at the converter level was not changed.

The reference document for the magnet polarity

- The reference document for the polarity of the (HL-)LHC magnets is the **EDMS ES no.90041**.

- The magnet terminals and the current leads to which they are connected will be marked with "**A**" and "**B**" (not "+" and "-").
- The fields and gradients are positive if the current enters the "A" terminal. Positive field means an upward pointing field direction while positive gradient is an increasing field along the outward pointing machine radius. The figures show the vertical field component.




CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

9LHC Project Document No.
LHC-DC-ES-0001 rev 3.2

CERN Div./Group or Supplier/Contractor Document No.
AB/CO, LHC/TCP, AT/MEL

EDMS Document No.
90041

Date: 2005-08-09

Engineering Specification

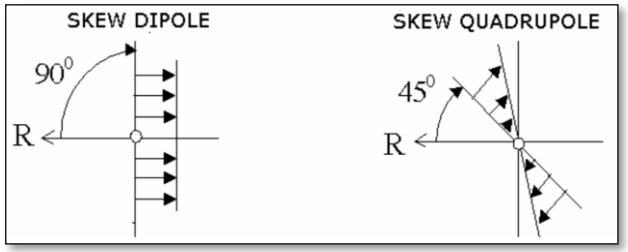
LHC MAGNET POLARITIES

Abstract

The aim of this document is to specify the current to field relationship in the LHC magnets. It defines the resultant field for a current entering a given terminal. A simple set of rules is given followed by diagrams demonstrating its application to each type of magnet

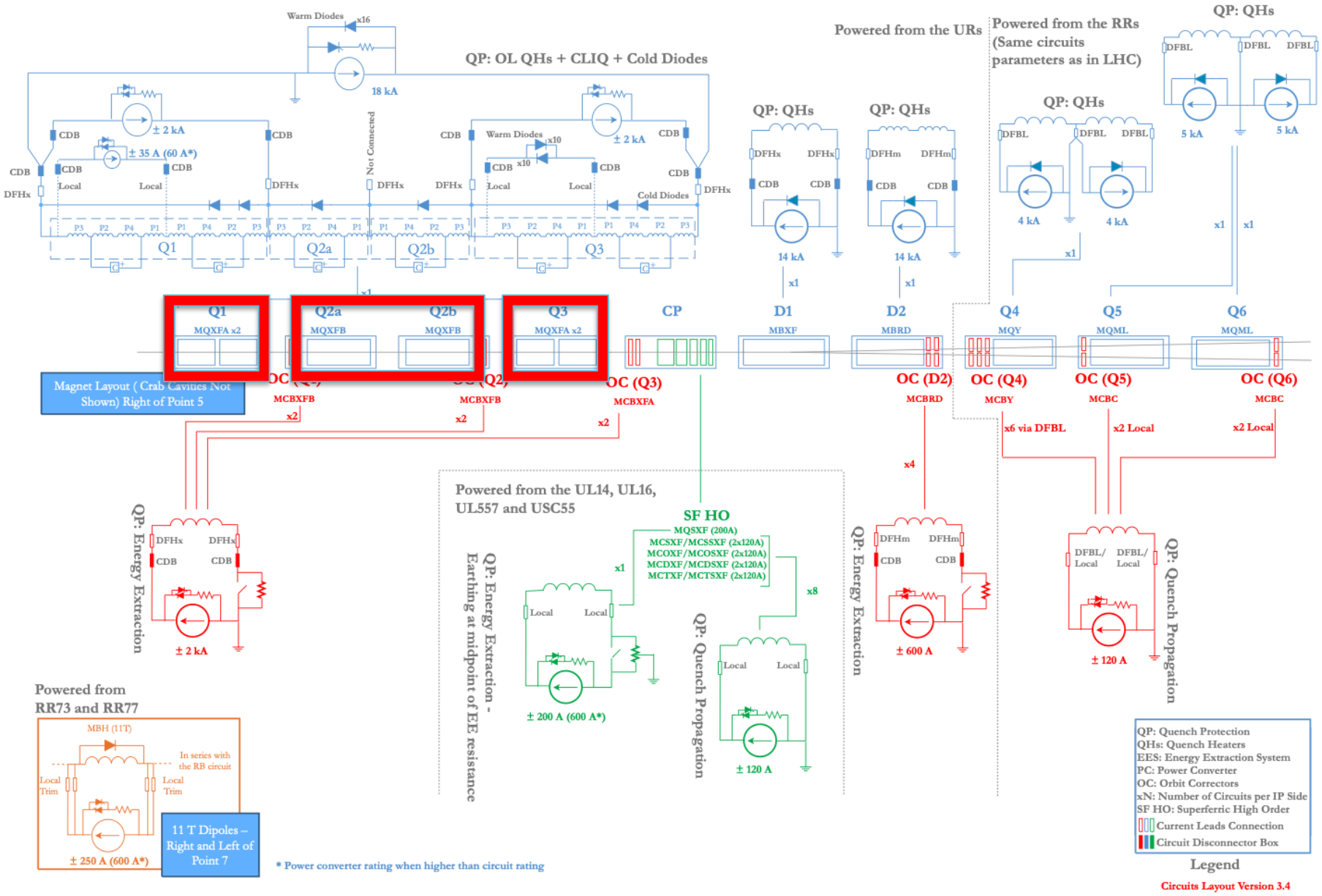
Prepared by :	*Checked by :*	*Original version 1.0 approved by:*
Paul Proudlock LHC/TCP **Stephan Russenschuck** AT/MEL **Markus Zerlauth** AB/CO	**M. Buzio** **L. Bottura** **O. Bruning** **J-L. Perinet-Marquet** **R. Ostojic** **G. De Rijk** **L. Rossi** **R. Schmidt** **T. Tortchanoff** **L. Walckiers** **R. Wolf**	**TCC on 1998-02-25** **P&LC on 1998-06-10** ***Revised version 3.2 approved by:*** **Rudiger Schmidt** **Oliver Bruning**

- Skew magnets are tilted clockwise by an angle of 90°/n.

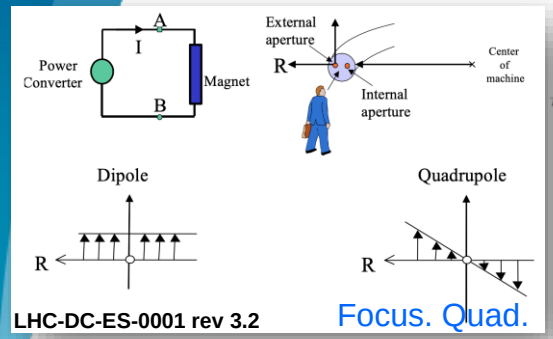


HL-LHC circuits layout

From the MCF web page

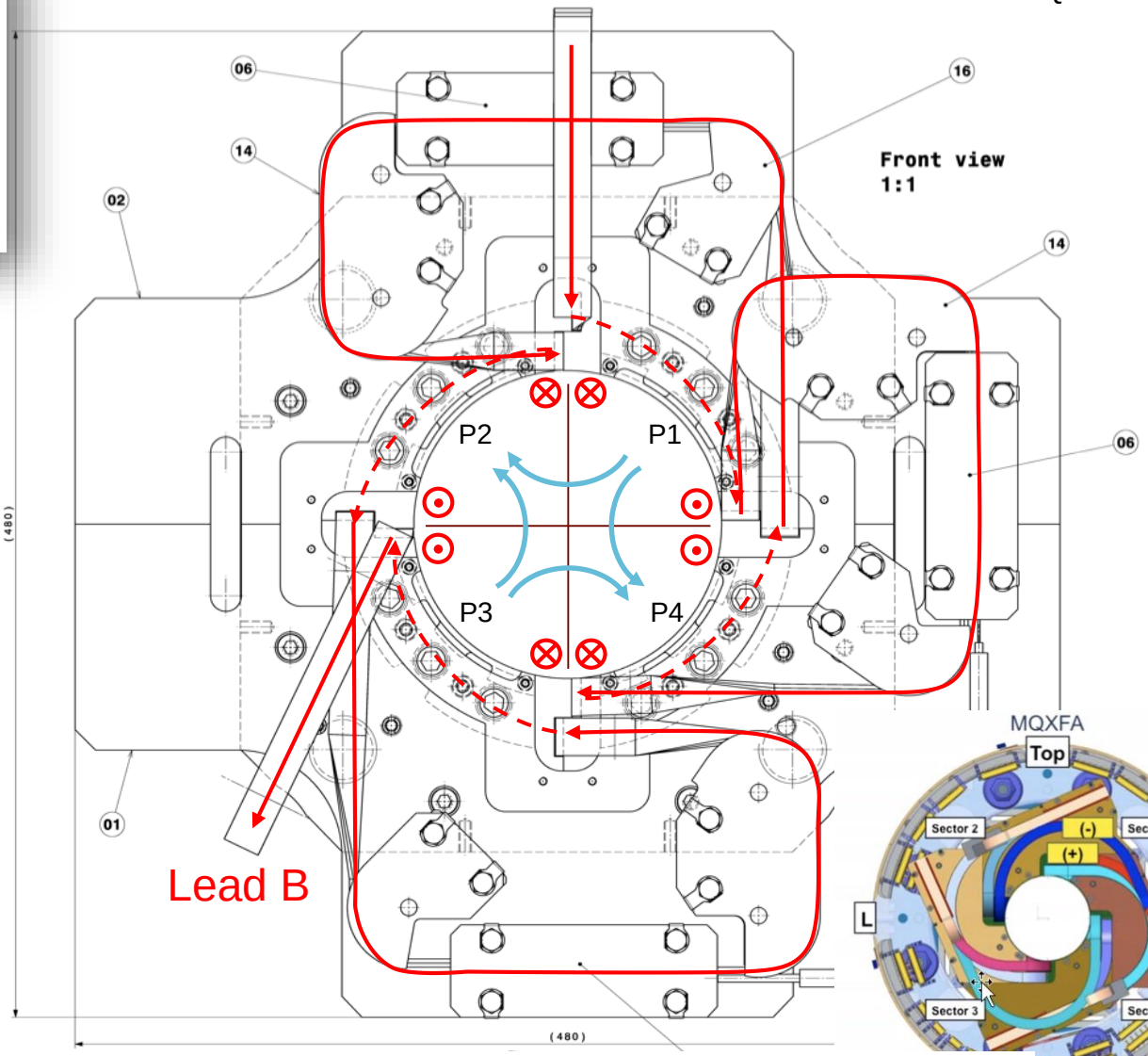


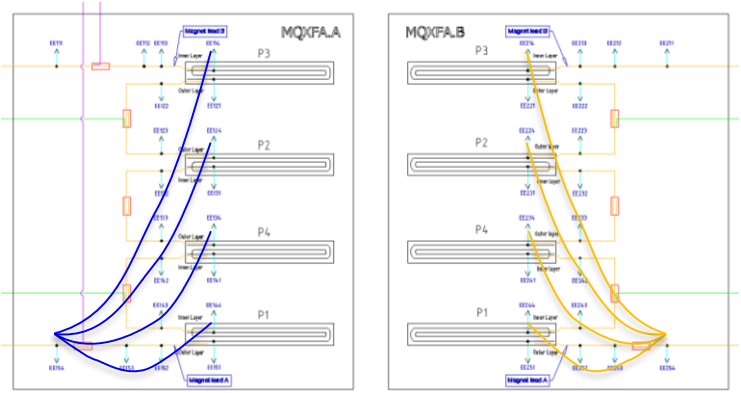
Current routing in MQXF cold masses



The pole connections, **polarities** and leads labelling defined on lhclmqxf_e0001 **are correct.**

The scheme of connection between poles is extremely clear and the connections are made on different planes wrt the end plate. Also, the rigidity of the bus-bars guarantees that **no inversion can be made on the terminals** when coming out of the cold mass.





