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the **Large Hadron Collider** project

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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

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rev 1.2	2001-09-26	13	Modifications: paragraph 3, 7
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Rev 2.1	2001-12-13	13	Modifications of paragraph 10: title and 2nd §.
		All	Revised version 2.1: Released
Rev 2.2	2004-04-23	13,14	Modifications chapter 10, addition chapter 11
Rev 2.3	2004-10-15	All	Revised by Stephan Russenschuck as LHC Magnet Polarity Coordinator Page 4: Removed B1 and B2 notation, replaced by Dipole / Quadrupole to avoid confusion (B1 and B2 are only well defined in a reference frame) Page 5: Removed A1 and A2 notation, replaced by Skew Dipole / Skew Quadrupole, **removed erroneous paragraph 6.** Page 6: Removed B1 and A1 notation in the upper drawing, replaced by dipole / skew dipole. Note that the definition is not coherent with the definitions in MAD or in the magnet calculation and measurement frame. Page 7: Removed B2 and A2 notation in the lower drawing Page 8: Removed B3 and A3 notation in the lower drawing Page 9: Removed A4, B4, and B5 notation in both drawings Page 10, 11: Removed B1, B3, B4, and B5 notation in drawing, text and table
3.0	2004-10-27	All	Submission for engineering check
	2004-12-15	All	Changing the term ‘magnets’ into ‘main magnets’ in sections 4 and 7.1 Removing the sentence on spool piece magnets in section 7.1 Released version
3.1	2004-12-03	All	Minor modifications New Released version
3.2	2005-08-09	15	Adding chapter on experimental magnets and compensators (section 6.1) New Released version

Table of Contents

1. REFERENCE DOCUMENTS

- Minutes of the TCC meeting 98-02 of 27 February 1998.
- Minutes of the P&LC meeting of 10 June 1998.
- Field Error Naming Conventions for LHC Magnets” – LHC-M-ES-0001.

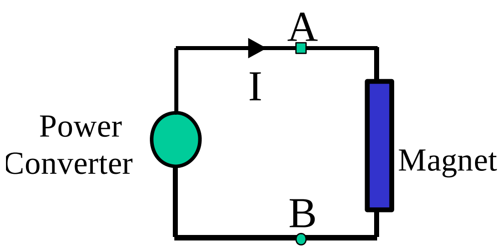
2. INTRODUCTION

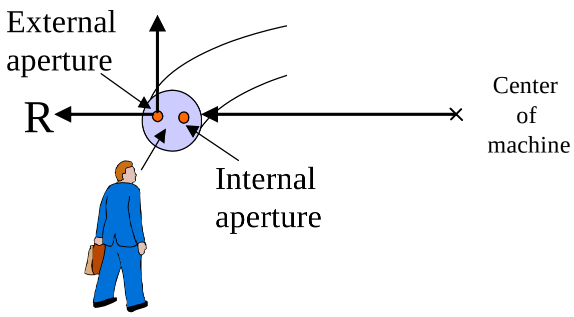
The following basic set of rules is conceived to give a simple method of identification of the magnet polarities as installed in the tunnel independent of the applied reference frames. It allows magnets of a given type to be manufactured and assembled without prior knowledge of its position or function in the machine. The final polarity of the operating current, and thus the optical function of the magnet, will be obtained by choosing the correct connection on the warm side of the machine.

This set of rules does not follow the conventions of the beam optics program MAD or the conventions for magnetic field computations and measurements. Appropriate transformations into the MAD or measurement reference frames have to be applied.

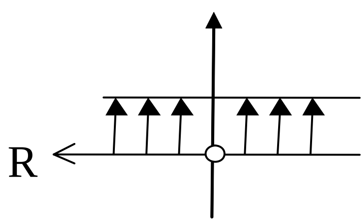
3. BASIC RULES

1. The magnet terminals and the current leads to which they are connected will be marked with “A” and “B” (not “+” and “-”).
2. 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.

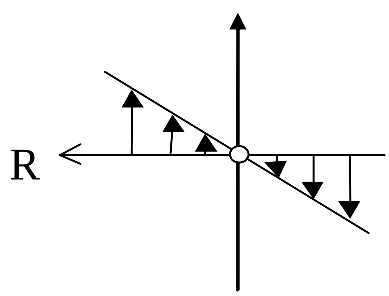




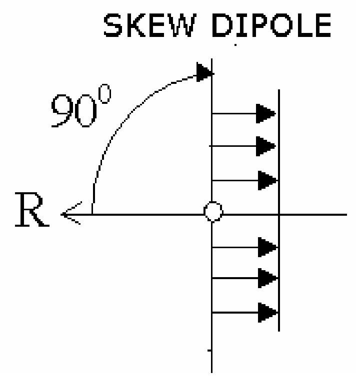
Dipole

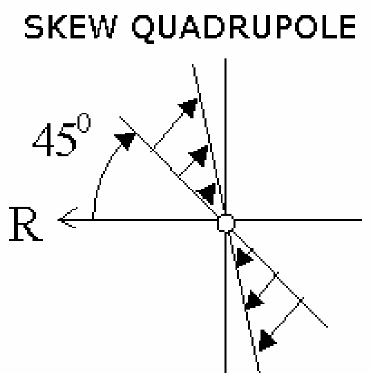


Quadrupole



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





4. The rules apply to both internal and external apertures. Twin aperture magnets often have only one pair of terminals serving the two apertures. In the case of conflict (e.g. the main dipoles), the external aperture takes priority for the application of the rules.

