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MAGNET POLARITY CONVENTIONS IN THE LCLS

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Brief Summary:
This document defines magnet field polarity conventions for dipoles, quadrupoles, and solenoid magnets on the LCLS beamlines. The conventions are based on a simple definition describing all beamline magnets as either "*positive*" or "*negative*", independent of their orientation or function. The specific polarities for each magnet are listed in PRD 1.1-006. This document does not describe power supply readback polarities, which must be defined in a separate document.

Change History Log:

Rev Number	Revision Date	Sections Affected	Description of Change
000	Oct. 3, 2005	All	Initial Version

Magnet Polarity Conventions in the LCLS

Introduction

Magnet polarities in the LCLS are defined here using a simple definition describing all beamline magnets as either "*positive*" or "*negative*". This general definition is valid for dipole, quadrupole, and solenoid magnets, which covers all possibilities in the LCLS beamlines (with the exception of the special muon spoiler toroid in the x-ray beamline). It assumes a beam-direction arrow is clearly painted on the exterior of each magnet. The proper polarity of each magnet ("*positive*" or "*negative*") is defined with a "P" or "N" in the polarity column of each magnet table in PRD 1.1-006, *Requirements for LCLS Magnet*, at:

http://www-ssrl.slac.stanford.edu/lcls/prd/1.1-006-r0.pdf

The proper magnetic field polarities are achieved in practice by the following:

- note the proper polarity ("*positive*" or "*negative*") from PRD 1.1-006,
- power the magnet (*e.g.*, in the magnetic measurements laboratory),
- measure the field orientation (*e.g.*, with a simple passive field probe†)
- note beam-direction arrow painted on side of magnet (flag if missing),
- re-connect the cables to arrange the proper polarity as shown in Figs. 3-5 below,
- mark the terminals on the magnet clearly and permanently with "+" and "–" at the proper points so that the positive cable from the power supply is connected to the positive magnet terminal (the magnet must be labeled so its beamline location, or at least its polarity, is clear).

† The **BLUE** tip of the *Magnaprobe* (small hand held probe consisting of bar magnet suspended in a gimbal mounting) points to a magnetic **north** pole, while the **RED** tip points to a **south** pole.

Table 1. Magnet polarity conventions based on effect on electrons.

Magnet type	**Polarity Convention**
Horizontal Dipole	*Positive* magnet bends electrons left as beam leaves observer
Vertical Dipole	*Positive* magnet bends electrons up
Normal Quadrupole	*Positive* magnet focuses electrons in the horizontal direction
Skew Quadrupole	*Positive* magnet is a 45° CW-rotated normal "*positive*" quadrupole*
Solenoid	*Positive* magnet rotates electrons clockwise*
Sextupoles	(There are no sextupole magnets in the LCLS)

* rotation is clockwise (CW) around beam-direction axis and defined as beam leaves observer

All dipole steering corrector magnets (PRD 1.1-007) are defined as "*positive*", since their nominal settings are zero and they are connected to bipolar power supplies. Trim coils used on main dipole magnets also have bipolar supplies but are defined with the same polarity as the main dipole they feed (with the trim power supply in *normal* polarity). Other magnets with bipolar power supplies have specific polarities as listed in PRD 1.1-006, but can also be inverted by running the power supply in its *reversed* polarity. In its *normal* polarity, the positive cable from the power supply will be connected to the positive magnet terminal, and the magnet will then have the proper field polarity. (One linac quadrupole, Q21201, must be reversed in polarity when switching between LCLS and non-LCLS operations. In this case the *normal* polarity will refer to its non-LCLS state.)

Coordinates

The magnet coordinates described here are ***not*** the global linac or LTU beamline coordinates, as described in LCLS-TN-03-8, but are the local magnet coordinates laid out with respect to the specific beam direction anywhere on the beamline. A right-handed coordinate system is oriented with z as the longitudinal coordinate (in the beam direction at the magnet's entrance), y as the vertical coordinate (pointing up), and x as the horizontal coordinate (perpendicular to both y and z), as shown in Fig. 1. The local coordinate system follows the beamline direction for each location of interest, as depicted in Fig. 2.