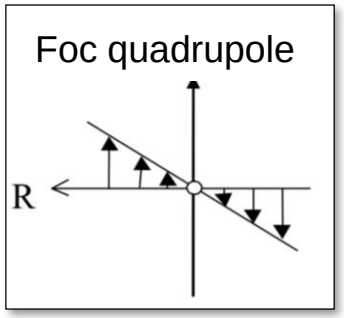
Holding point #1:
during assembly or test, perform systematic comparative measurements of the resistances across the voltage taps,
the minimum being $R_{EE154-EE144}$ $R_{EE154-EE134}$ $R_{EE154-EE124}$ $R_{EE154-EE114}$

(respectively, $R_{EE254-EE244}$ $R_{EE254-EE234}$ $R_{EE254-EE224}$ $R_{EE254-EE214}$)

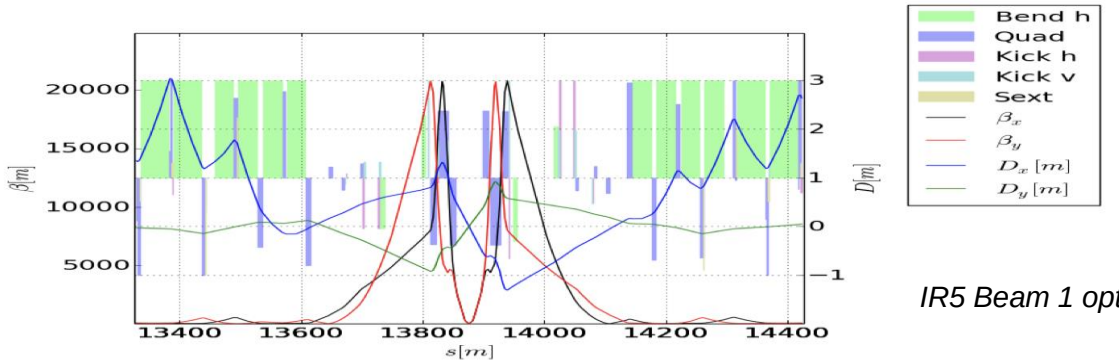
obtaining the result: $R_{EE154-EE144} < R_{EE154-EE134} < R_{EE154-EE124} < R_{EE154-EE114}$

Connection for Q1/Q3 magnets: different configuration, same conclusions

Connection to the PC and cold diodes

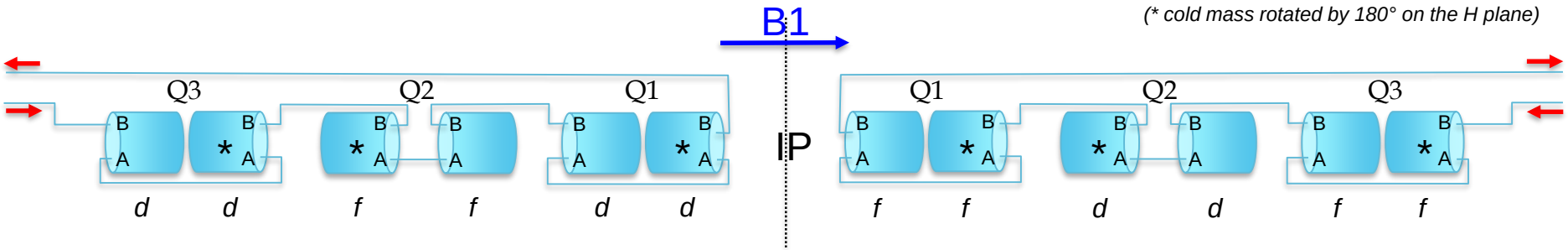


From the optics point of view, Q1 is always defocusing in the horizontal plane on the left of the IP for B1 and focusing on the right.



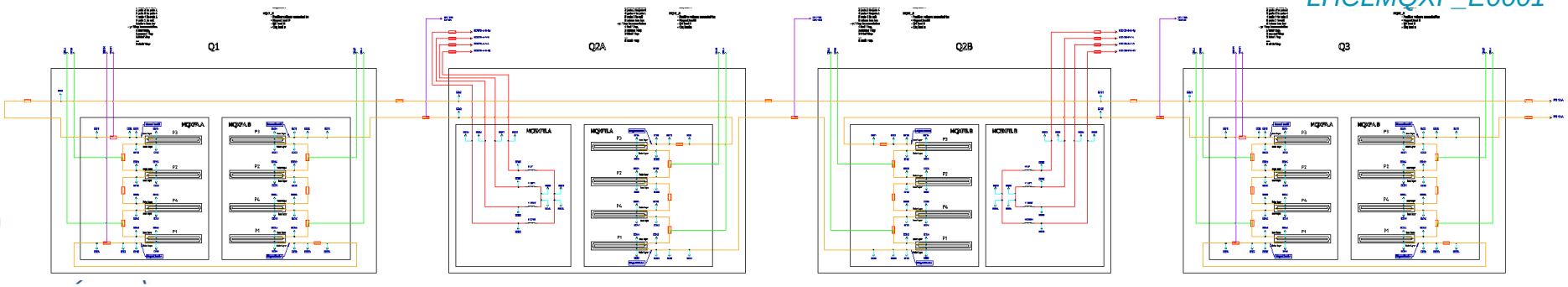
IR5 Beam 1 optics

(cold mass rotated by 180° on the H plane)*



The B terminal of Q3B is <u>always</u> connected to the PC+; the return line (B terminal of Q1A) is <u>always</u> connected to the PC-
This must be also taken into account for the polarity of the cold diodes.

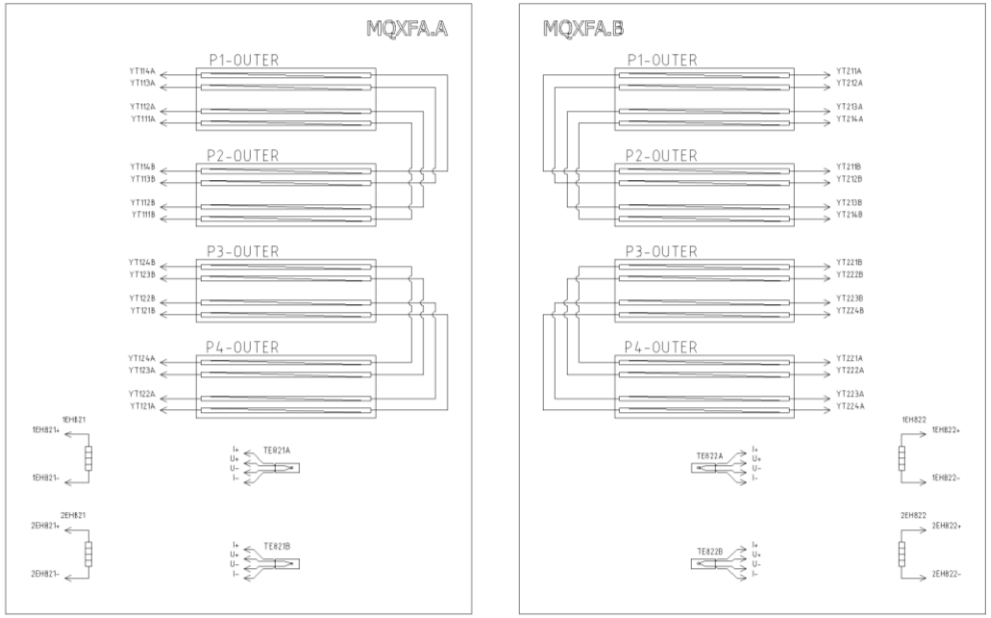
LHCLMQXF_E0001



Quench heaters connection (beyond polarity check)

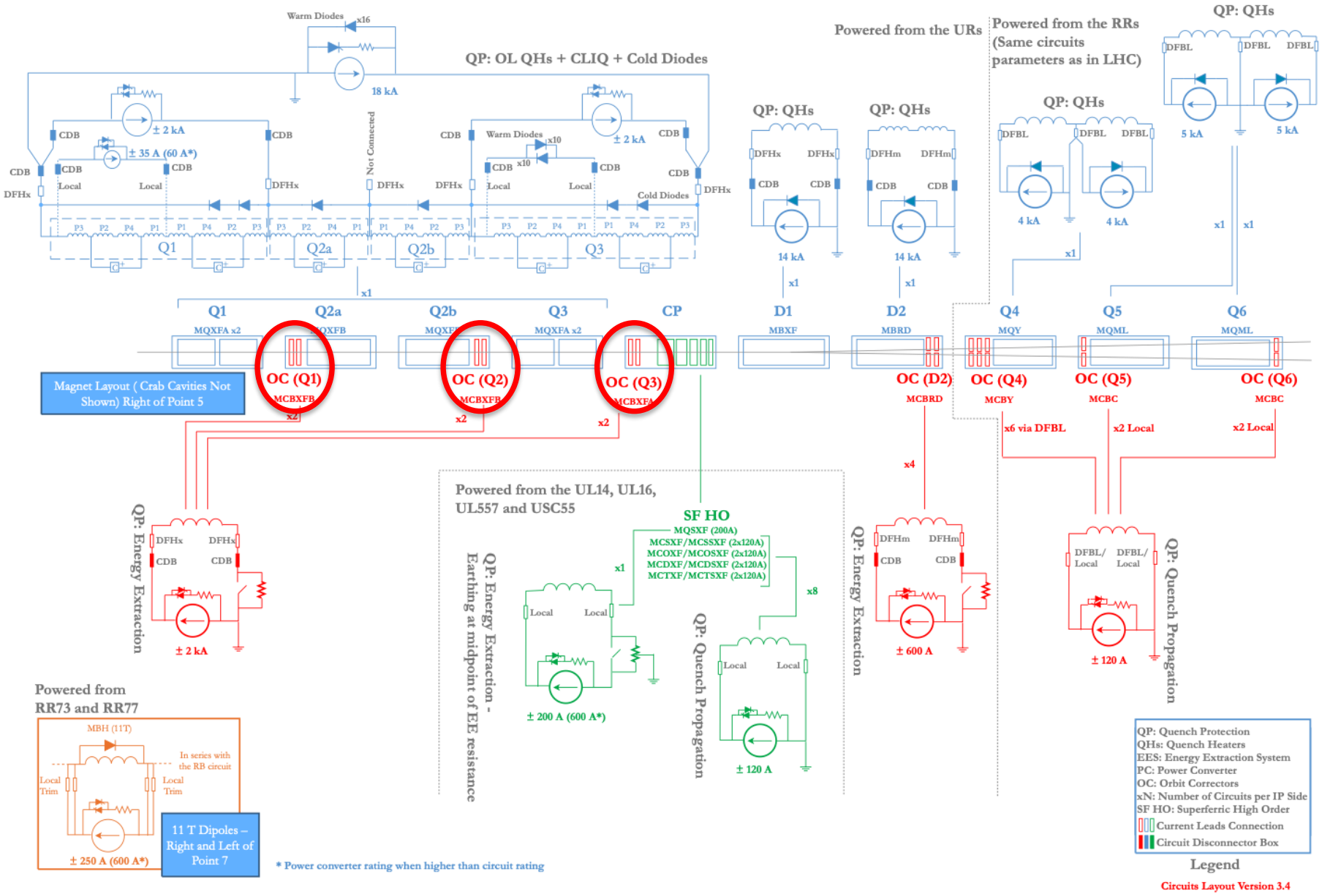
- For the quench heaters connection, there is no issue of polarity.
- Nonetheless, the inter-connection of the quench heaters across poles is important to avoid undesirable and dangerous multipoles, that could be responsible of high losses in case of spurious firing with beam.
- The wires connecting the quench heaters are thin and come out of the cold masses in bundles. Their interconnection relies on the labeling and mapping of connection.