5. The set of rules applies to the magnets as installed in the machine and therefore ignores at which end the connections are placed. It is supposed that each magnet will be installed in the same direction. (See paragraph 4 below for special case.)

4. SPECIAL CASE FOR TURNED MAGNETS

In general, magnets are installed facing the same (normal) direction around the machine with their connections at any end of the magnet. However, a few magnets will be turned to face the opposite direction. If this occurs, the magnet is identical to the normal facing magnets and the terminal markings remain the same. Compensation for the resultant change of polarity, violating the basic rules, is made by an appropriate change of connection on the warm side.

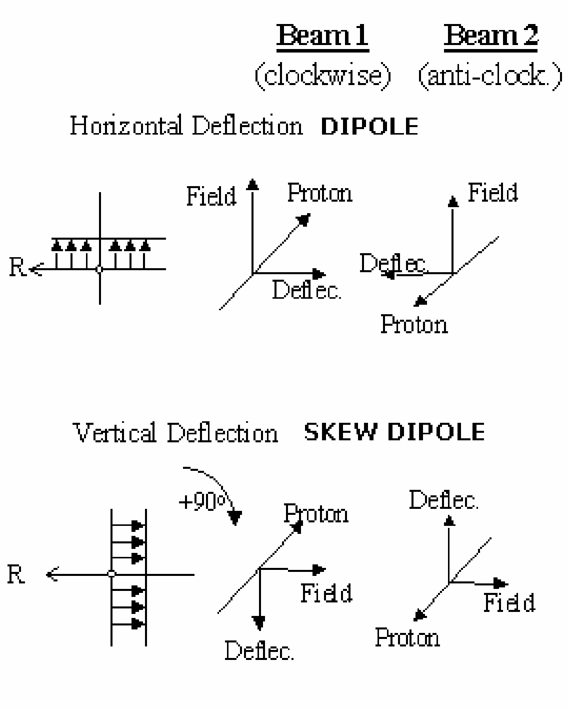
5. APPLICATION OF THE RULES

Examples of the application of the above rules to the LHC magnets are given in the following illustrations. They define the resultant field and optical function for all types of LHC magnets, considering the direction of the beam and the terminal into which the current enters. The illustrations are made looking in direction of beam 1 (circulating clockwise) with the machine centre to the right.

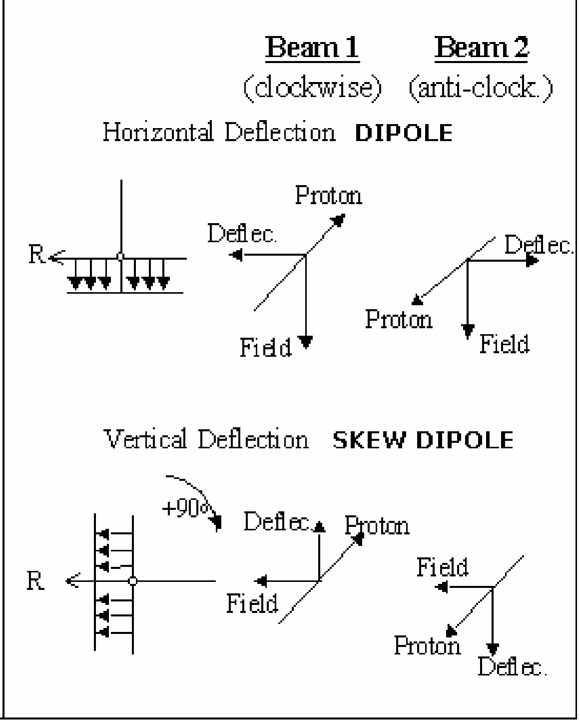
Beam 1 is taken as the clockwise rotating beam and beam 2 as the anti-clockwise. Beam 1 is in the external aperture in sectors 1-2, 5-6, 6-7, 7-8, while beam 2 is in the external aperture in sectors 2-3, 3-4, 4-5, 8-1.