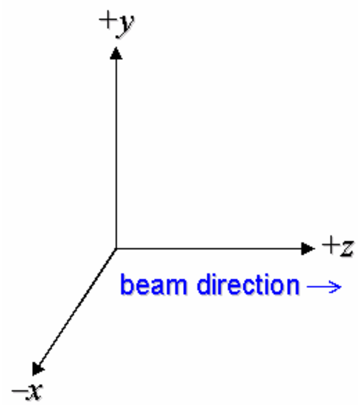

Figure 1. Right-handed coordinate system with $+z$ in the beam direction, $+y$ in the vertical direction (up), and x in the horizontal direction ($+x$ points into this paper: to the left when looking in the direction of $+z$).

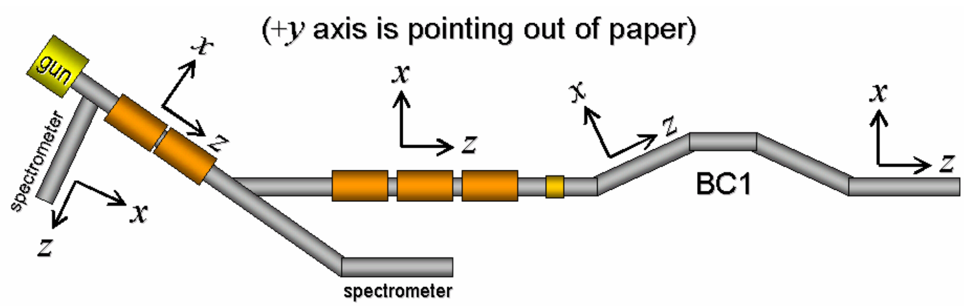

Figure 2. Cartoon layout (plan view) of injector-through-BC1 beamline with local coordinate systems placed at various locations as examples (the $+y$ axis points out of the paper here).

Dipole Magnets

For a horizontal bending magnet, a "*positive*" bend deflects electrons in the $+x$ direction (to the left as beam leaves the observer). Similarly, for a vertical bending magnet, a "*positive*" bend deflects electrons in the $+y$ direction (up). If the magnet is located where it can bend both electrons and positrons (*e.g.*, such as the '50B1' dipole at the end of the linac), the electron bending is used to set the polarity definition. Steering corrector dipole magnets are naturally included in this definition (and all steering corrector dipoles are defined as "*positive*"). All dipole magnets in the LCLS are oriented in such a way as to be easily identified as either horizontal or vertical bends, even though they may be oriented a few degrees off of this precise definition. The permanent magnet dipoles in the safety dump line have no power supply, but do have a defined polarity, which must be attained by proper magnet orientation during installation. Fig. 3 shows both a horizontal and a vertical "*positive*" dipole magnet with associated field polarities.