Holding point #2: check that the QH interconnection correspond to the scheme below (when performing the magnetic measurements, inject current in one QH circuit and check the induced signals on the different coils or use pulsed signals and quench antennas).



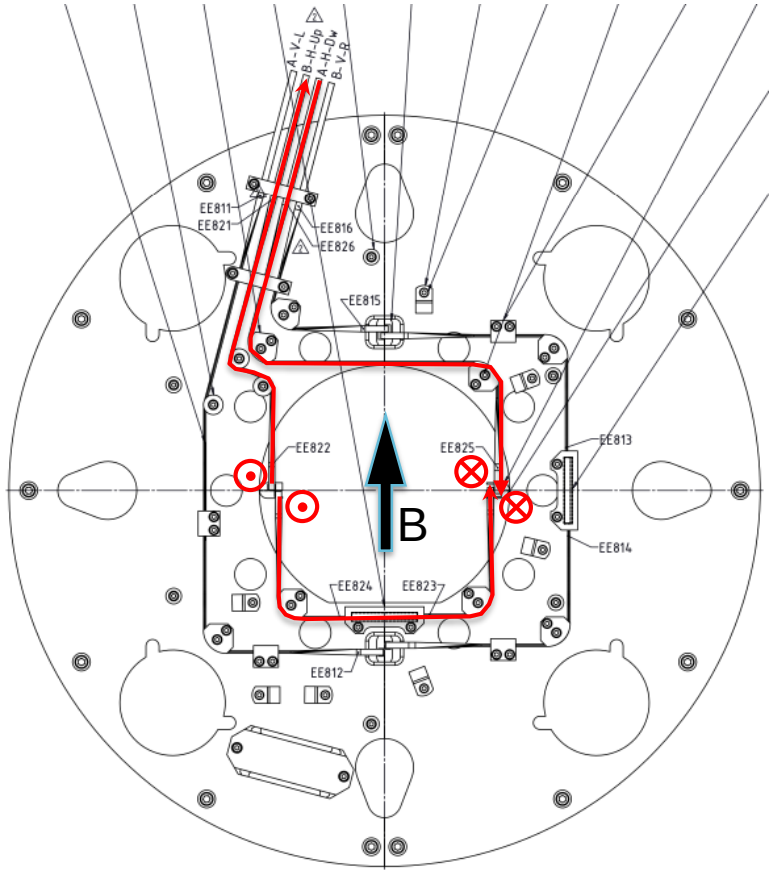
HL-LHC circuits layout

From the MCF web page

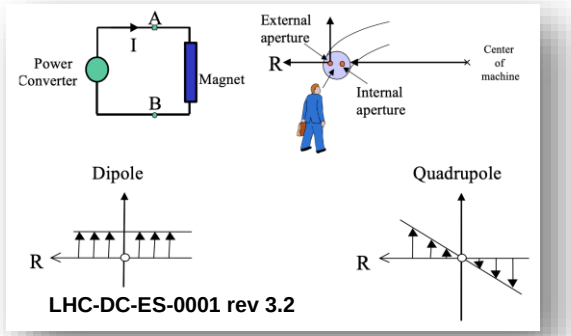


Current routing for MCBXF H correctors

(Only the drawings for MCBXFB are on CDD, but the connection side assembly for MCBXFA is identical)



LHCMCBXFB0057



Poles connection, **polarities** and leads labelling **are coherent** with LHC-DC-ES-001.

Holding point #3:
During assembly, perform comparative measurements of the resistances across the voltage taps, between one lead and the Vtaps

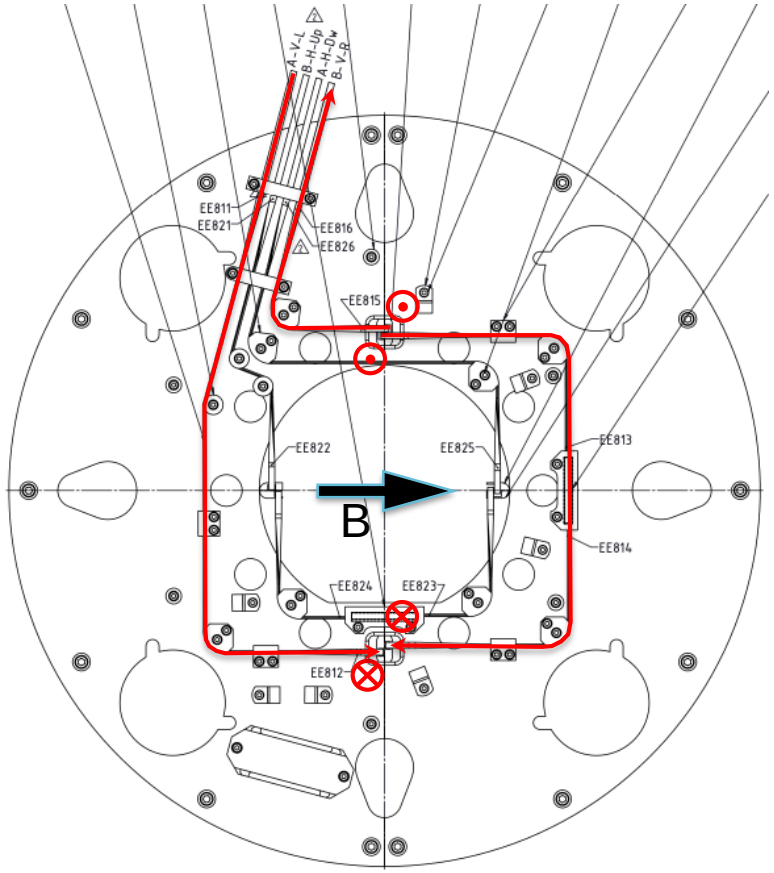
i.e. obtaining the result:

$$R_{EE825\text{-}EE826} < R_{EE824\text{-}EE826} < R_{EE822\text{-}EE826}$$

Alternatively, perform magnetic measurements to check the compliance with the electrical scheme.

Current routing for MCBXF V correctors

(Only the drawings for MCBXFB are on CDD, but the connection side assembly for MCBXFA is identical)



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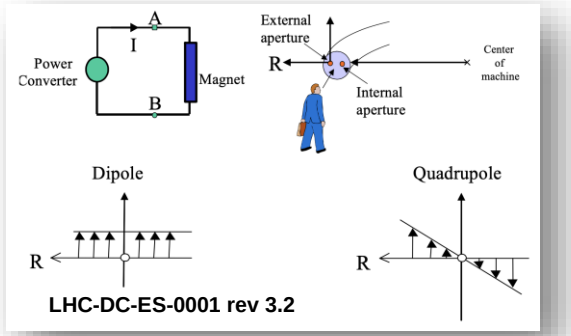
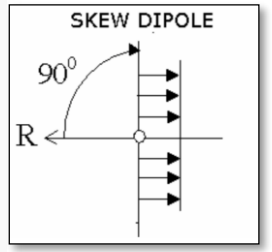




Poles connection, **polarities** and leads labelling **are coherent** with LHC-DC-ES-001.

Holding point #4:
During assembly, perform comparative measurements of the resistances across the voltage taps, between one lead and the Vtaps