SINGLE APERTURE DIPOLES

Current into Terminal "A"

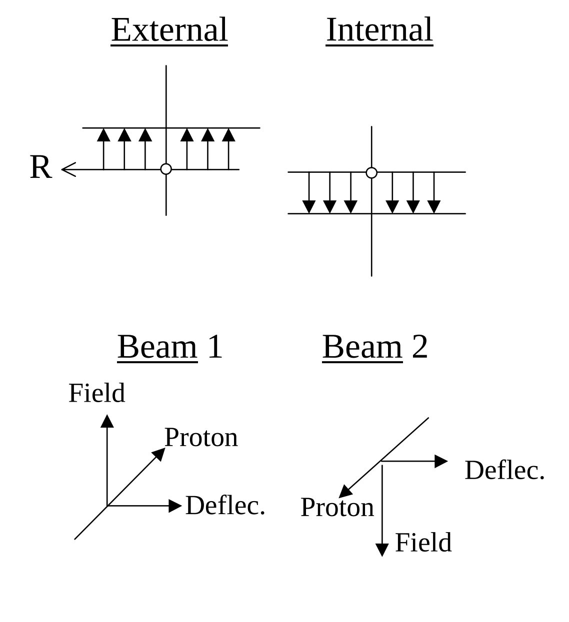


Current into Terminal "B"