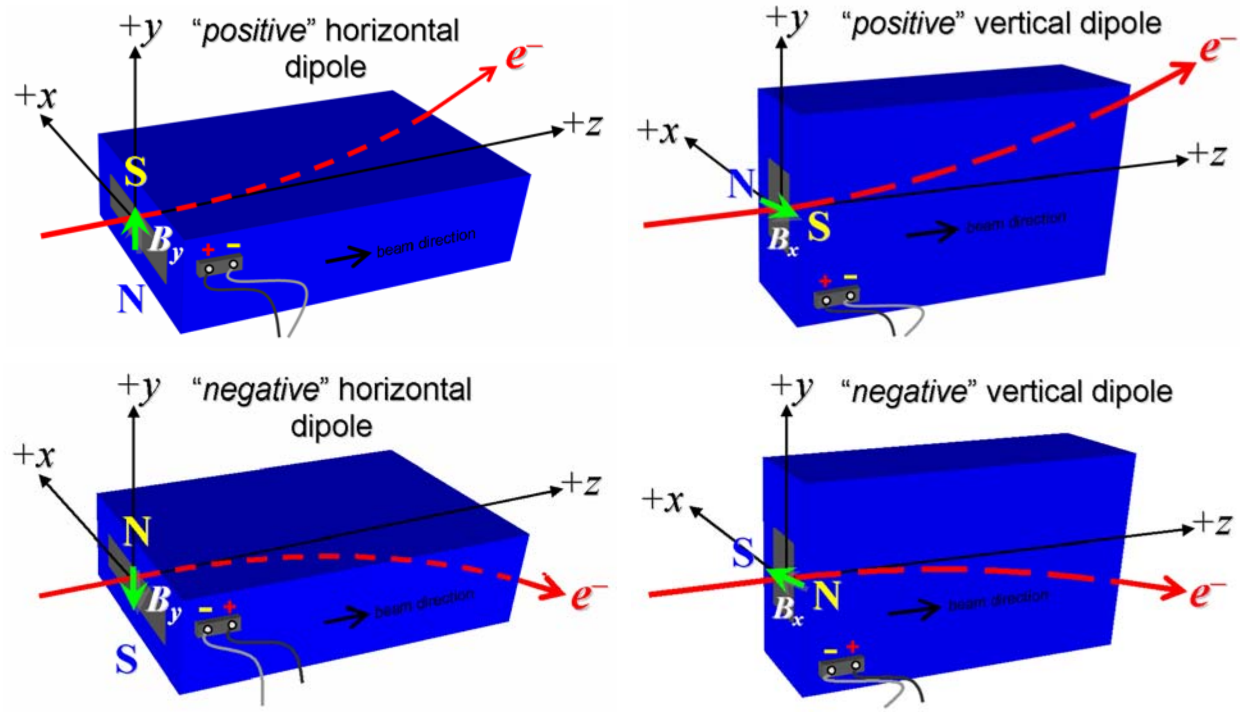

Figure 3. A "*positive*" horizontally bending dipole magnet (top-left) bends electrons in the +*x* direction (left as beam leaves observer), while a "*positive*" vertically bending dipole magnet (top-right) bends electrons in the +*y* direction (up). Of course, "*negative*" dipoles are reversed from this ("*negative*" horizontal bend at lower-left and "*negative*" vertical bend at lower-right).

Quadrupole Magnets

Normal Quadrupole:

A "*positive*" normal quadrupole magnet (**QF**) focuses electrons horizontally (*x* direction). A "*negative*" normal quadrupole magnet (**QD**) focuses electrons vertically (*y* direction). If the magnet is located where it can focus both electrons and positrons (*e.g.*, such as '50Q1' at the end of the linac), the electron focusing is used to set the polarity definition. Fig. 4 shows both "*positive*" and "negative" normal quadrupole magnets with associated field polarities.

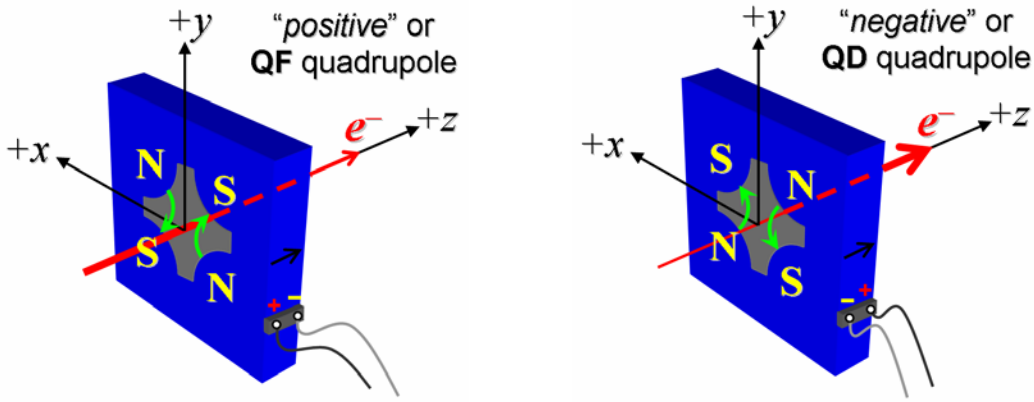

Figure 4. A "*positive*" normal quadrupole magnet (left) focuses electrons in x (a '**QF**' quadrupole), while a "*negative*" quadrupole magnet (right) focuses electrons in y (a '**QD**' quadrupole).