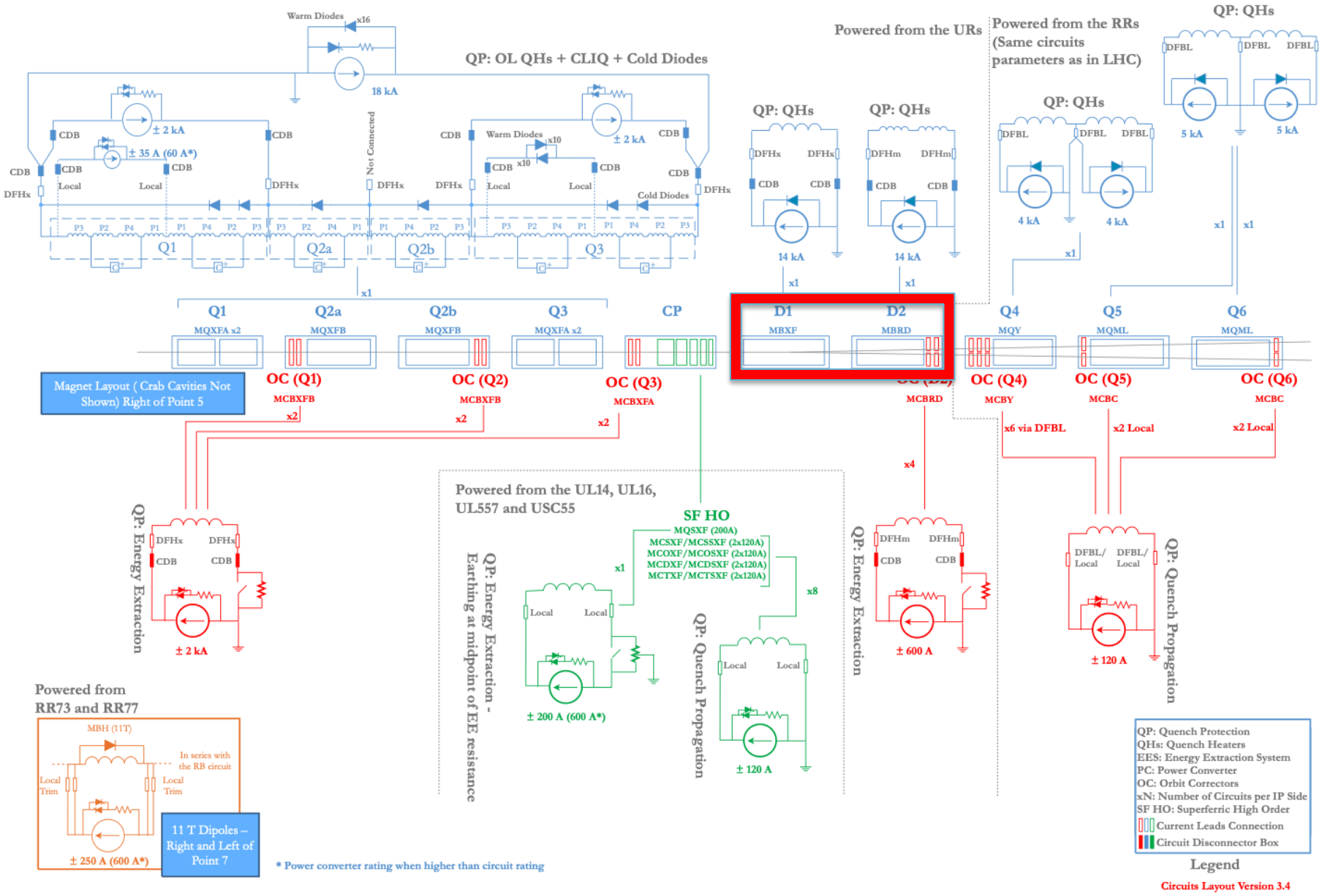
i.e. obtaining the result:

$$R_{EE812-EE811} < R_{EE813-EE811} < R_{EE815-EE811}$$

Alternatively, perform magnetic measurements to check the compliance with the electrical scheme.

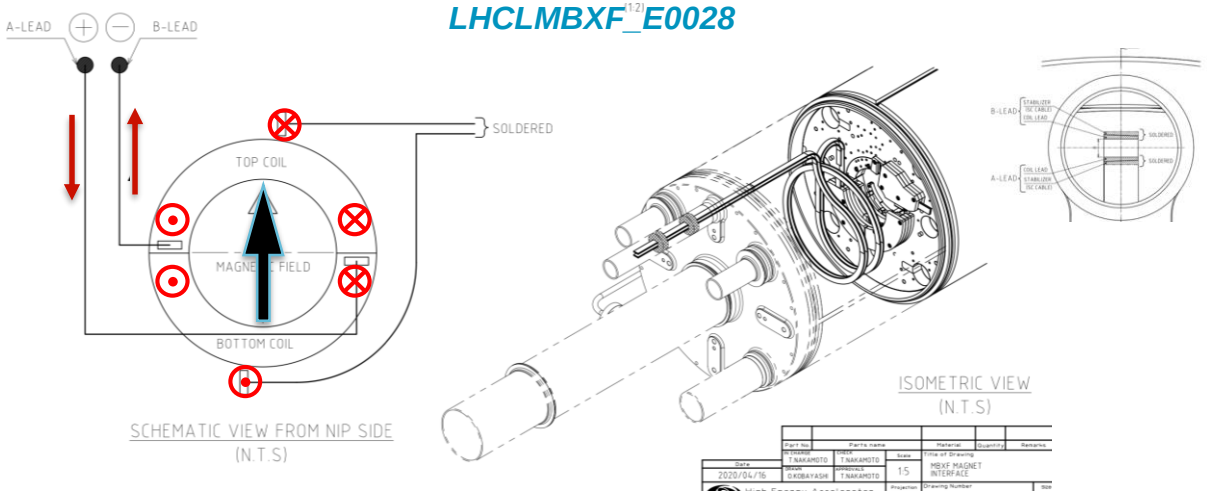
HL-LHC circuits layout

From the MCF web page

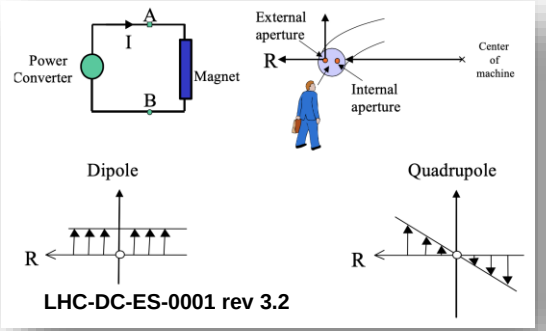


MBXF (D1) electrical scheme and bus routing

Poles connection, **polarities** and leads labelling **are coherent** with LHC-DC-ES-001.



LHCLMBXF_E0028

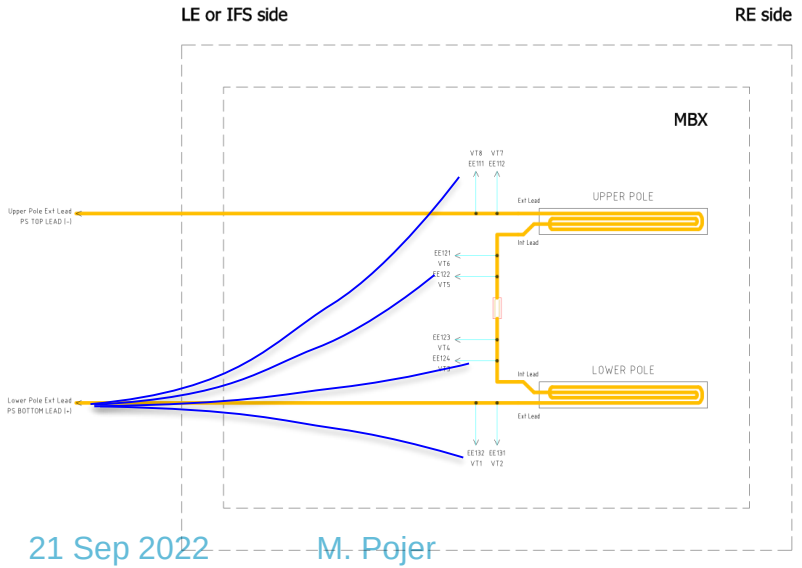


Holding point #5:
During assembly, perform comparative measurements of the resistances across the voltage taps, between one pole and the Vtaps

i.e. obtaining the result:

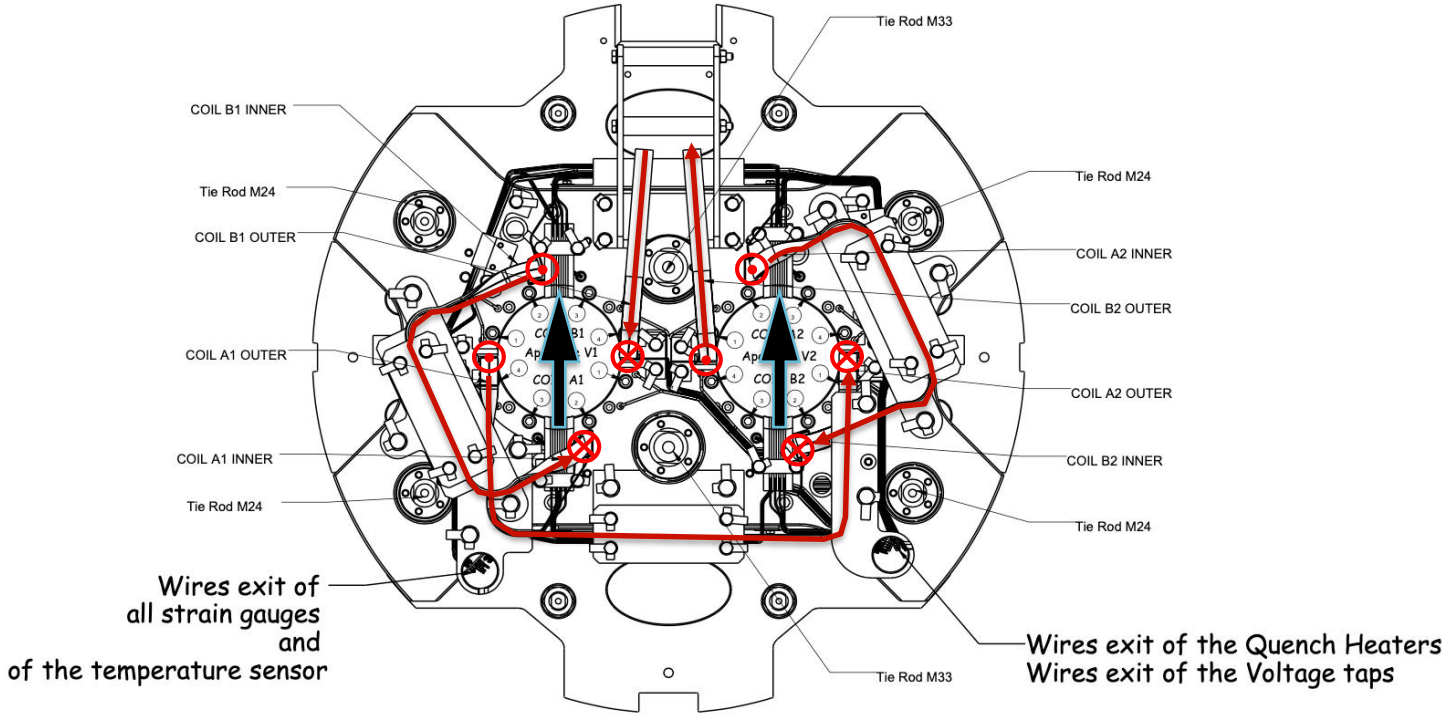
$R_{EE132\text{-}LeadPos} < R_{EE124\text{-}LeadPos} < < R_{EE121\text{-}LeadPos} < R_{EE111\text{-}LeadPos}$

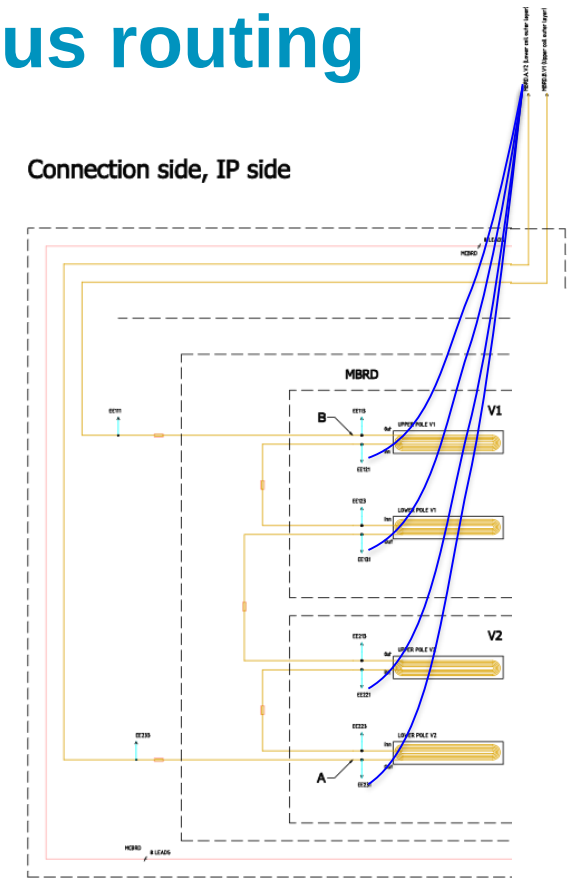
Alternatively, perform magnetic measurements to check that lead B in on the top and lead A on the bottom of the outgoing bus.