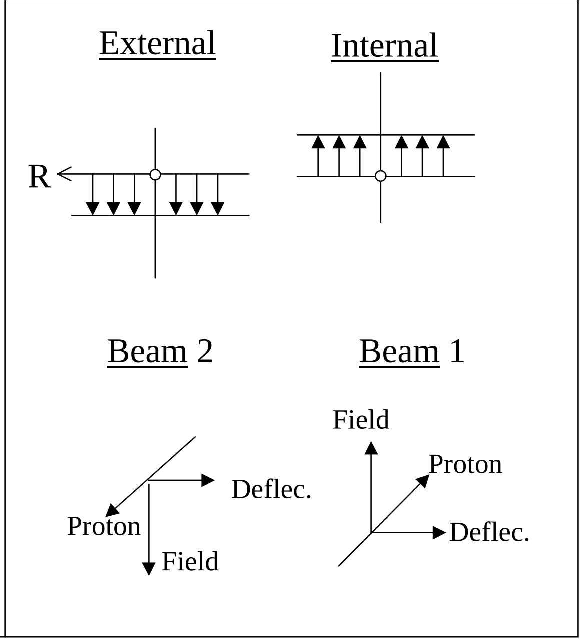


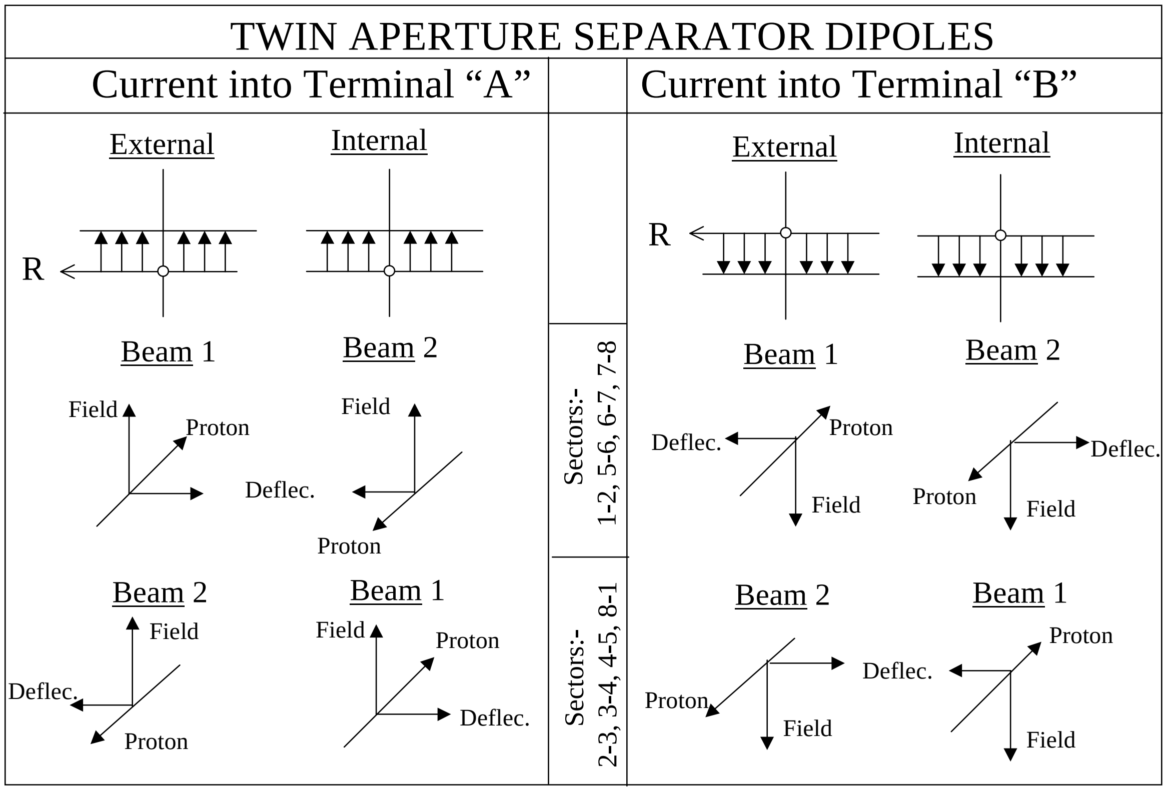
TWIN APERTURE MAIN DIPOLES

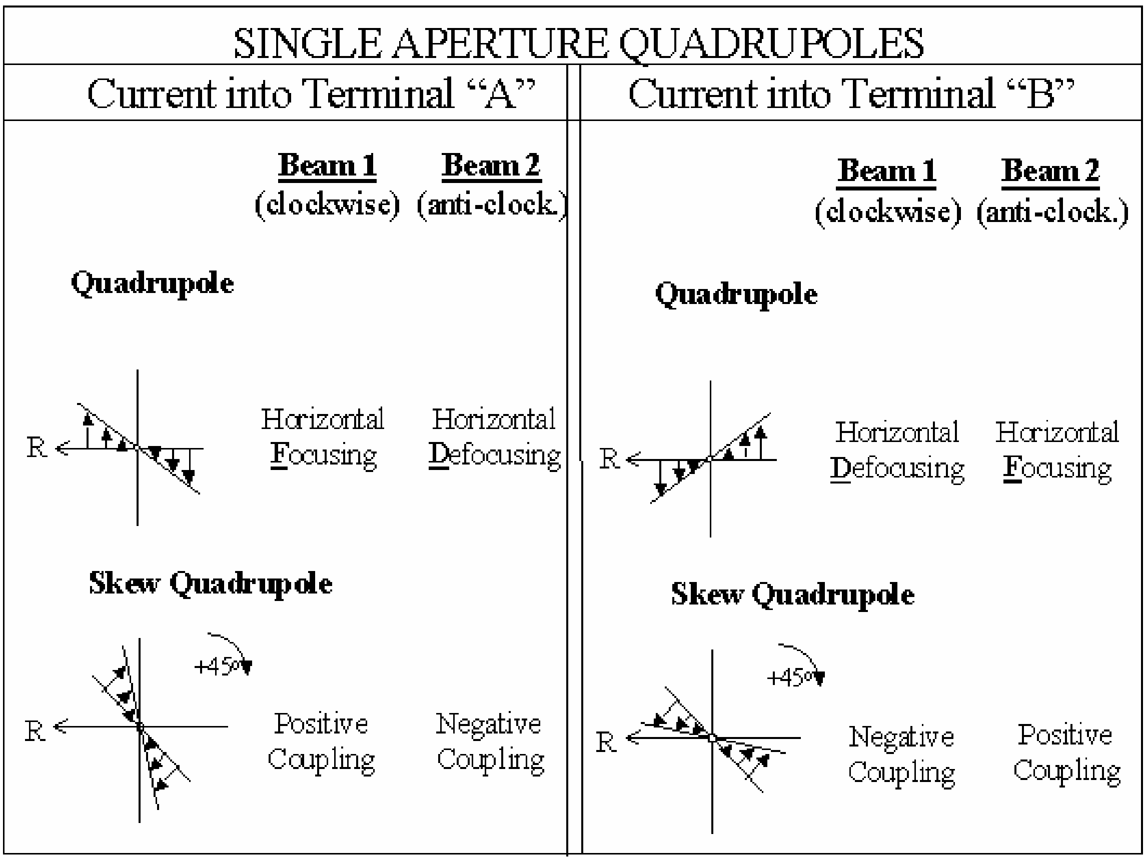
Current into Terminal "A"
Sectors: 1-2, 5-6, 6-7, 7-8



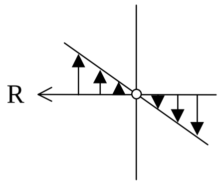
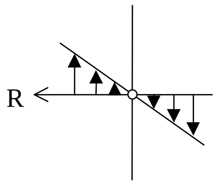
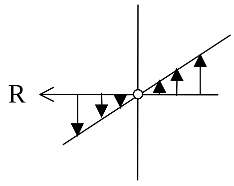
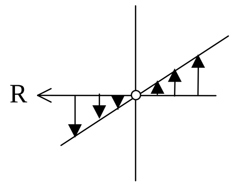
Current into Terminal "B"
Sectors: 2-3, 3-4, 4-5, 8-1



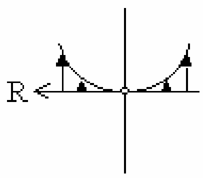
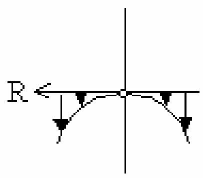
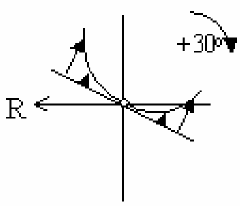
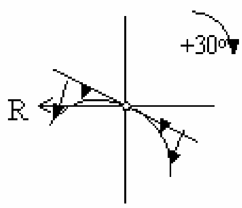