Skew Quadrupole:

A "*positive*" skew quadrupole is simply a 45° clockwise-rotated normal "*positive*" quadrupole (rotation around z-axis seen as beam leaves observer), which then maps an electron from $+x$ into $-dy/dz$ ($\equiv -y'$). Fig. 5 shows a "*positive*" skew quadrupole magnet with associated field polarity.

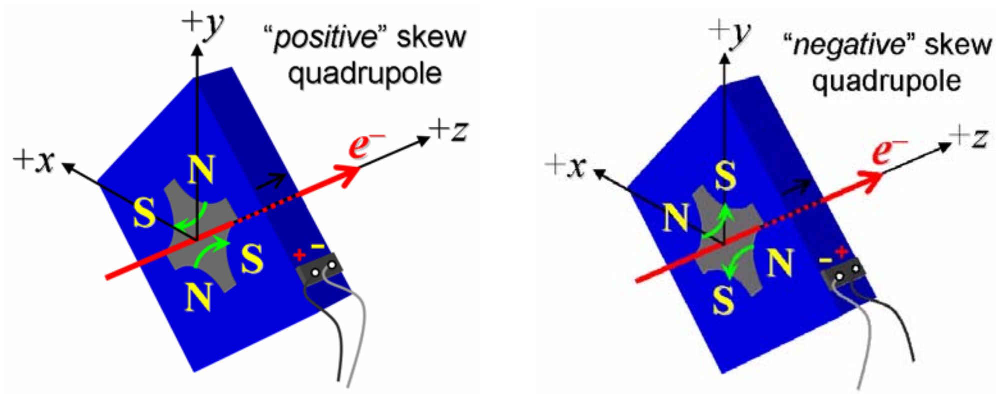

Figure 5. A "*positive*" skew quadrupole magnet (left) is simply a 45° clockwise-rotated (around z axis) normal "*positive*" quadrupole, which then maps an electron from $+x$ into $-dy/dz$ ($\equiv -y'$). A "*negative*" skew quadrupole (right) is reversed from this.

Solenoid Magnets

A "*positive*" solenoid magnet rotates electrons clockwise (as beam leaves observer) with its longitudinal magnetic field pointing in the main direction of the beam. A "*negative*" solenoid has opposite field direction and therefore opposite rotation. Fig. 6 shows a "*positive*" solenoid magnet with associated field polarity.

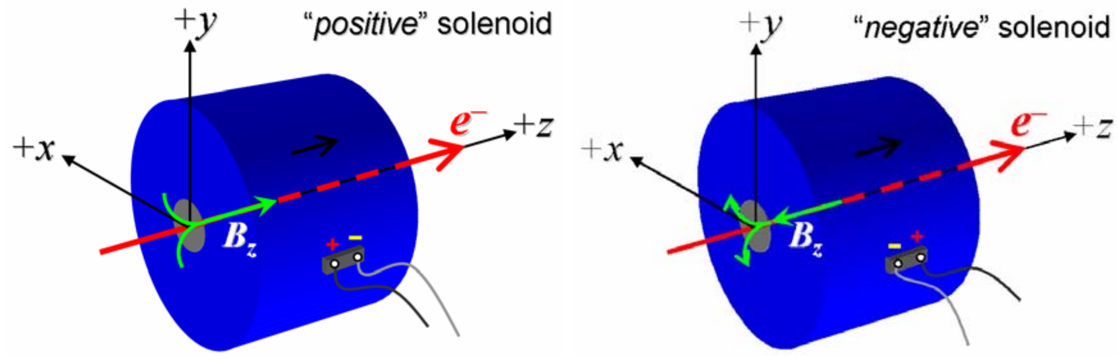

Figure 6. A "*positive*" solenoid magnet (left) rotates electrons in a clockwise direction (around *z* axis as beam leaves observer) with longitudinal magnetic field pointing in direction of beam. A "*negative*" solenoid magnet (right) rotates electrons in a counter-clockwise direction.

Sextupole Magnets

There are currently no sextupole or higher order magnets in the LCLS accelerator.

Control System Readback

These polarity definitions do not translate into specifications for the polarity of the power supply's control system readback. In many cases, magnets of both polarities are powered in series on one power supply, so the readback polarity must be defined by some other criterion. Readback polarities are therefore not prescribed here, and must be addressed in a separate document.