LHCLMBXF_E0024

MBRD (D2) electrical scheme and bus routing





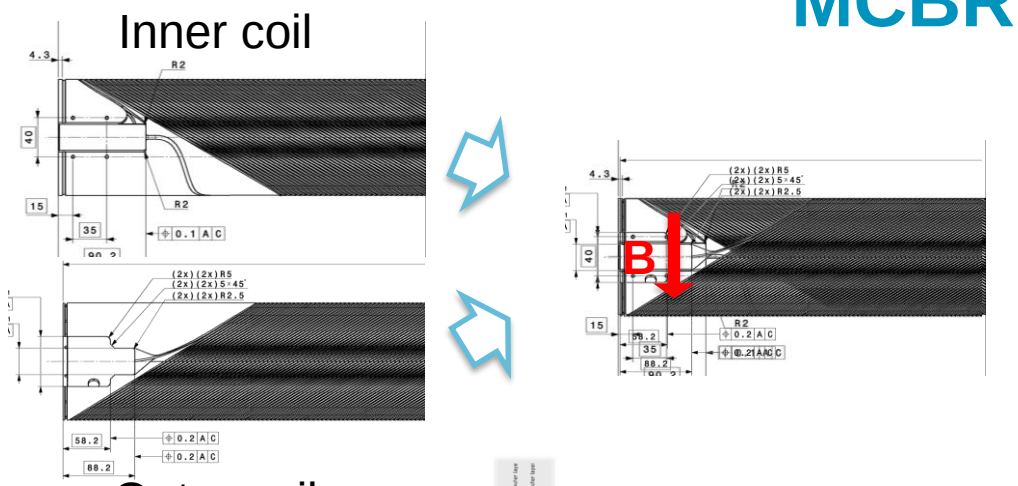
Lead A is the "in" of V1
Lead B is the "out" of V2

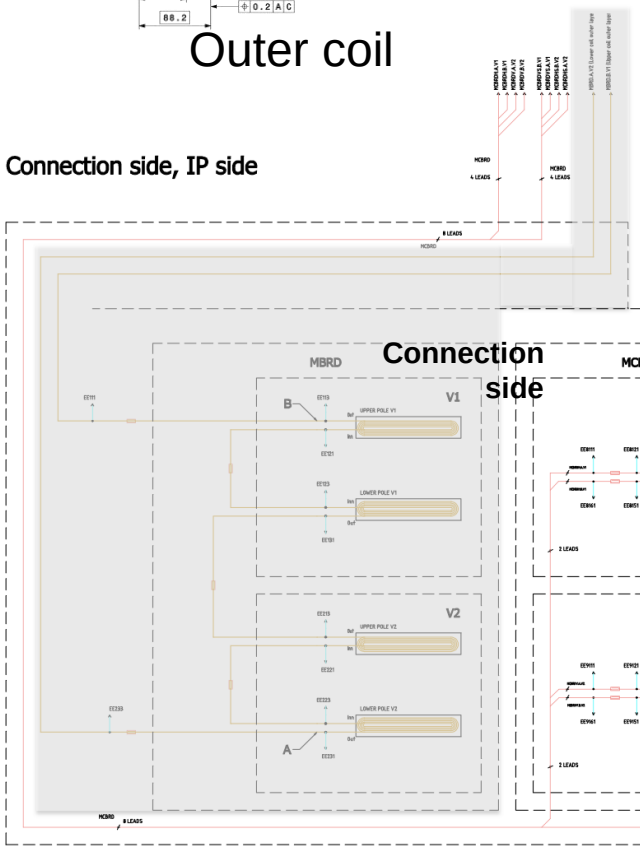
Holding point #6:
perform comparative measurements of the resistances across the voltage taps, between one pole and the Vtaps
i.e. obtaining the result:

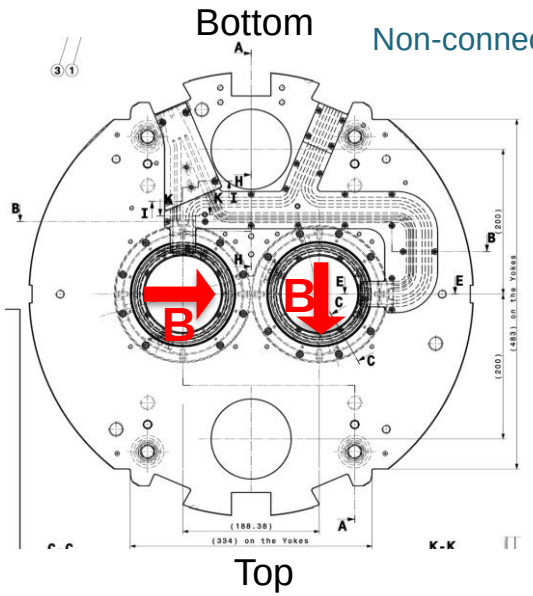
$R_{EE231\text{-}LeadPos} < R_{EE221\text{-}LeadPos} << R_{EE131\text{-}LeadPos} < R_{EE121\text{-}LeadPos}$

Alternatively, perform magnetic measurements.

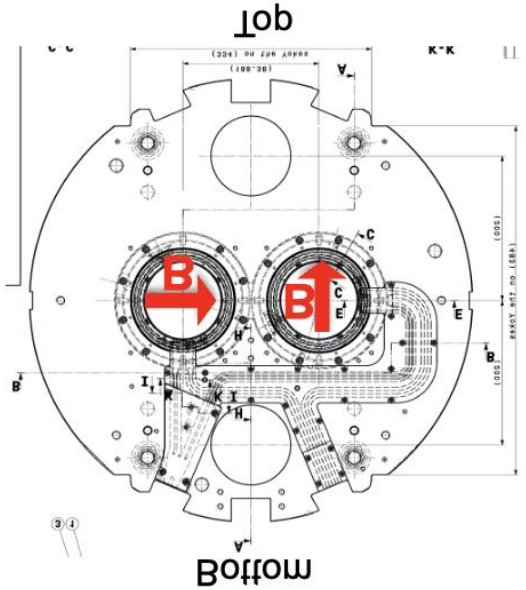
MCBRD verification







Connection side and beam direction



As long as the A lead is the one 'entering' in the inner coil and the lead B is 'exiting from the outer coil, the polarities are coherent with **LHC-DC-ES-001**.

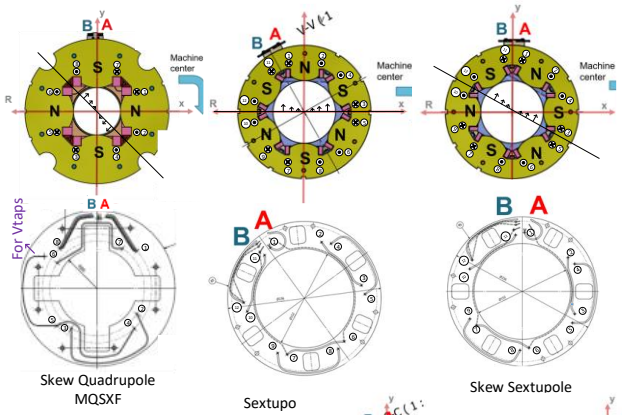
Holding point #7:
During assembly, perform comparative measurements of the resistances across the voltage taps, between one current pole and the Vtaps, to check the proper busbars routing

i.e. obtaining the result:

$R_{EE8121\text{-}MCBRDH.A.V1} < R_{EE8151\text{-}MCBRDH.A.V1}$
$R_{EE9121\text{-}MCBRDV.A.V2} < R_{EE9151\text{-}MCBRDV.A.V2}$
$R_{EE8251\text{-}MCBRDVS.B.V1} < R_{EE8221\text{-}MCBRDVS.B.V1}$
$R_{EE9251\text{-}MCBRDHS.B.V2} < R_{EE9221\text{-}MCBRDHS.B.V2}$

Alternatively, perform magnetic measurements to check the compliance with the electrical scheme.