TWIN APERTURE SEPARATOR DIPOLES
Current into Terminal "A"
Current into Terminal "B"
External
Internal
R
Beam 1
Beam 2
Field
Proton
Deflec.
Sectors:- 1-2, 5-6, 6-7, 7-8
Sectors:- 2-3, 3-4, 4-5, 8-1


SINGLE APERTURE QUADRUPOLES
Current into Terminal "A"
Current into Terminal "B"
Beam 1 (clockwise)
Beam 2 (anti-clock.)
Quadrupole
R
Horizontal Focusing
Horizontal Defocusing
Skew Quadrupole
+45°
Positive Coupling
Negative Coupling

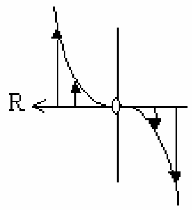
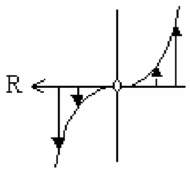
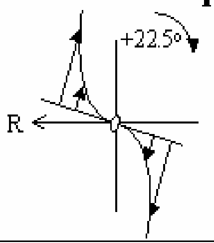
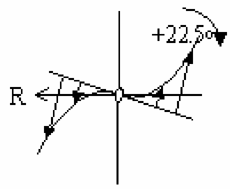
TWIN APERTURE MAIN QUADRUPOLES

Current into Terminal "A"			Current into Terminal "B"	
External	Internal		External	Internal
				
Beam 1 (clockwise) Horizontal **F**ocusing	**Beam 2** (anti-clock.) Horizontal **D**efocusing	Sectors:- 1-2, 5-6, 6-7, 7-8	**Beam 1** (clockwise) Horizontal **D**efocusing	**Beam 2** (anti-clock.) Horizontal **F**ocusing
Beam 2 (anti-clock.) Horizontal **D**efocusing	**Beam 1** (clockwise) Horizontal **F**ocusing	Sectors:- 2-3, 3-4, 4-5, 8-1	**Beam 2** (anti-clock.) Horizontal **F**ocusing	**Beam 1** (clockwise) Horizontal **D**efocusing

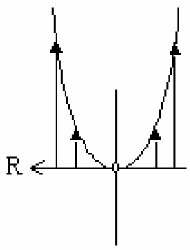
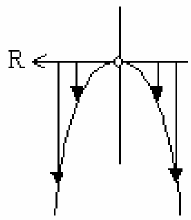
SINGLE APERTURE SEXTUPOLES

Current into Terminal "A"			Current into Terminal "B"		
	Beam 1 (clockwise)	**Beam 2** (anti-clock.)		**Beam 1** (clockwise)	**Beam 2** (anti-clock.)
Sextupole 	**SF** Horizontal chromaticity correction	**SD** Vertical chromaticity correction	**Sextupole** 	**SD** Vertical chromaticity correction	**SF** Horizontal chromaticity correction
Skew Sextupole 	**Positive** skew sextupole	**Negative** skew sextupole	**Skew Sextupole** 	**Negative** skew sextupole	**Positive** skew sextupole

SINGLE APERTURE OCTUPOLES

Current into Terminal "A"			Current into Terminal "B"		
	Beam 1 (clockwise)	**Beam 2** (anti-clock.)		**Beam 1** (clockwise)	**Beam 2** (anti-clock.)
Octupole 	**OF**	**OD**	**Octupole** 	**OD**	**OF**
Skew Octupole 	**Positive** skew octupole	**Negative** skew octupole	**Skew Octupole** 	**Negative** skew octupole	**Positive** skew octupole

SINGLE APERTURE DECAPOLES

Current into Terminal "A"			Current into Terminal "B"		
	Beam 1 (clockwise)	**Beam 2** (anti-clock.)		**Beam 1** (clockwise)	**Beam 2** (anti-clock.)
Decapole 	**Positive** decapole	**Negative** decapole	**Decapole** 	**Negative** decapole	**Positive** decapole

6. CONNECTION OF CORRECTOR MAGNETS

Corrector magnets used to correct field errors in a magnet are powered in such a way that their vertical field component in the outer part of the aperture points in the same direction as the main field component when the bipolar power converter for the corrector circuit is in "positive" polarity. Should a fixed polarity power converter be used for an error of fixed polarity then it must be connected so as to cancel the error. This will need a treatment on a case-by-case basis.

Applying this to the correctors of the main dipoles and following this convention implies that the correctors of beam 1 (clockwise) always have their current entering the terminal A, while the correctors of beam 2 always have their current entering terminal B for a positive current from the power converter.