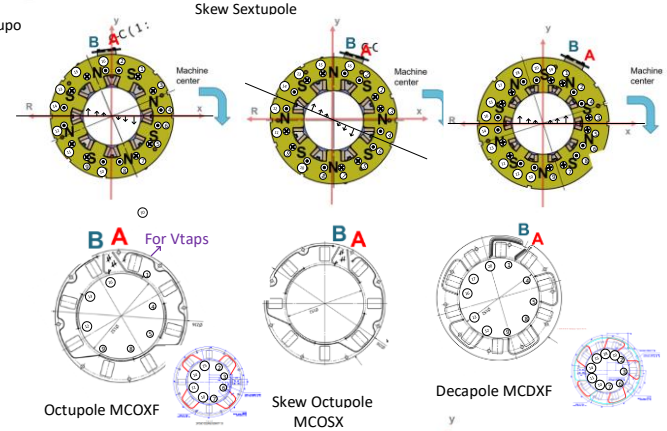
High Order correctors



Skew Quadrupole MQSXF

Sextupo

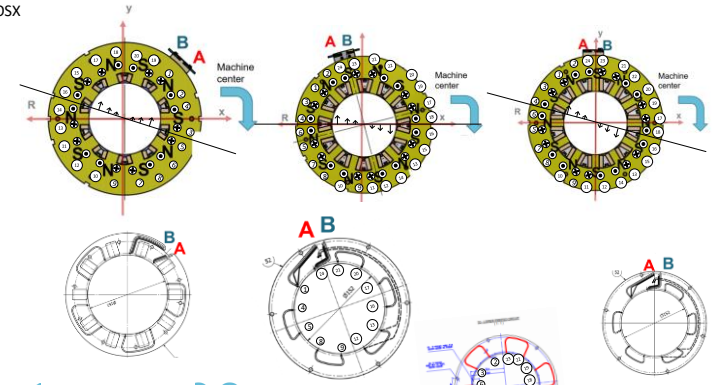
Skew Sextupole



Octupole MCOXF

Skew Octupole MCOSX

Decapole MCDXF

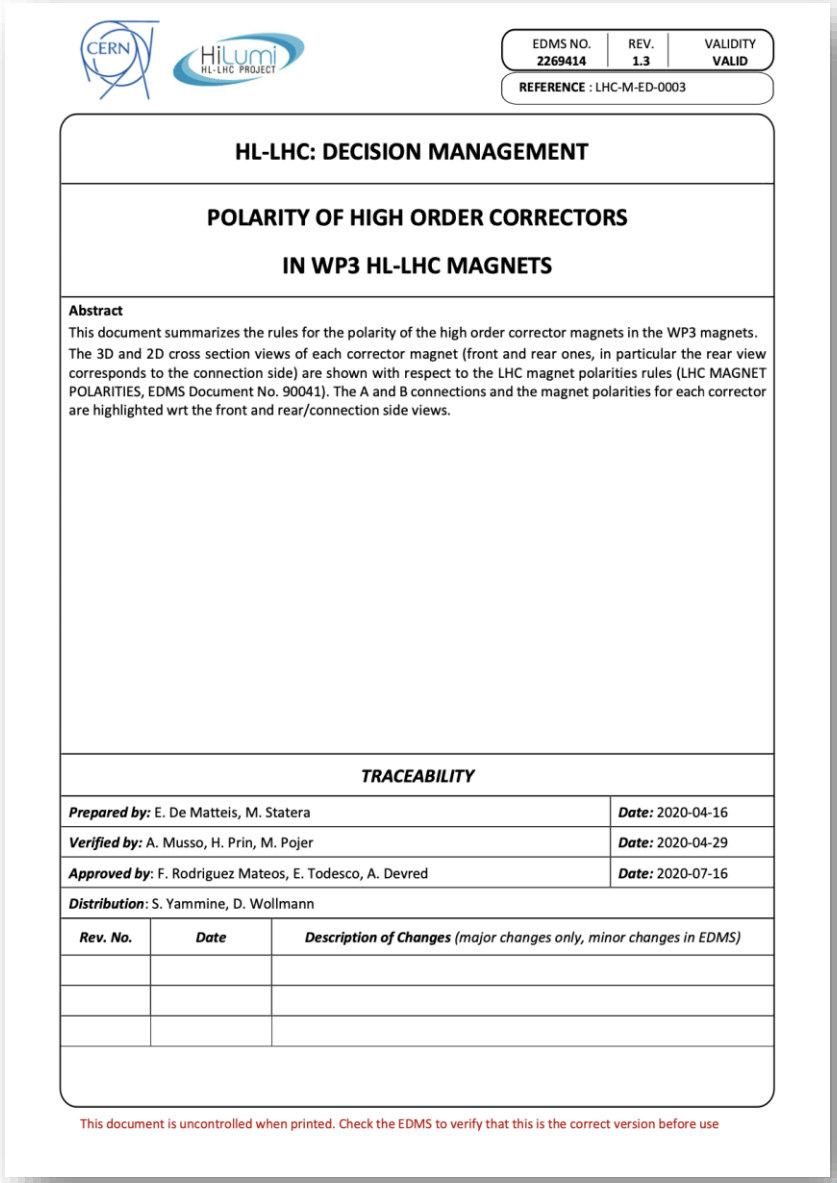


Skew Decapole MCDSXF

Dodecapole MCTXF

Skew Dodecapole MCTSXF

Courtesy of S. Yammine



CERN HiLumi HL-LHC PROJECT

EDMS NO.	REV.	VALIDITY
2269414	1.3	VALID

REFERENCE : LHC-M-ED-0003

HL-LHC: DECISION MANAGEMENT

POLARITY OF HIGH ORDER CORRECTORS

IN WP3 HL-LHC MAGNETS

Abstract

This document summarizes the rules for the polarity of the high order corrector magnets in the WP3 magnets. The 3D and 2D cross section views of each corrector magnet (front and rear ones, in particular the rear view corresponds to the connection side) are shown with respect to the LHC magnet polarities rules (LHC MAGNET POLARITIES, EDMS Document No. 90041). The A and B connections and the magnet polarities for each corrector are highlighted wrt the front and rear/connection side views.

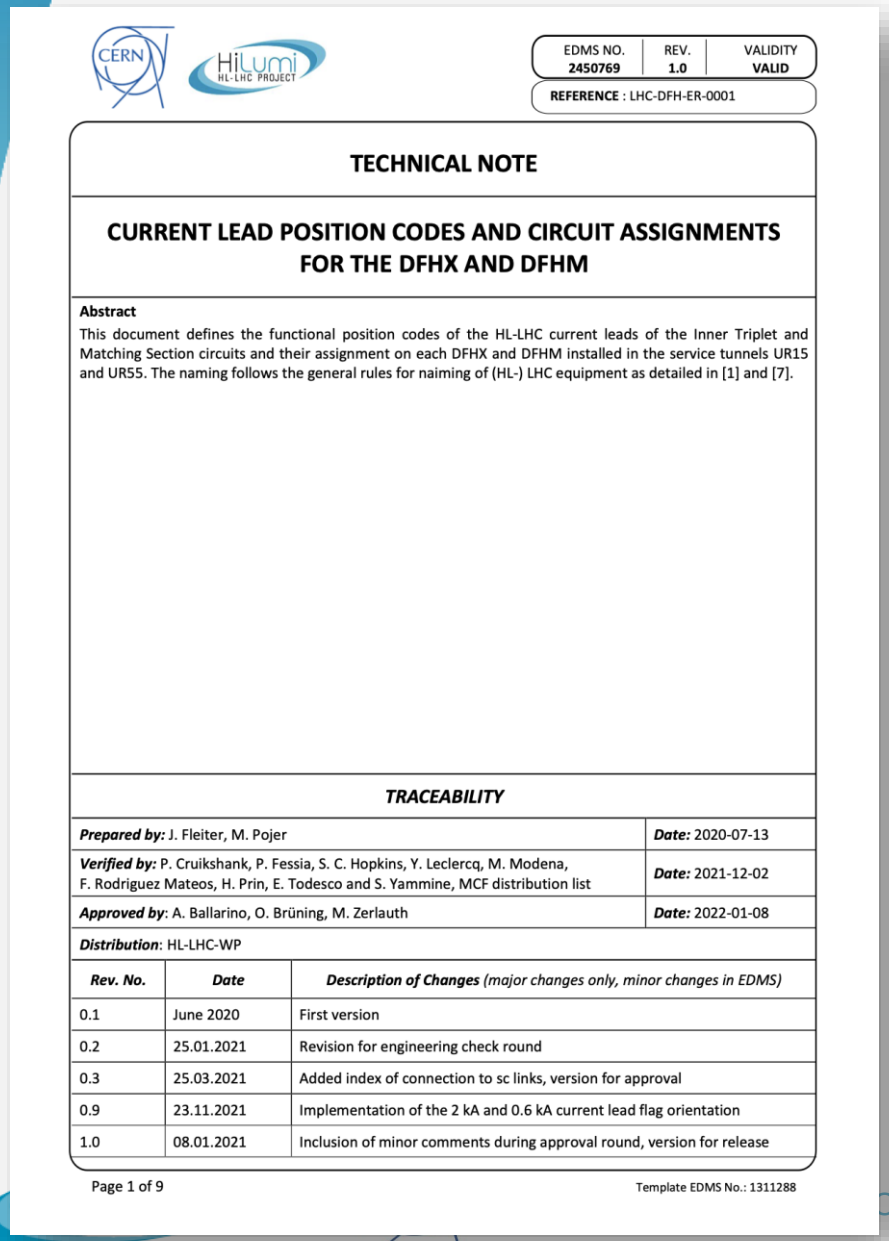
TRACEABILITY

Prepared by: E. De Matteis, M. Statera	***Date:*** 2020-04-16
Verified by: A. Musso, H. Prin, M. Pojer	***Date:*** 2020-04-29
Approved by: F. Rodriguez Mateos, E. Todesco, A. Devred	***Date:*** 2020-07-16
Distribution: S. Yammine, D. Wollmann	

Rev. No.	*Date*	*Description of Changes (major changes only, minor changes in EDMS)*

This document is uncontrolled when printed. Check the EDMS to verify that this is the correct version before use

Current lead position codes and circuits assignment



EDMS NO. 2450769 | REV. 1.0 | VALIDITY VALID

REFERENCE : LHC-DFH-ER-0001

TECHNICAL NOTE

CURRENT LEAD POSITION CODES AND CIRCUIT ASSIGNMENTS FOR THE DFHX AND DFHM

Abstract

This document defines the functional position codes of the HL-LHC current leads of the Inner Triplet and Matching Section circuits and their assignment on each DFHX and DFHM installed in the service tunnels UR15 and UR55. The naming follows the general rules for naiming of (HL-) LHC equipment as detailed in [1] and [7].

TRACEABILITY

Prepared by: J. Fleiter, M. Pojer	***Date:*** 2020-07-13
Verified by: P. Cruikshank, P. Fessia, S. C. Hopkins, Y. Leclercq, M. Modena, F. Rodriguez Mateos, H. Prin, E. Todesco and S. Yammine, MCF distribution list	***Date:*** 2021-12-02
Approved by: A. Ballarino, O. Brüning, M. Zerlauth	***Date:*** 2022-01-08
Distribution: HL-LHC-WP	

Rev. No.	*Date*	*Description of Changes (major changes only, minor changes in EDMS)*
0.1	June 2020	First version
0.2	25.01.2021	Revision for engineering check round
0.3	25.03.2021	Added index of connection to sc links, version for approval
0.9	23.11.2021	Implementation of the 2 kA and 0.6 kA current lead flag orientation
1.0	08.01.2021	Inclusion of minor comments during approval round, version for release

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FUNCTIONAL POSITION CODE OF CURRENT LEADS

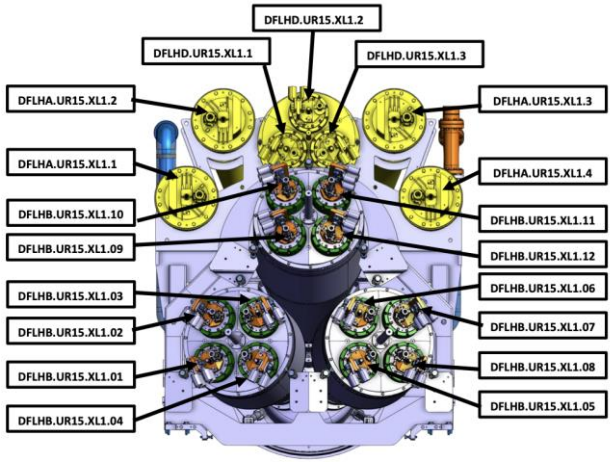


Figure 2: Front view of the warm terminal of IT HL-LHC current leads installed in the DFHX for Point 1 Left with their functional position codes.

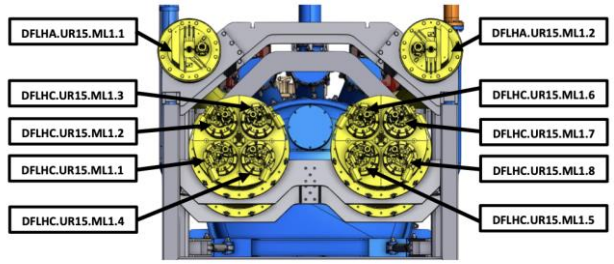


Figure 3: Front view of the warm terminal of MS HL-LHC current leads installed in the DFHM for Point 1 Left with their functional position codes.

CURRENT LEAD ASSIGNMENTS

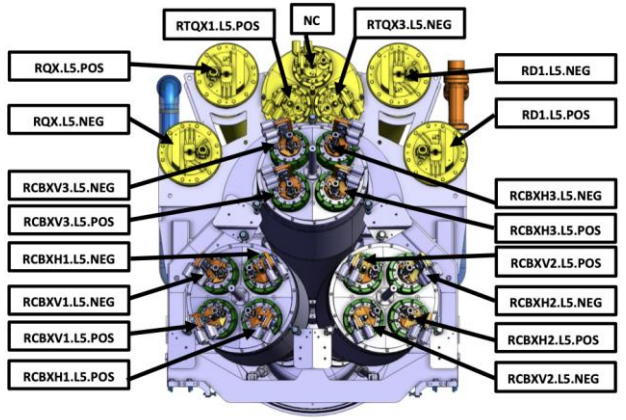


Figure 5: Front view of the warm terminal of IT HL-LHC current leads installed in the DFHX for Point 5 Left with the circuit assignment.

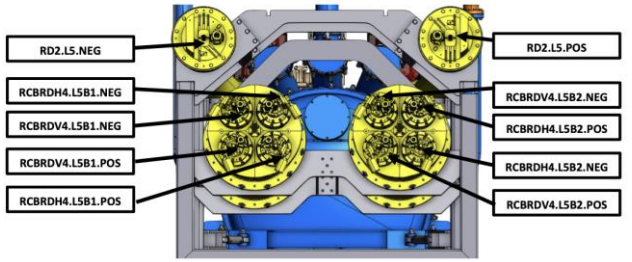
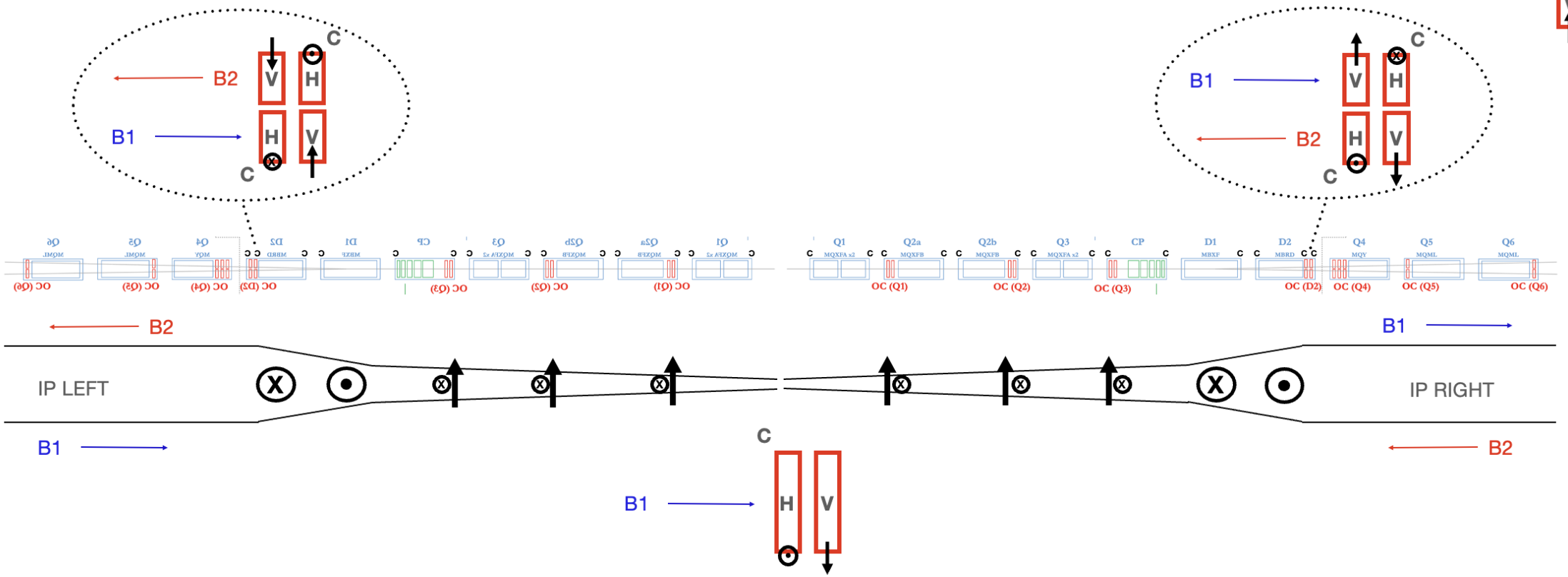


Figure 6: Front view of the warm terminal of MS HL-LHC current leads installed in the DFHM for Point 5 Left with the circuit assignment.

Dipole fields orientation in the IPs

Standard MCBRD package:

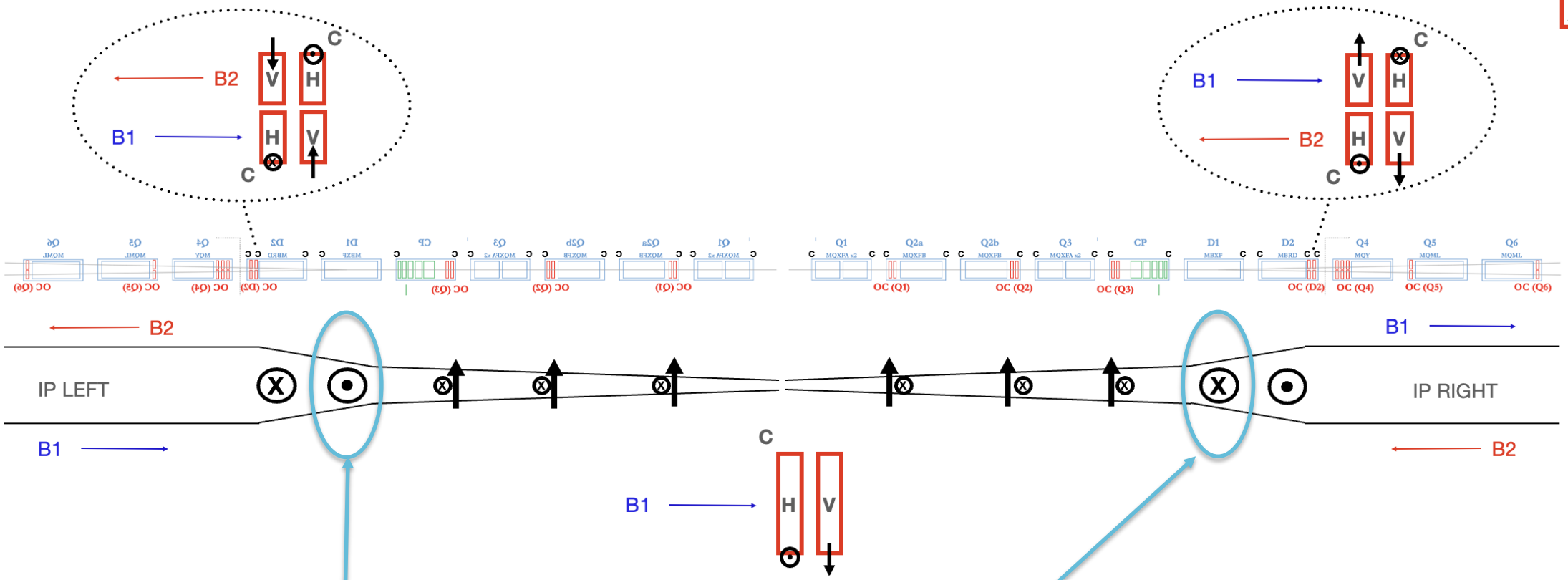


Polarity convention for common correctors OC(Q1,Q2,Q3):

(The beam convention is opposite to the polarity convention for all orbit correctors in the IP)

Dipole fields orientation in the IPs

Standard MCBRD package:



Polarity convention for common correctors OC(Q1,Q2,Q3):

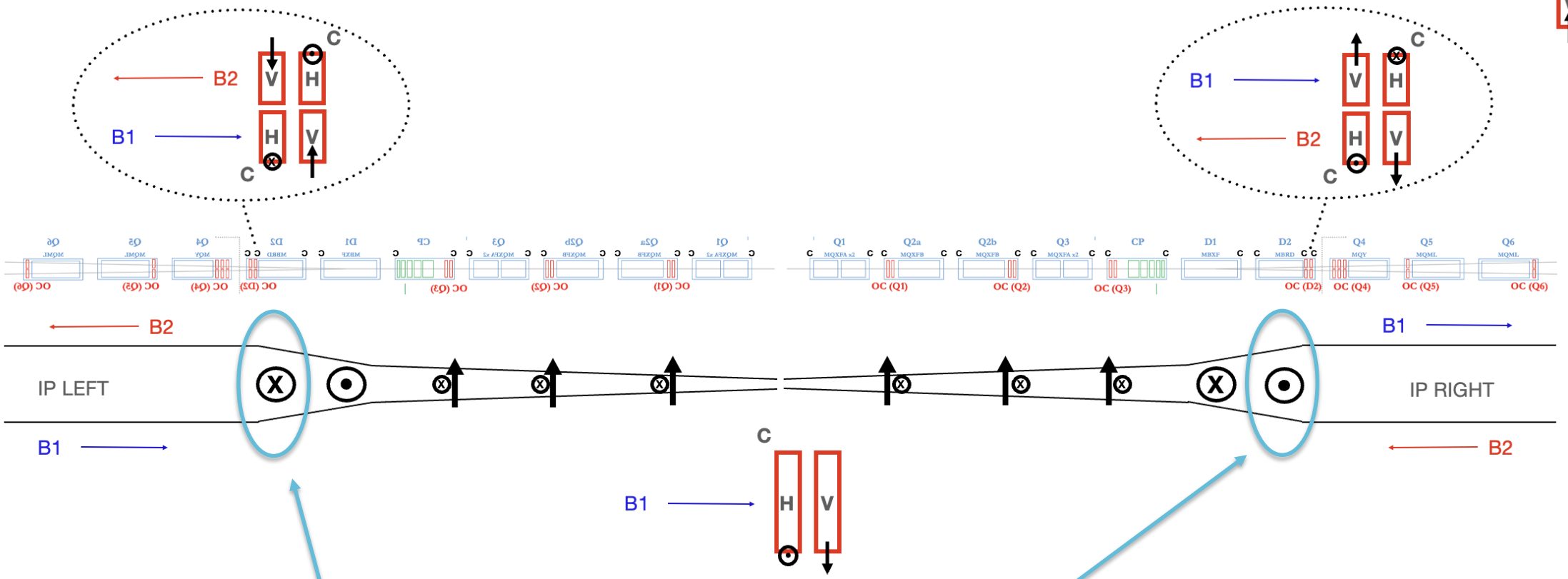
Upward field, in agreement with magnet A/B leads