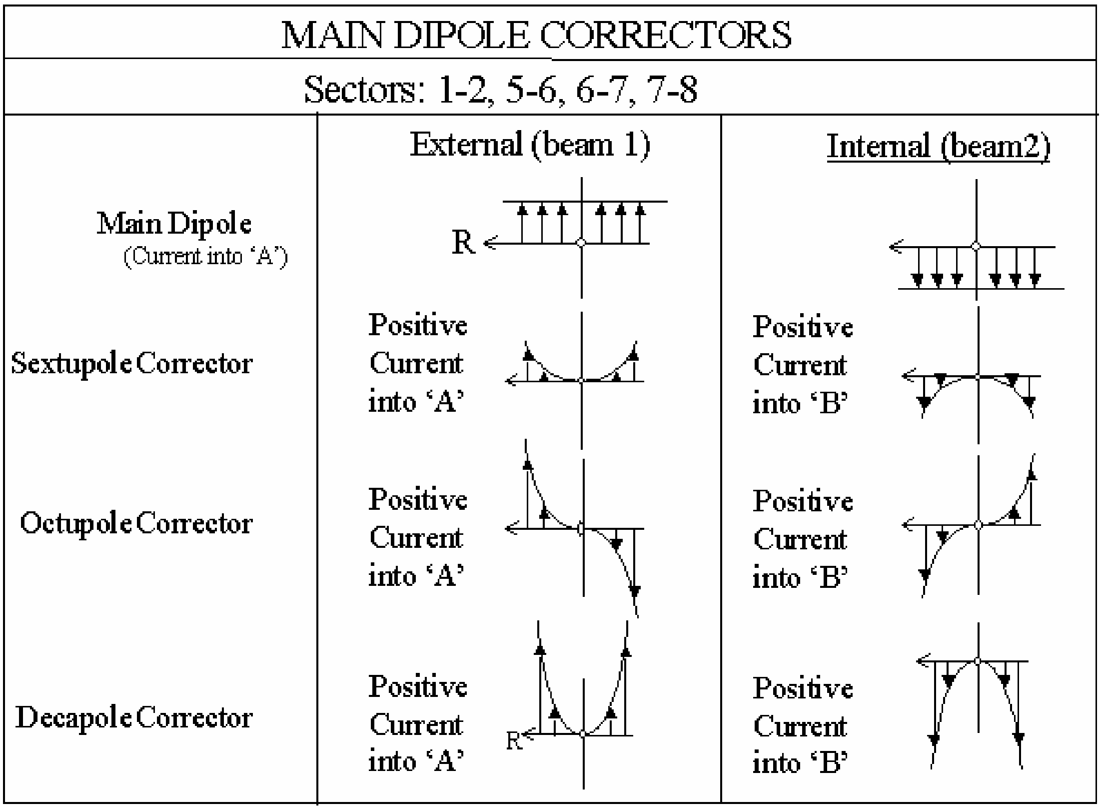
Hence for the powering of the machine:

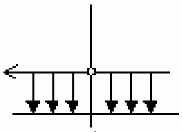
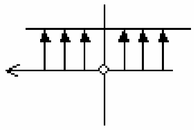
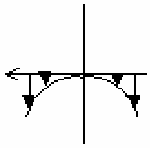
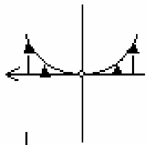
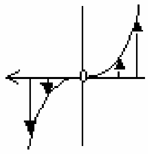
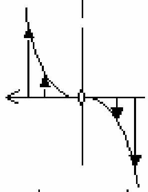
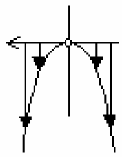
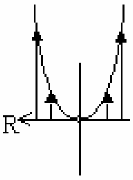
When beam 1 is in the external aperture (sectors 1-2, 5-6, 6-7, 7-8)

- Main dipole current enters the A terminal.
- For the spool pieces of the external aperture, current enters the A terminal.
- For the spool pieces of the internal aperture, current enters the B terminal.

When beam 2 is in the external aperture, (sectors 2-3, 3-4, 4-5, 8-1)

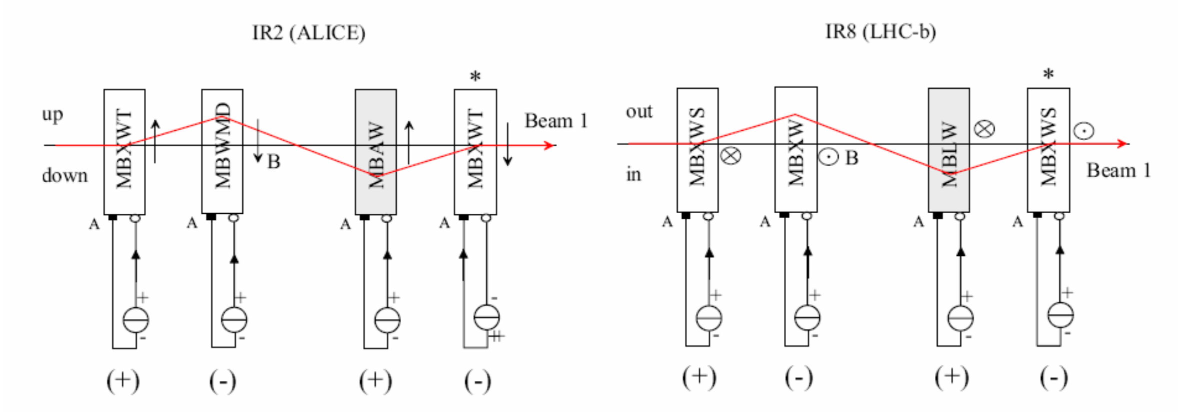
- Main dipole current enters the B terminal.
- For the spool pieces of the external aperture, current enters the B terminal.
- For the spool pieces of the internal aperture, current enters the A terminal.



MAIN DIPOLE CORRECTORS		
Sectors: 2-3, 3-4, 4-5, 8-1		
	External (beam 2)	**Internal (beam1)**
Main Dipole (Current into 'B')		R 
Sextupole Corrector	Positive Current into 'B' 	Positive Current into 'A' 
Octupole Corrector	Positive Current into 'B' 	Positive Current into 'A' 
Decapole Corrector	Positive Current into 'B' 	Positive Current into 'A' R 

6.1 EXPERIMENTAL MAGNETS AND COMPENSATORS

The conventions defined for magnets of the LHC machine will also be valid for the normal conducting experimental magnets and their compensators. The experiments in these insertion points use spectrometer (dipole) magnets which distort the beam trajectories. This effect is locally compensated with three orbit correctors placed in the straight sections between the interaction point and the final focussing triplet. As an example, the electrical layouts of the spectrometer dipole magnet compensations in IR2 and IR8 are shown in the following figure:



The compensators are powered according to the rules for the orbit correctors in the arc, i.e., a positive kick (upwards or outwards) on Beam 1 is obtained by a positive setting on the bi-polar power supply and the current entering the B terminal of the compensators. Notice the change of polarity for the turned, vertically deflecting magnet MBXWT in IR2 while the turned, horizontally deflecting magnet MBXWS keeps its optical function (see also section 7 on turned magnets).

7. TURNED MAGNETS

Magnets are placed in the machine in what is known as normal direction. For various reasons a magnet may be turned with respect to its normal direction in the machine. The physical construction and electrical connections of these magnets are not changed, but their optical function may change. While a magnet with an odd harmonic (dipole, sextupole…) does not change its optical function when turned, a magnet with an even harmonic (quadrupole, octupole…) does. The opposite is the case for skew magnets where the odd harmonics (vertical deflection dipole, skew sextupole …) change function and the even (skew quadrupole, skew octupole) do not. If there is a change of function then the magnet polarity must be inverted on the warm side in order to correct this. The table below summarises the situation.

Dipole: no change	Skew Dipole: inverted
Quadrupole: inverted	Skew Quadrupole: no change
Sextupole: no change	Skew Sextupole: inverted
Octupole: inverted	Skew Octupole: no change
Decapole: no change	Skew Decapole: inverted
Dodepole: inverted	Skew Dodepole: no change

7.1 SPECIAL CASE FOR THE SPOOL SPIECES OF TURNED MAGNETS

Spool piece magnets are installed in larger magnet assemblies (main dipoles and main quadrupoles). Some of the magnet assemblies are installed turned and their optical function may change. However, the field error of the magnet with respect to the main field does not change.

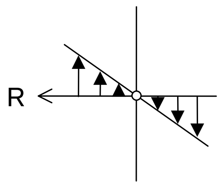
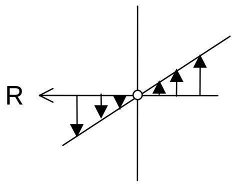
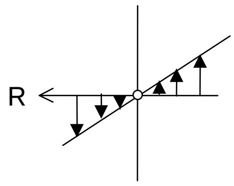
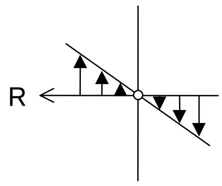
If the optical function of the magnet assembly should remain unchanged when the magnet is turned, three cases are distinguished:

- Dipole magnet with vertical field direction – the polarity remains
- Dipole magnet with horizontal field direction – the polarity must change
- Quadrupole magnet – the polarity must change

If the polarity of the main magnet changes, the polarity of the spool piece magnet has also to be changed.