Downward field, opposite to magnet A/B leads

DFLHA.UR15.XL1.3	B	RD1.L1. NEG	DFLHA.UR15.XR1.3	A	RD1.R1. NEG
DFLHA.UR15.XL1.4	A	RD1.L1. POS	DFLHA.UR15.XR1.4	B	RD1.R1. POS

Dipole fields orientation in the IPs

Standard MCBRD package:



Polarity convention for common correctors OC(Q1,Q2,Q3):

Downward field, opposite to magnet A/B leads

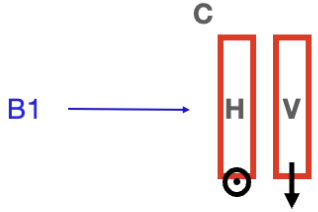
Upward field, in agreement with magnet A/B leads

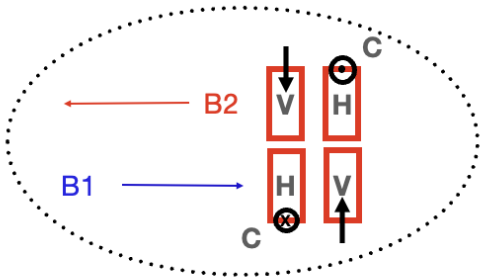
DFLHA.UR15.ML1.1	A	RD2.L1.NEG	DFLHA.UR15.MR1.1	A	RD2.R1.POS
DFLHA.UR15.ML1.2	B	RD2.L1.POS	DFLHA.UR15.MR1.2	B	RD2.R1.NEG

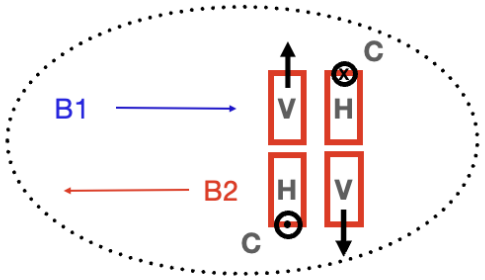
Dipole fields orientation in the IPs

(The beam convention is opposite to the polarity convention for all orbit correctors in the IP)

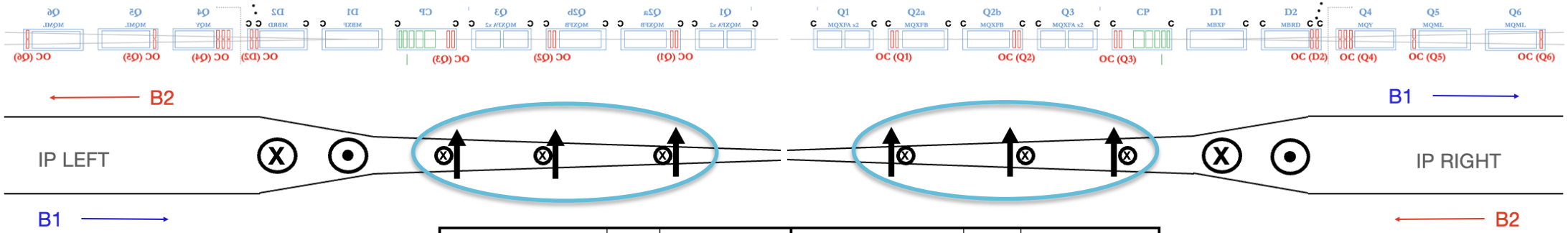
Standard MCBRD package:







Polarity convention for common correctors OC(Q1,Q2,Q3):



Current lead functional position code	Type	Circuit assignment	Current lead functional position code	Type	Circuit assignment
DFLHB.UR15.XL1.1	A	RCBXV1.L1. POS	DFLHB.UR15.XR1.1	A	RCBXV1.R1. NEG
DFLHB.UR15.XL1.2	B	RCBXV1.L1. NEG	DFLHB.UR15.XR1.2	B	RCBXV1.R1. POS
DFLHB.UR15.XL1.3	A	RCBXH1.L1. NEG	DFLHB.UR15.XR1.3	A	RCBXH1.R1. NEG
DFLHB.UR15.XL1.4	B	RCBXH1.L1. POS	DFLHB.UR15.XR1.4	B	RCBXH1.R1. POS
DFLHB.UR15.XL1.5	A	RCBXV2.L1. NEG	DFLHB.UR15.XR1.5	A	RCBXV2.R1. POS
DFLHB.UR15.XL1.6	B	RCBXV2.L1. POS	DFLHB.UR15.XR1.6	B	RCBXV2.R1. NEG
DFLHB.UR15.XL1.7	A	RCBXH2.L1. NEG	DFLHB.UR15.XR1.7	A	RCBXH2.R1. NEG
DFLHB.UR15.XL1.8	B	RCBXH2.L1. POS	DFLHB.UR15.XR1.8	B	RCBXH2.R1. POS
DFLHB.UR15.XL1.9	A	RCBXV3.L1. POS	DFLHB.UR15.XR1.9	A	RCBXV3.R1. NEG
DFLHB.UR15.XL1.10	B	RCBXV3.L1. NEG	DFLHB.UR15.XR1.10	B	RCBXV3.R1. POS
DFLHB.UR15.XL1.11	A	RCBXH3.L1. NEG	DFLHB.UR15.XR1.11	A	RCBXH3.R1. NEG
DFLHB.UR15.XL1.12	B	RCBXH3.L1. POS	DFLHB.UR15.XR1.12	B	RCBXH3.R1. POS

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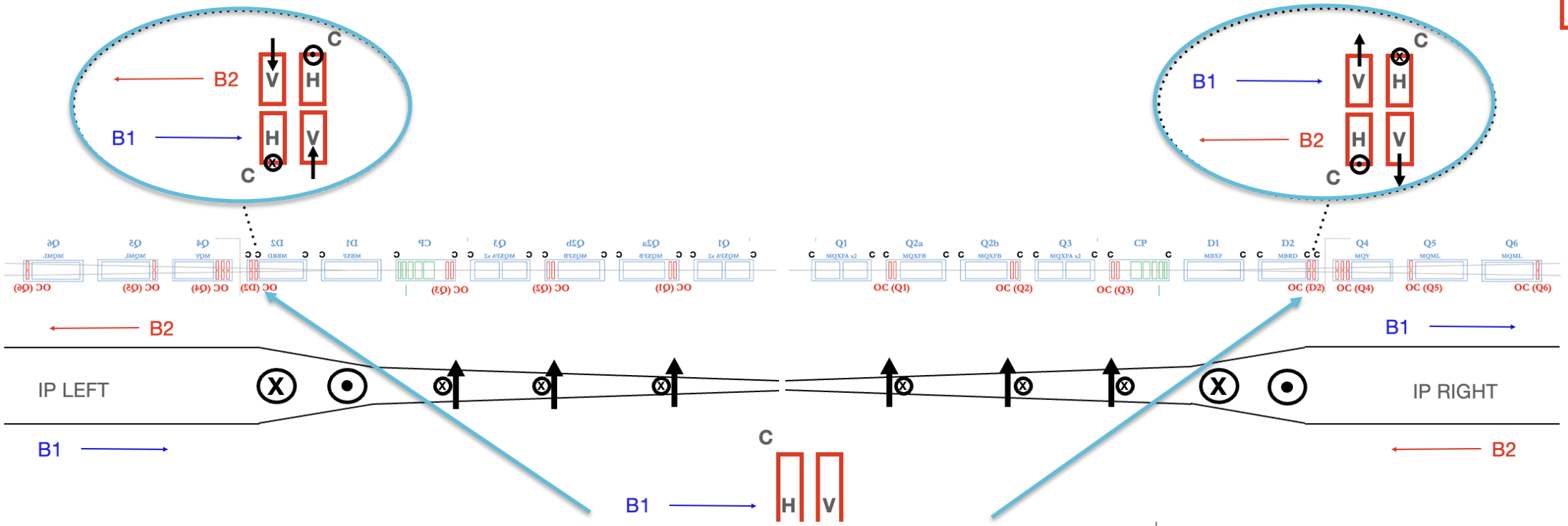
Dipole fields orientation in the IPs

(The beam convention is opposite to the polarity convention for all orbit correctors in the IP)

Standard MCBRD package:



Current lead functional position code	Type	Circuit assignment	Current lead functional position code	Type	Circuit assignment
DFLHC.UR15.ML1.1	A	RCBRDV4.L1B1.POS	DFLHC.UR15.MR1.1	A	RCBRDV4.R1B1.NEG
DFLHC.UR15.ML1.2	B	RCBRDV4.L1B1.NEG	DFLHC.UR15.MR1.2	B	RCBRDV4.R1B1.POS
DFLHC.UR15.ML1.3	A	RCBRDH4.L1B1.NEG	DFLHC.UR15.MR1.3	A	RCBRDH4.R1B1.NEG
DFLHC.UR15.ML1.4	B	RCBRDH4.L1B1.POS	DFLHC.UR15.MR1.4	B	RCBRDH4.R1B1.POS
DFLHC.UR15.ML1.5	A	RCBRDV4.L1B2.POS	DFLHC.UR15.MR1.5	A	RCBRDV4.R1B2.NEG
DFLHC.UR15.ML1.6	B	RCBRDV4.L1B2.NEG	DFLHC.UR15.MR1.6	B	RCBRDV4.R1B2.POS
DFLHC.UR15.ML1.7	A	RCBRDH4.L1B2.POS	DFLHC.UR15.MR1.7	A	RCBRDH4.R1B2.POS
DFLHC.UR15.ML1.8	B	RCBRDH4.L1B2.NEG	DFLHC.UR15.MR1.8	B	RCBRDH4.R1B2.NEG

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Thanks for the attention

Questions?