8. TWIN APERTURE QUADRUPOLE WITH SAME FUNCTIONS

In most cases in LHC, the optical function in each aperture of twin aperture quadrupole is opposite. There are exceptions. In this case the polarity convention is given below:

TWIN APERTURE QUADRUPOLES WITH SAME FUNCTION			
Terminal "A"		Terminal "B"	
External	Internal	External	Internal
			
Beam 1 QF	**Beam 2** QF	**Beam 1** QD	**Beam 2** QD
Beam 2 QD	**Beam 1** QD	**Beam 2** QF	**Beam 1** QF

9. SINGLE APERTURE MAGNETS COVERING BOTH BEAMS

Where both beams pass through a single aperture magnet beam 1 (clockwise) is used to define the polarity.

10. LABELLING OF CURRENT LEADS ON A DFB (ELECTRICAL FEEDBOX)

For magnets operating at cryogenic temperatures, the currents are fed into the cryostats via current leads, mounted on four different types of electrical feed boxes (DFBA, DFBM, DFBL and DFBX). Every electrical circuit powering LHC magnets uses two current leads, except the individually powered quadrupoles (MQM, MQY) which uses a third current lead for the common return busbar, and the main inner triplet circuits which use four current leads due to the embedded power converters.

The assignment of current leads to the electrical circuits has been specified for all DFBs [1] [2] [3] [4]. Each current lead is given a unique name and index (according to its location on the DFB) and the name and pole of power converter that is connected to this lead.

The polarity definition of a current lead on a DFB is derived from the magnet terminal it is connected to at its cold end. The current lead that is connected to the A terminal of the magnet takes the name of this terminal (A). The other lead is B.

In case of the individually powered quadrupoles with a common return busbar and the mid-point connection of the spool-piece sextupole corrector circuits, this third lead is called C.

11. POLARITY CONVENTIONS FOR THE MAD SEQUENCE FILE

The LHC Reference Database will allow for an automatic generation of the MAD sequence file. Based on the current version of physical and electrical layout data it will generate the sequence file for the optics program. Together with the strength file, used to define the numerical values of the strength constants defined in the sequence file, it will provide the complete input data needed for a MAD simulation.

The sequence file will contain the sequence of LHC magnets around the LHC circumference and an according strength constant. The strength constant is identical for all magnets powered in one electrical circuit, while the sign of this strength constant is depending on the connection of the magnet within the circuit (current is entering terminal A or terminal B).

As defined in this specification, a positive field or field gradient of the magnet will correspond to the definition of a positive strength constant in the sequence file[1]. A negative field or field gradient of the magnet will be taken into account by defining a strength constant of negative sign in the sequence file. The numerical value for each strength constant defined in the sequence file can be found in the strength file.

In general, the polarity convention as explained will be applied for the generation of the sequence file. Still, the large number of existing strength files used by AB-ABP are based on a slightly different convention, defining negative numerical values for some of the strength constants. These negative values will require an inversion of sign for the strength constant in the MAD sequence file (with respect to the previous definition) for the following electrical circuits (and as such magnets):

- Defocusing circuits of the type **ROD, RSD1 and RSD2** (containing sextupole and octupole magnets of the type MS and MO) will require an inversion of the sign for the strength constant in the MAD sequence file

- Defocusing main quadrupole magnets MQ in the circuits **RQ** will require an inversion of the sign for the strength constant in the MAD sequence file. Exceptions to this case are the warm twin aperture quadrupoles MQWA used as Q4 and Q5 in the insertions 3 and 7 (see next item)

- The warm twin aperture magnets MQWA, connected in the circuits **RQ4** and **RQ5** in the insertions 3 and 7 will be given a positive strength constant in the MAD sequence file when installed left of the IP and a negative strength constant when installed at the right side of the IP

- The inner triplet (Q1 to Q3 in insertions 1,2,5 and 8) is powered via a set of embedded power converters and the strength constant assigned to each individual magnet will consequently be a sum of several single power converter strengths (valid for magnets of type MQXA and MQXB). Magnets of this type appear in the circuit types **RQX**, **RTQX1** and **RTQX2**, the resulting strengths in e.g. left of IR2 will look as follows:

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[1] Positive Field indicates upward pointing field direction while positive gradient is an increasing field along the outward pointing machine radius.

Q3 (MQXA): *K1:= kqx.l2;*
Q2 (2 MQXB): *K1:= -kqx.l2-kqxt2.l2;*
Q1 (MQXA): *K1:= kqx.l2+kqxt1.l2;*

- Some strengths of dipole orbit corrector magnets are defined as angles in the MAD sequence file and are to be entered by definition as positive values in the sequence file

12. REFERENCES

[1] M. Zerlauth et al.: 'Current Lead Assignment on the DFBAs, EDMS Doc.Nr.: 355582

[2] M. Zerlauth et al.: 'Current Lead Assignment on the DFBLs, EDMS Doc.Nr.: 386685

[3] M. Zerlauth et al.: 'Current Lead Assignment on the DFBMs, EDMS Doc.Nr.: 355562

[4] J.Jzbasnik et al.: 'Inner Triple Feedboxes DFBX-Power Converters', EDMS Doc.Nr.: 313365